AN EVALUATION OF THE BIOCLIMATIC CHART FOR CHOOSING DESIGN STRATEGIES FOR A THERMOSTATICALLY-CONTROLLED RESIDENCE IN SELECTED CLIMATES

A Dissertation

by

SOPA VISITSAK

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

December 2007

Major Subject: Architecture

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Approved by:

Chair of Committee,	Jeff S. Haberl
Committee Members,	Mark J. Clayton
	Larry O. Degelman
	David E. Claridge
Head of Department,	Mark J. Clayton

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ABSTRACT

An Evaluation of the Bioclimatic Chart for Choosing Design Strategies for
a Thermostatically-Controlled Residence in Selected Climates.
(December 2007)

Sopa Visitsak, B. Arch., King Mongkut's Institute of Technology, Ladkrabang;
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Chair of Advisory Committee: Dr. Jeff S. Haberl

To be successful in sustainable building design, architects must consider energy efficient design strategies in the early design stage. Unfortunately, many architects still rely on simplified analysis, synthesis techniques, and historical examples. Although, building energy simulations are becoming more common in the design of buildings, architects rarely use simulation in the early design stage.

The "Bioclimatic" charts have been used in the early design stage to define potential building design strategies to achieve indoor thermal comfort. Currently, many architects use the Givoni-Milne bioclimatic design chart (Milne and Givoni, 1979), which was developed based on principle reasoning and heuristics. There have been many attempts to develop computerized programs to further the bioclimatic analysis; however, there have been very limited efforts to test and evaluate the design strategies of the chart using simulations of a thermostatically-controlled building.

Therefore, the purpose of this research is to promote comfortable buildings that reduce energy use through appropriate building design strategies. The objectives of the research are to develop a more accurate bioclimatic chart for a thermostatically-controlled residence by testing and evaluating the Givoni-Milne bioclimatic chart. The analysis is performed with DOE-2.1e program (Winkelmann, 1993) and TMY2 weather data (Marion and Urban, 1995) for several climates. To achieve these objectives, four main tasks were accomplished: 1) investigate the Givoni-Milne Bioclimatic Chart using representative weather data from several climates, 2) analyze and modify the design strategy boundaries using DOE-2 program and TMY2 weather data to simulate the effects of varied conditions of a thermostatically-controlled residence in different climates, 3) compare these new design strategy boundaries to the original Givoni-Milne design strategy boundaries, and 4) develop general guidelines for the new bioclimatic chart.

In summary, there were some differences in the results from the Givoni-Milne bioclimatic chart and the DOE-2 simulation results. These results imply that without further modification, the G-M Chart may have only a limited use for a thermostatically-controlled residence. Therefore, to improve the usefulness of the bioclimatic chart the new bio-climatic chart for choosing design strategies for a thermostatically-controlled residence in the hot-humid climate of Houston, Texas, was developed. This new bioclimatic chart for a thermostatically-controlled residence will be a useful tool for architects and engineers in the early design stage. Similar versions of the new bioclimatic for other climates could then be developed.

DEDICATION

To my beloved parents and my family
for their unconditional love and support.

ACKNOWLEDGMENTS

There are a number of people who have contributed their time and support towards the completion of this dissertation. It would be a very long list to include all of the persons who have helped directly and indirectly with this study. However, without those persons, I would not have been able to go through the academic difficulties, the great economic pressure, and time constraints. I would like to faithfully acknowledge all of those who have sincerely aided me during the period of the completion of this dissertation.

This study would not have been possible without the continued support and encouragement of my advisory committee, whose profound knowledge in buildings research was the primary inspiration of this study. Therefore, my heartfelt appreciation would go to Dr. Jeff S. Haberl for his kindness and eagerness in educating me and guiding me not only about how to conduct a good research, but also how to become a good professor. He has been very patient with me, and has never left me alone in the dark whenever I was struggling with all kinds of pressure and troubles during the long period of completion.

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Finally, I would like to respectfully pay tribute to the Lord Buddha for his teachings that have given me the intellectual mind and wisdom to overcome countless barriers and reach my destination.

NOMENCLATURE

A/C	Air-Conditioning.
Btu	British Thermal Unit.
BEPS	Building Energy Performance Summary.
°C	Degrees, Celsius.
CDD50 °F	Cooling Degree-Days (Base-50 °F).
CDD65 °F	Cooling Degree-Days (Base-65 °F).
CDD10 °C	Cooling Degree-Days (Base-10 °C).
CDD18 °C	Cooling Degree-Days (Base-18 °C).
clo-value	Clothing thermal resistance value.
CWF	Custom Weighting Factors.
DHW	Domestic Hot Water.
ET*	Effective Temperature Index.
°F	Degrees, Fahrenheit.
GBH	Global Horizontal solar radiation.
H	Height.
HDD50 °F	Heating Degree-Days (Base-50 °F).
HDD65 °F	Heating Degree-Days (Base-65 °F).
HDD10 °C	Heating Degree-Days (Base-10 °C).
HDD18 °C	Heating Degree-Days (Base-18 °C).
HVAC	Heating, Ventilating, and Air-Conditioning.
IAQ	Indoor Air Quality.
kW	Kilo Watt.
lba	Pound of dry air.
lbw	Pound of water.
MRT	Mean Radiant Temperature.
P	Pressure of the air.
P_{cm}	Precipitation in centimeters.

P_{in}	Precipitation in inches.
Psat	Saturation pressure of water vapor.
Pw	Partial pressure of water vapor.
°R	Degrees, Rankin.
Ra	Dry air gas constant.
RH	Relative Humidity.
R-value	Thermal resistance value.
SHGC	Solar Heat Gain Coefficient.
T	Temperature.
T_C	Temperature in degrees Celsius.
Tdb	Dry-bulb temperature.
Tdp	Dewpoint temperature.
T_F	Temperature in degrees Fahrenheit.
Twb	Wet-bulb temperature.
t_o	Operative temperature.
U-value	Heat transfer coefficient value.
W	Humidity ratio.
ϕ	Relative humidity.
ρ	Density of the air.
υ	Specific volume.

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CHAPTER I

INTRODUCTION

1.1 BACKGROUND

With the energy crisis of 1973, most architects, engineers, and building owners rekindled their interest in energy efficient designs. Since then, the implementation of energy efficient designs has dramatically reduced the growth of non-renewable energy consumption in buildings (Lechner, 1991). However, to successfully create these energy efficient designs, architects must consider energy efficient design strategies during the early design stage (see Figure 1.1). After a building is designed, it becomes significantly more difficult to reduce its energy use. To design sustainable buildings, many architects tend to rely on simplified analyses, synthesis techniques, and historical examples. With powerful desktop computers becoming commonplace, computerized building energy

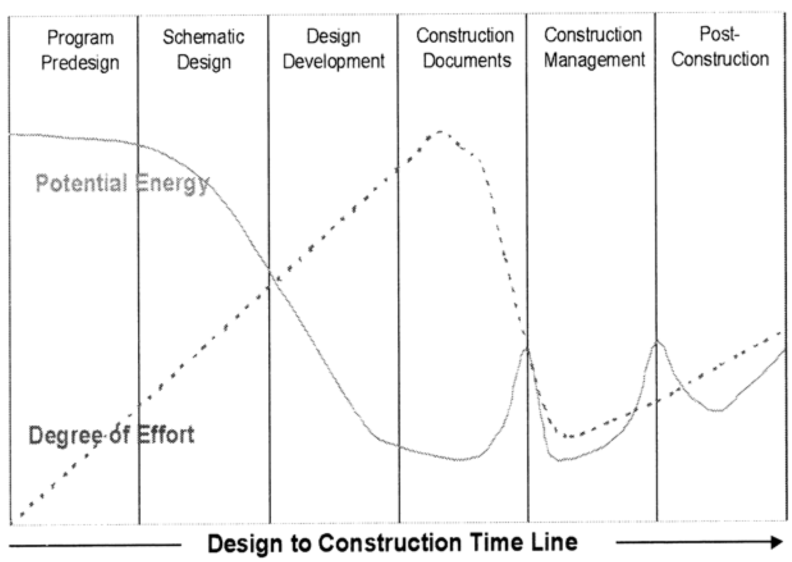


Figure 1.1 *Impact of input during the early design stage on building energy performance (Deru et al. 2003, p.27). Copyright © 2003 by ASHRAE (Reprinted with permission).*

This dissertation follows the format of the *ASHRAE Transactions*.

simulations are becoming more readily accessible. However, architects rarely use simulations early in the design stage because simulations are complex and therefore difficult for many architects to learn how to use, and too expensive to be used cost effectively on many projects.

Currently, many architects use the Givoni-Milne bioclimatic design chart (Milne and Givoni, 1979) (see Figure 1.2), which was developed based on first principles and heuristics. “The Building Bioclimatic Chart indicates that whenever ambient outdoor temperature and humidity conditions fall within the designated limits of a control strategy, then the interior of a building designed to effectively execute that strategy will remain comfortable.” (Watsons & Labs, 1983, p.33) There have been many attempts to develop computerized programs (Clayton, 1987; Acenas, 1989; Milne and Yoshikawa, 1979; Li and Milne, 1994; Marsk and Raines, 1998; etc.) to further the bioclimatic analysis; however, there have been very few efforts made to actually test and evaluate the design strategies of the G-M bioclimatic chart using simulation.

Therefore, the proposed research seeks to improve the usefulness of the G-M bioclimatic chart using an advance energy simulation program and representative weather data to test and evaluate the boundaries of the design strategies for a thermostatically-controlled residence.

1.2 PURPOSE AND OBJECTIVE

The purpose of this research is to promote comfortable buildings that reduce energy use by developing tools that identify appropriate building design strategies. The primary objective of this research is to develop a new bioclimatic chart for thermostatically-controlled residences by testing and evaluating the original G-M bioclimatic chart using simulation. This analysis will be performed using an hourly energy simulation program and the appropriate weather data of several representative cities in various climates. To achieve this objective, the following four main tasks have been defined:

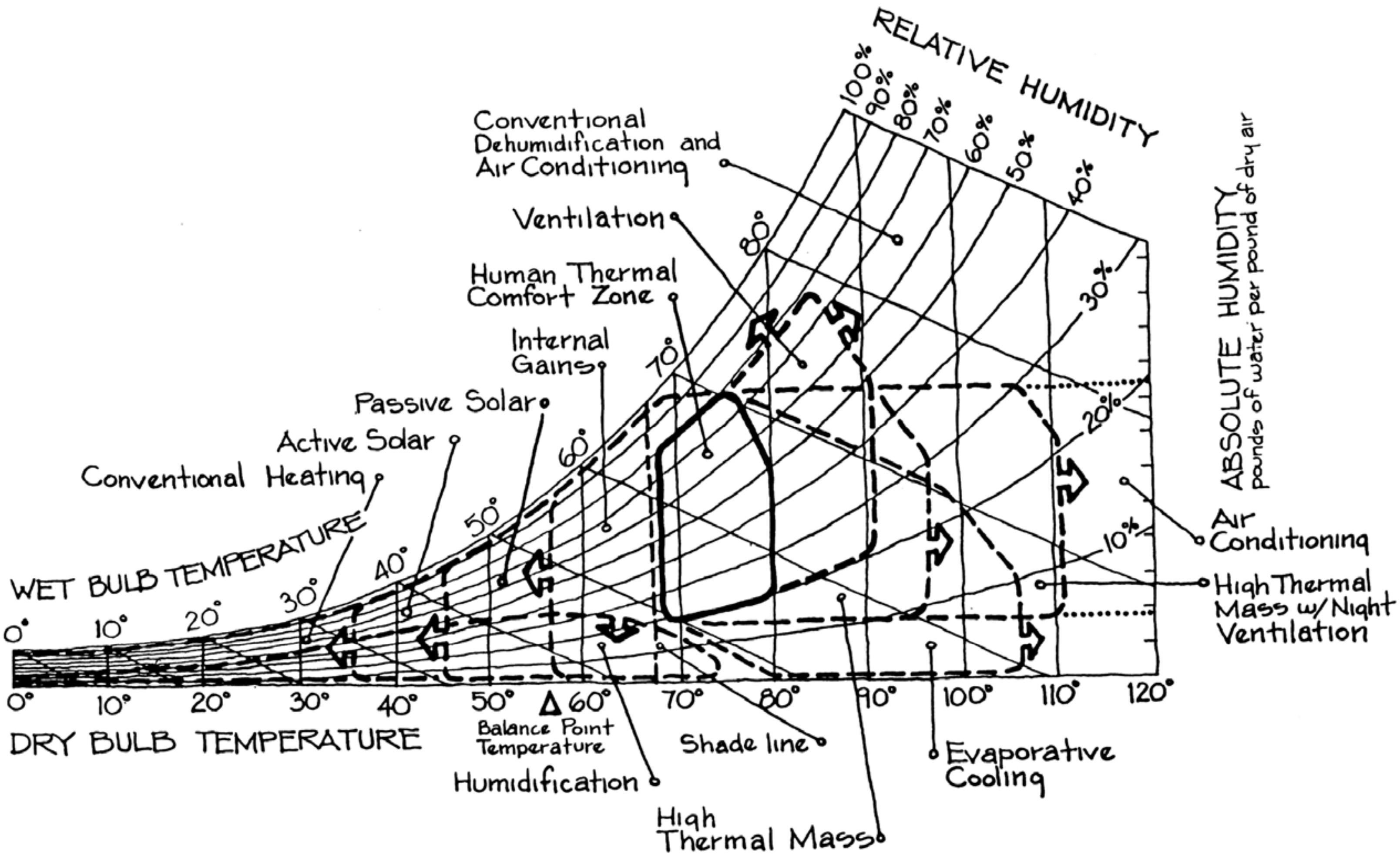


Figure 1.2 *Givoni-Milne bioclimatic chart (Givoni and Milne 1981; in Guthrie 1995, p.107). Copyright © 1981 by Baruch Givoni and Murray Milne (Reprinted with permission).*

1) Investigate the G-M bioclimatic chart using representative weather data from several climates.
2) Analyze and modify the design strategy boundaries using an hourly energy simulation program and representative weather data in order to simulate the effects of varying conditions of a thermostatically-controlled residence in different climates.
3) Compare these new design strategy boundaries to the original G-M design strategy boundaries.
4) Develop general guidelines for a new bioclimatic chart.

1.3 ORGANIZATION OF THE DISSERTATION

This dissertation is divided into seven Chapters, including: 1) Introduction, 2) Literature Review, 3) Significance of the Study, 4) Methodology, 5) Data Analysis and Results, 6) Design Guidelines for the New Bioclimatic Chart, and 7) Summary and Recommendations for Future Study.

Chapter I: Introduction. This chapter provides the background of the study, the purpose and objective of the research, and the organization of the dissertation.

Chapter II: Literature Review. This chapter reviews and discusses the previous studies to provide the basis for conducting this research. The review includes: thermal comfort, building pre-design tools, climate design strategies for residential buildings, building simulation programs, and climate and weather data for building simulations.

Chapter III: Significance of the Study. This chapter discusses the importance of the research, the expected contributions to this area of study, and the scope and limitations of the study.

Chapter IV: Methodology. This chapter describes the methodology applied in this research. The methodology includes: procedures for mapping TMY2 weather data onto the psychrometric chart, climates and representative cities selection, procedures for simulating selected design strategies, and procedures for analyzing and projecting the simulation results onto the psychrometric chart.

Chapter V: Results. This chapter presents and discusses the DOE-2 simulation results and analyses, which include: weather analysis for selected climate, results of the DOE-2 simulation and the G-M Chart analysis, and comparison of the G-M chart analysis and the DOE-2 simulation results.

Chapter VI: Design Guidelines for the New Bioclimatic Chart. This chapter discusses the new bioclimatic chart design guidelines for the selected climate.

Chapter VII: Summary and Future Study Recommendations. This chapter summarizes the research work and includes future study recommendations.

CHAPTER II

LITERATURE REVIEW

This review of the literature related to this research includes: 1) thermal comfort; 2) bioclimatic charts, other pre-design tools, and computerized programs; 3) design strategies for residential buildings; 4) building simulation programs; and 5) climate classifications and representative weather data. The journals and publications that were reviewed include: ASHRAE Fundamentals, ASHRAE Standard 55 (1974, 1981, 1992, 1994, and 2004a), ASHRAE Journal, ASHRAE Transactions, AIA Research Corporation (1978), Time-Saver Standards (7th ed., 1997), DOE-2 Version 2.1e User's Manual (Winkelmann et al., 1993a; 1993b), DOE-2.1e (Version 107) Documentation Update Package No.2-4 (LBNL, 2000a; 2000b; 2001), and the TMY2 User's Manual (Marion and Urban, 1995). Selected portions of the following books were also found to be relevant to this thesis: the Fanger (1972), Olgyay (1963), Givoni (1976, 1994, and 1998), Milne and Givoni (1979), Mazria (1979), Balcomb and Jones (ed.) et al. (1983), Watson & Labs (1983), Lechner (1991), Duffie and Beckman (1991), Cook (ed.) (1989), Stein and Reynolds (1992, 2000), Moore (1993), Watson (ed.) (1993), Kreider and Rabl (1994), McQuiston et al. (2000), and Ramsey and Sleeper (2000).

2.1 THERMAL COMFORT

2.1.1 Introduction

Thermal comfort for a building's human occupants is the primary objective of most buildings' heating and cooling system designs. There are numerous studies regarding thermal comfort in different climates around the world. The significant studies that are recognized world-wide, which are related to this field of study include: the studies of the Effective Temperature index (ET) conducted since the 1920s (ASHRAE, 1967, 1974, 1981, 1992, 1995, and 2004c); the heat balance equation, including the "Predicted Mean Vote" (PMV), and the "Predicted Percentage of Dissatisfied" (PPD) by

Fanger (1972); the ASHRAE comfort charts (1967, 1974, 1981, 1992, 1995, and 2004a); and other significant thermal comfort studies such as Givoni (1976, 1994, and 1998), Nevins et al. (1975), Berglund and Fobelets (1987), McIntyre (1978), Arens et al. (1980), Tanabe (1987), Wu (1988), Busch (1992), Berglund (1995), Dear and Brager (1998), and Rohles Jr. (2007).

2.1.2 Definitions of Thermal Comfort and Comfort Conditions

Thermal comfort for a human subject is defined as "…the condition of mind which express satisfaction with the thermal environment; it requires subjective evaluation." (ASHRAE Standard 55, 1992, p.3). "In general, comfort occurs when body temperatures are held within narrow ranges, skin moisture is low, and the physiological effort of regulation is minimized." (ASHRAE, 2001a, p. 8.1)

There are many factors that affect human comfort. Some factors are difficult to control such as one's state of mind, behavioral conditions, culture, age, etc. The most important variables that influence the condition of thermal comfort that can also be measured are: 1) activity level, 2) clothing (clo-value), 3) air temperature, 4) mean radiant temperature, 5) relative air velocity, and 6) the water vapor pressure in the ambient air or the humidity level (Fanger, 1970, p.15). This research focuses on comfort in terms of heating, ventilating, and air-conditioning (HVAC) systems that maintain thermal comfort, which contribute to the good health of the building's occupants.

2.1.3 Effective Temperature Index (ET)

In 1923, with the advent of air conditioning (Lechner, 1991), the American Society of Heating and Ventilating Engineers (ASHVE, now ASHRAE) developed the original Effective Temperature index (Houghten and Yaglou, 1923) (see Figure 2.1). This index correlates the combined effects of air temperature, air humidity, and air movement upon human thermal comfort (Threlkeld, 1970). Yaglou (1947) recognized that the scale (as shown in Figure 2.1, Chapter 7 of the ASHRAE Handbook of Fundamentals., 1967) "…overemphasizes the effect of humidity in cooler and neutral

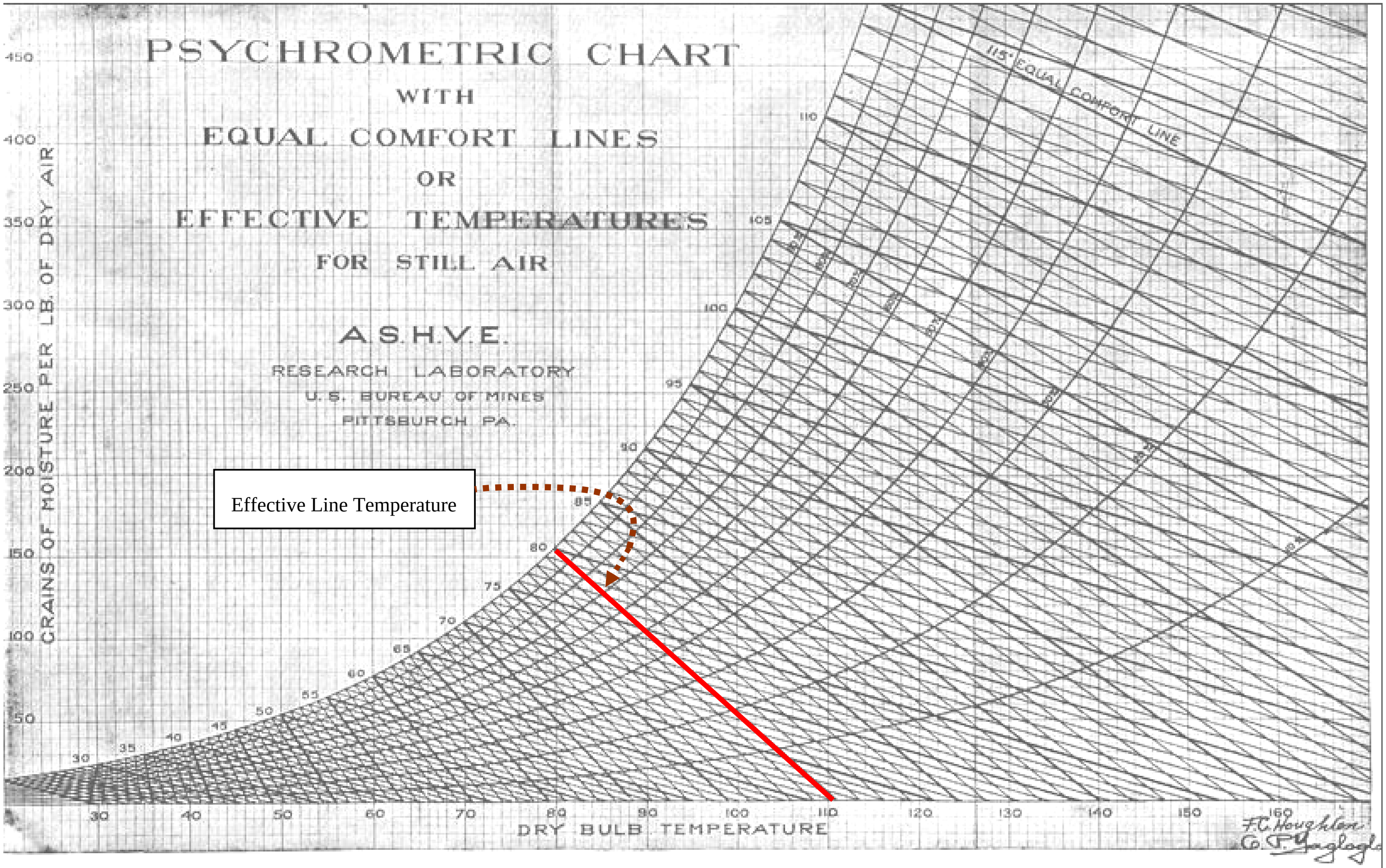


Figure 2.1 *Standard psychrometric chart with lines marking the original Effective Temperature (ET*) (Houghten & Yaglou 1923, pp. 166-167). Copyright © 1925 by ASHVE (Reprinted with permission).*

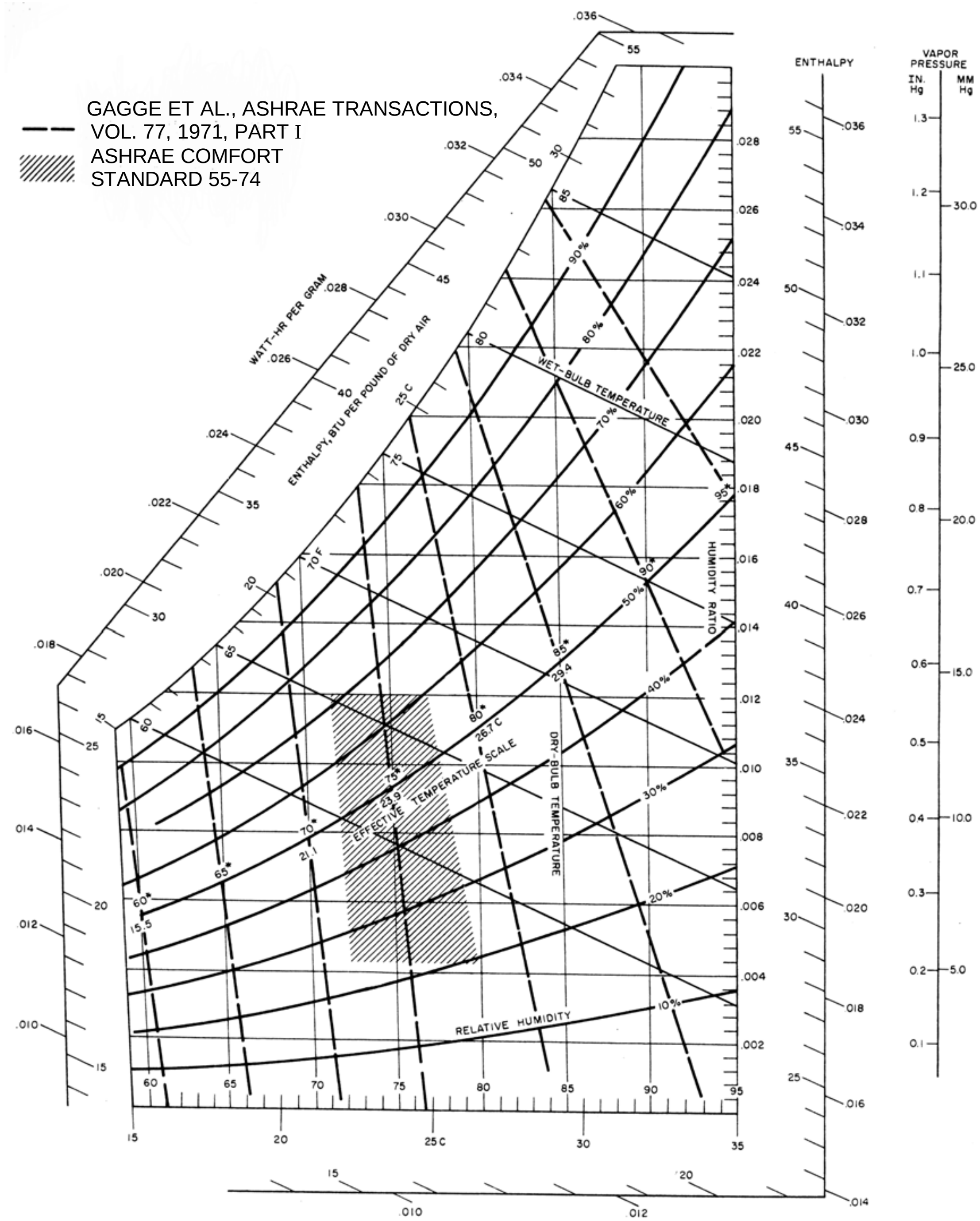


Figure 2.2 *ASHRAE Standard Effective Temperature (SAT*) Scale and ASHRAE comfort Standard 55-74 (ASHRAE 1981a, p.8.21). Copyright © 1981 by ASHRAE (Reprinted with permission).*

conditions, underemphasizes its effect in warm conditions, and does not fully account for air velocity under hot-humid conditions.” (ASHRAE, 1981a, p. 8.16). In 1971, according to ASHRAE, Gagge defined a new improved Standard Effective Temperature (SET) using a rational approach. This approach defined that the temperature of an environment at 50% relative humidity will result in the same total heat loss from the skin as the actual environment (Gagge et al., 1971) (see Figure 2.2). The SET* Scale was developed for a sedentary person (~ 1 met) wearing light clothing (0.6 clo) at a fixed, low-level of air movement (0.2 m/s.) with an exposure of 1 hour. Therefore, the SET is an important thermal comfort index used to define the thermal comfort zone in this study.

2.1.4 The Fanger Study

Fanger’s research on the effects of climatic factors on thermal sensations was initially conducted in the 1960’s, when he derived the first mathematical model for assessing human comfort conditions and a heat balance equation (Fanger, 1972). His equation makes it possible to calculate the optimal thermal comfort for any activity level, clothing, given a combination of environmental variables (i.e., air temperature, humidity, mean radiant temperature, and air velocity). His equation has been used in many studies including those conducted by the International Standards Organization (ISO) 7730 (ISO, 1984) to evaluate comfort conditions in buildings. Fanger also quantified thermal sensation by using a 7-point thermal sensation scale ranging from –3 to +3, and a derived thermal sensation index using the “Predicted Mean Vote” (PMV) and the “Predicted Percentage of Dissatisfied” (PPD) (Fanger, 1970, p.131). Figure 2.3 shows the Predicted Percentage of Dissatisfied (PPD) as a function of the Predicted Mean Vote (PMV). The lowest PPD value that can be obtain under perfect conditions is 5%, which means only 95% of any group of people is expected to be satisfied at a PMV is equal to zero. The PMV and PPD indices are used for making predictions of the acceptable thermal comfort levels in this study.

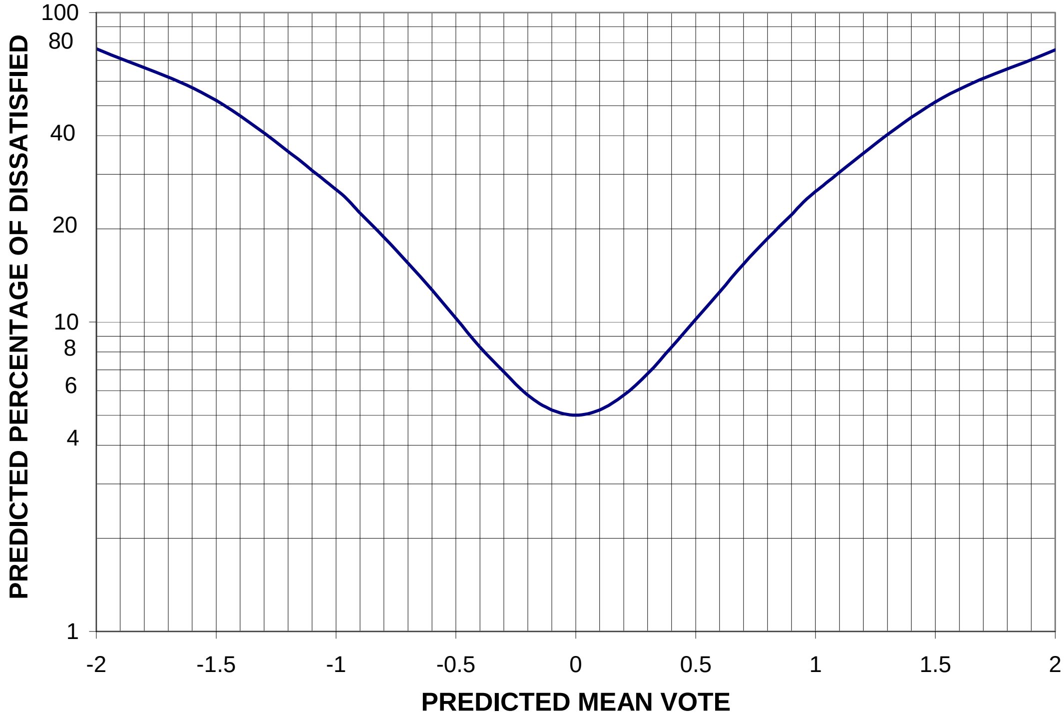


Figure 2.3 *Predicted Percentage of Dissatisfied (PPD) as a function of Predicted Mean Vote (PMV) (Adapted from Fanger 1972, p.131).*

2.1.5 ASHRAE Comfort Zone

The ASHRAE comfort zone is defined as the range of indoor climatic conditions (i.e., temperature, humidity, airspeed) within which the majority of persons experience thermal comfort. The ASHRAE comfort zone is usually drawn on a conventional psychrometric chart. The comfort zone defines the indoor air temperature and humidity for a sedentary person. The shape of the ASHRAE comfort zone has evolved over time and can be traced from the original ASHRAE comfort chart (1930) (see Figure 2.4) to the current ASHRAE Standard 55 (1981, 1992, 1995, and 2004a) (see Figure 2.5- Figure 2.8). The original ASHRAE comfort chart displays the summer and winter comfort zones superimposed upon the Effective Temperature chart developed at the Pittsburgh laboratory of Yaglou and Drinker (1930) (see Figure 2.4). The comfort scale indicates the variations in comfort sensation within the various zones.

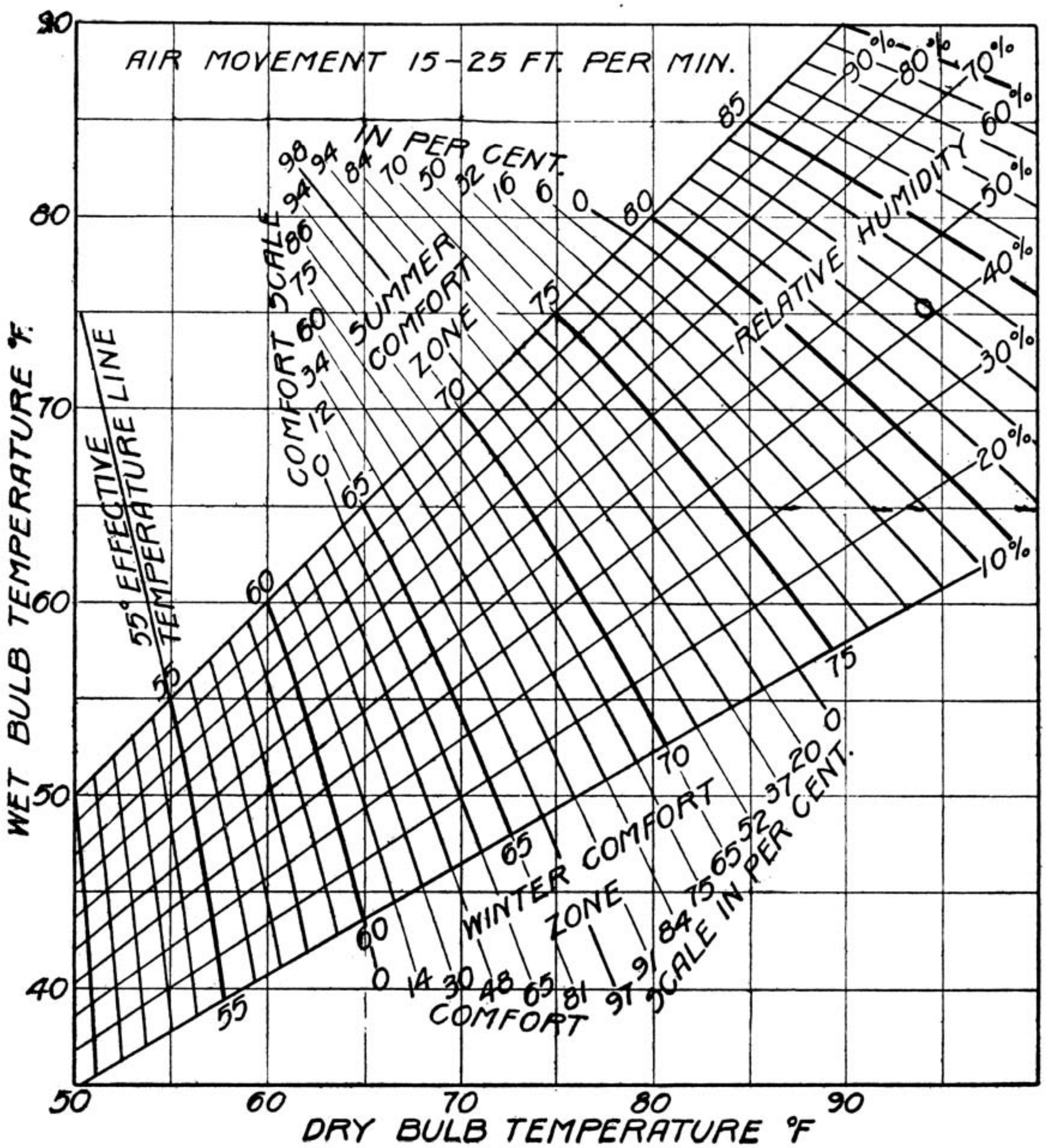


Figure 2.4 *Original ASHRAE comfort chart (Yaglou and Drinker 1930, p. 278). Copyright © 1930 by ASHVE (Reprinted with permission).*

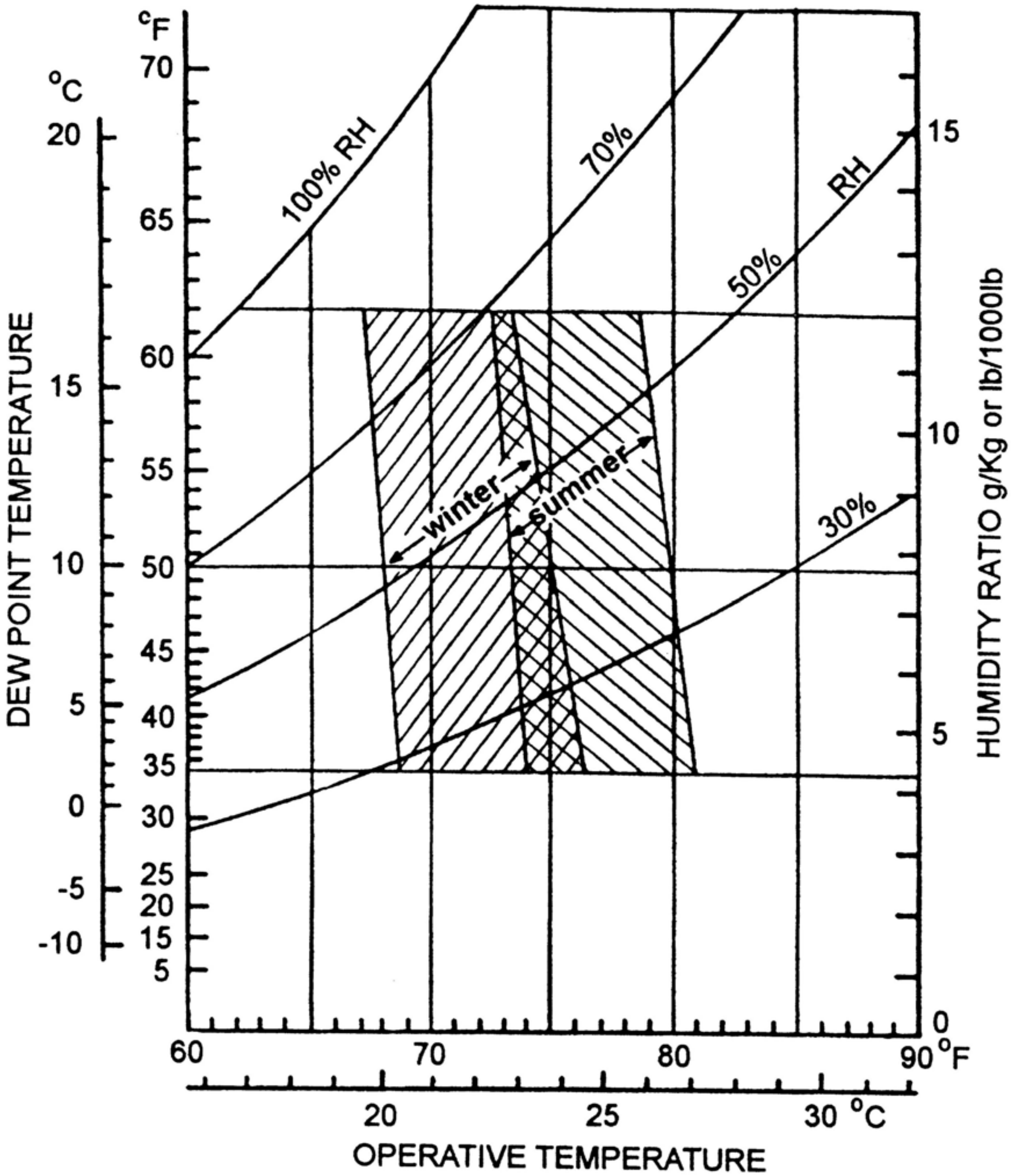


Figure 2.5 *ASHRAE comfort zone: ASHRAE Standard 55-1981 (ASHRAE 1981, p.5). Copyright © 1981 by ASHRAE (Reprinted with permission).*

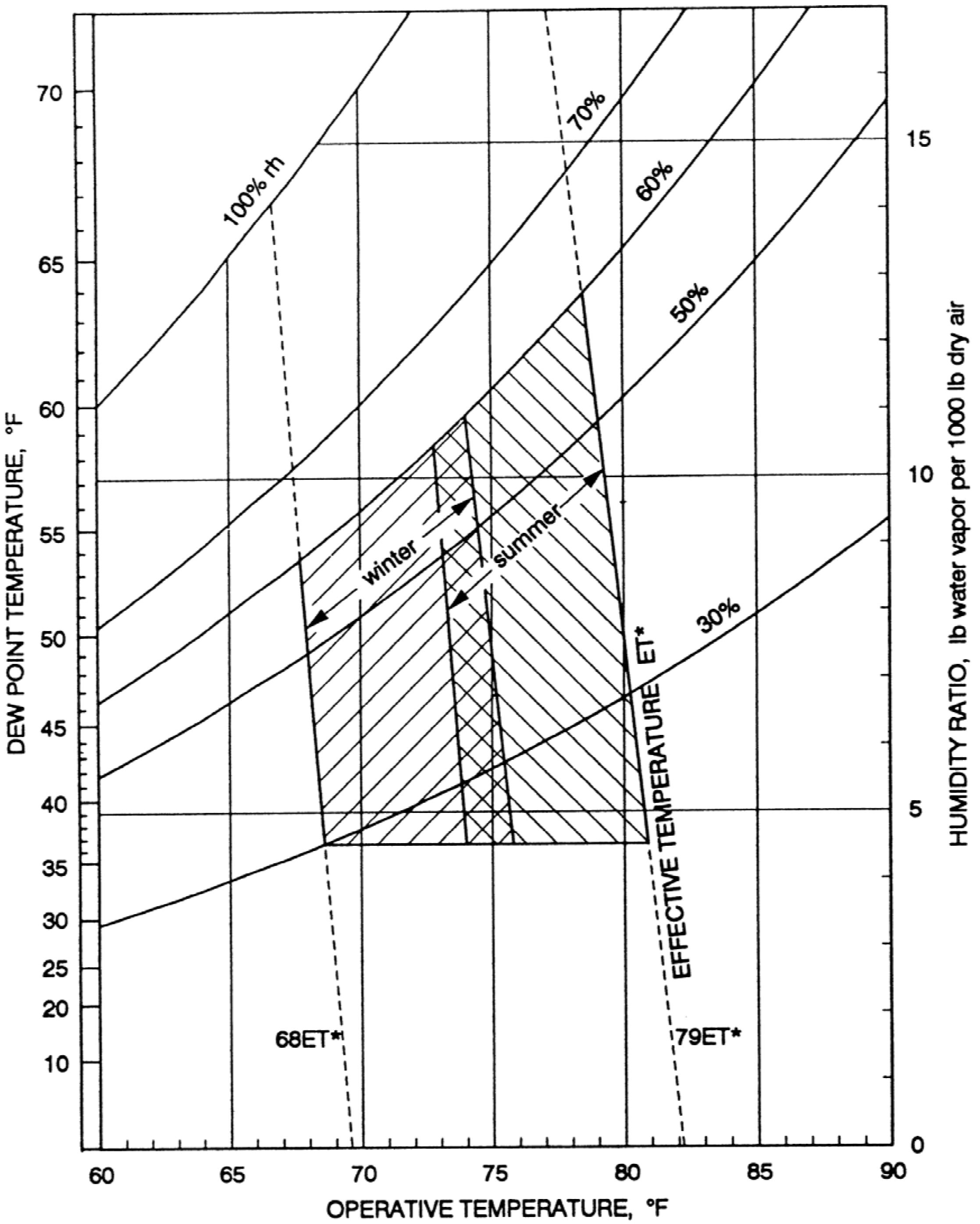


Figure 2.6 *ASHRAE comfort zone: ASHRAE Standard 55-1992 (ASHRAE 1992, p.8). Copyright © 1992 by ASHRAE (Reprinted with permission).*

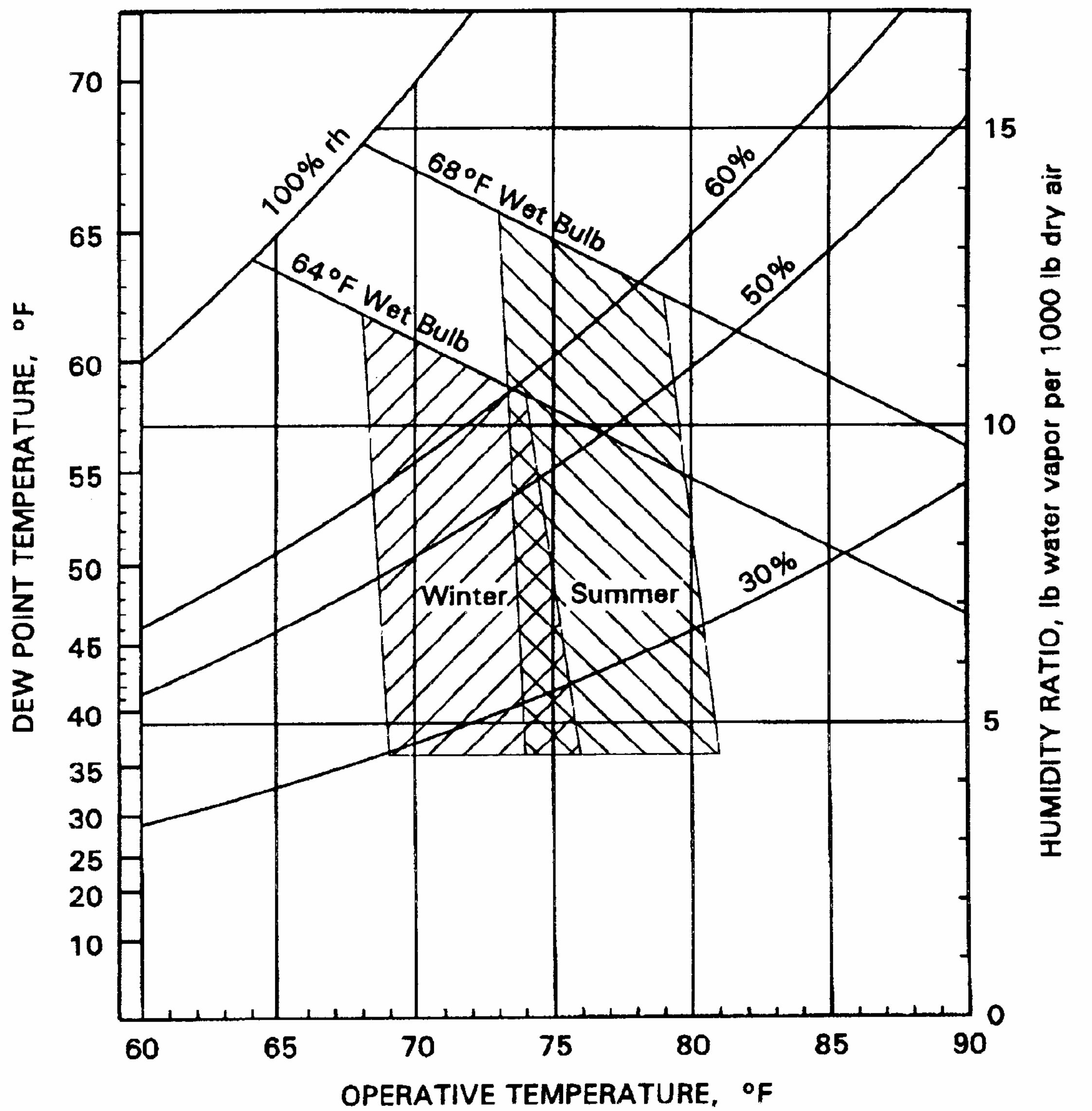


Figure 2.7 *ASHRAE comfort zone: ASHRAE Standard 55a-1995 (ASHRAE 1995, p.4). Copyright © 1995 by ASHRAE (Reprinted with permission).*

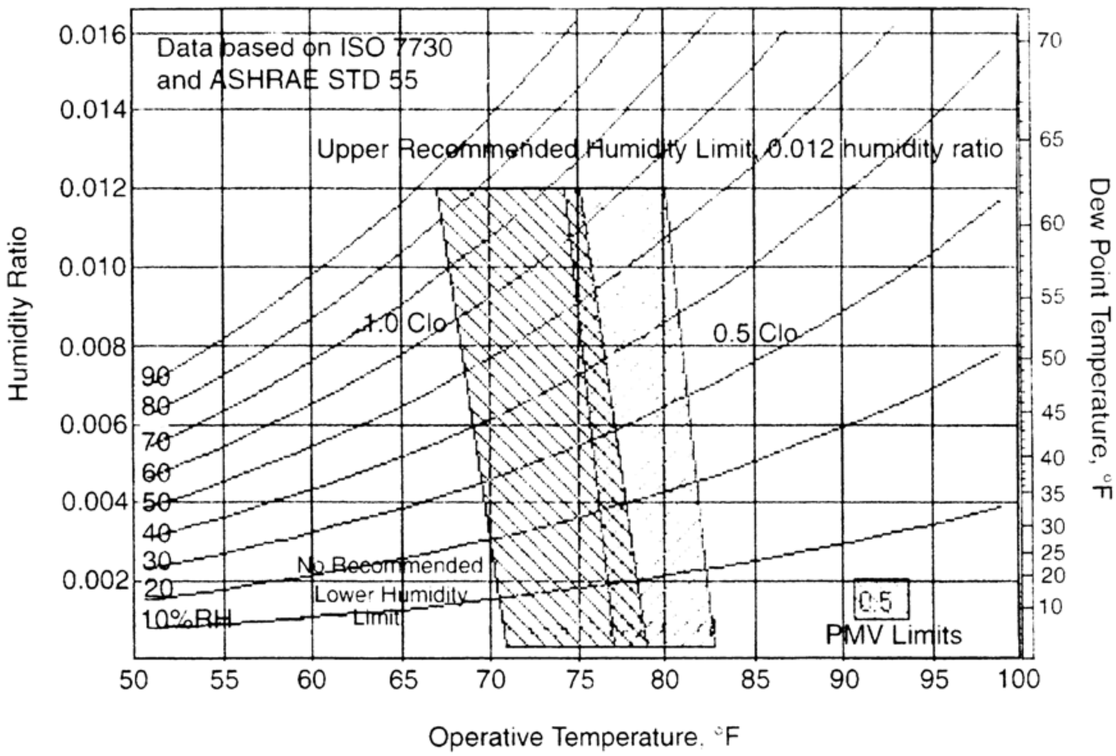


Figure 2.8 *ASHRAE comfort zone: ASHRAE Standard 55-2004 (ASHRAE 2004, p.5). Copyright © 2004 by ASHRAE (Reprinted with permission).*

The differences between Standard 55-1981 (Figure 2.5), 1992 (Figure 2.6), and 1995 (Figure 2.7), are in the upper humidity limits. Standard 55-1981 marks the upper limit at a 0.012 lbw/lba humidity ratio, which was based primarily on consideration of indoor air quality. Standard 55-1992 contains an upper limit of a relative humidity level of 60% in order to prevent mold and mildew growth (Olesen, 2000). In Standard 55a-1995, the upper limit was changed to 64 °F (18 °C) wet-bulb in the wintertime and 68°F (20 °C) wet-bulb in the summertime. The upper limits of the Standard 55-1995 correspond to the Berglund study conducted in 1995 (ASHRAE, 2001a), which determined the thermally acceptable levels for both medium and high humidity during summer comfort temperatures, and according to subjects wearing 0.55 clo.

These recommended humidity limits have inspired significant discussion during each revision of the Standard 55. In 2004, ASHRAE published the new version of the

Standard-55 (ASHRAE, 2004; Olesen and Brager, 2004) (see Figure 2.8), which focuses solely on thermal comfort criteria. Unlike the previous versions (Standard 55-1981, 1992, and 1995), which limited the lower humidity to the 36 °F (2 °C) dewpoint, the Standard 55-2004 has no lower humidity limit. This is because the influence of the humidity lower limit, as related to thermal comfort, is relatively small. The upper limit of the new version returned to the limit used in 1981, and is now used only to control humidity levels when there is an HVAC system. The new version also includes a computer program that allows users to adjust various thermal comfort factors and to calculate the PMV and PPD indices. In order to evaluate indoor thermal comfort as well as to prevent mold and mildew growth in building, the ASHRAE Standard 55-1992, which contains the upper limit of relative humidity level at 60%, was used in this study.

2.1.6 Other Significant Studies

Other significant thermal comfort studies include the studies of Givoni (1976, 1994, and 1998), Nevins et al. (1975), Berglund and Fobelets (1987), McIntyre (1978), Arens et al. (1980), Tanabe (1987), Wu (1988), Busch (1992), Berglund (1995), Dear and Brager (1998), and Rohles Jr. (2007).

Givoni investigated various thermal indices that affect human comfort and used his results to develop an Index of Thermal Stress (I.T.S.) (Givoni, 1969, pp. 75-102). He then used the I.T.S. to develop his comfort chart (Givoni, 1976). Milne and Givoni suggested an approximation of the comfort zone for Americans that falls roughly between 68-78 °F and 20%-80% relative humidity (RH), and excluded the corner of these “hot-humid” coordinates (Milne and Givoni, 1979. p.98) (see Figure 1.2). Givoni then justified the comfort boundaries for various countries with different climate conditions. For hot-humid climates, based on his personal evaluation of previous studies, Givoni extended the upper limits of both the accepted temperature and humidity to higher levels (Givoni, 1998. pp. 37-38). Given its historical significance, Givoni’s comfort chart was carefully considered for this study.

Several studies have investigated the relationship of relative humidity, air velocity, and thermal comfort. In order to prevent discomfort from warmth, Nevins et al. (1975) recommend that on the warm side of the comfort zone the relative humidity should not exceed 60%. Arens et al. (1980; ref. Watson and Labs, 1983, p.27) found that the effects of increased air movement extend the upper limit of the comfort zone to higher temperatures. Their study displayed the same results as the studies of McIntyre (1978; ref. Givoni, 1998, p.18), Tanabe et al. (1987), and Wu (1988; ref. Givoni, 1998, p.19). Berglund and Fobelets (1987) found that airspeeds of 50 fpm or less have no affect on neutral environments. Busch's field study of more than 1,100 Thai office workers found that Thai conditions of acceptable thermal comfort exist over a broad range of effective temperatures, adjusting the right side of the summer comfort zone approximately 7 °F (4 °C) (Busch, 1992). Similar results were shown by Lechner (1991, p. 31) who identified a shifting-up of the comfort zone on the right side due to high air velocity and a shifting down of the comfort zone on left side due to a high mean radiant temperature or a high level of physical activity. Based on these studies, the recommendation of Nevins et al. (1975) to limit the relative humidity at 60%, which corresponded to the ASHRAE Standard 55-1992 comfort chart, will be considered. The relationship of, air velocity and thermal comfort will also be carefully considered in this research.

A study of the impact of comfort preferences was performed by Dear and Brager (1998). In this study, Dear and Brager developed an adaptive model of thermal comfort and preference by assembling a quality-controlled database from field experiments in 160 office buildings. They found that people in warm climate zones prefer warmer indoor temperatures than people in cold climate zones. Their research also showed that occupants in natural-ventilated buildings are tolerant of a significantly wider range of temperatures. Therefore, based on these studies, the boundaries of the thermal comfort zone would need to be modified to accommodate the climate zone in which the building is located and other conditions.

The study of Rohles Jr. (2007) proposed a temperature range that is judged as comfortable by most subjects (a modal comfort envelop); which takes into account variations in activity, clothing, age, and other factors. This temperature range is from 68 °F to 76 °F (20 °C to 24.4 °C), which is close to the range of the ASHRAE Comfort Zone (ASHRAE, 1992; 1995; 2004) during the winter when the “clo” value is equal to “1”. This may results in increased cooling energy use in the building, which is a concern in this study. In addition, the effects from the activity levels on thermal comfort are less for residential building, and the clothing value during the summer and winter can be taken care by adjusting heating or cooling setpoint of a thermostat.

In summary, the comfort zone defined by the ASHRAE Standard 55-1992 comfort chart will be used for this research. Givoni’s comfort charts and several other factors that affect the limits of the comfort zone will also be considered.

2.2 BIOCLIMATIC CHART, OTHER PRE-DESIGN TOOLS, AND COMPUTERIZED PROGRAMS

2.2.1 Introduction

In 1920, the American Institute of Architects (AIA.) first published the architectural design steps (AIA Handbook, 1958, p. vii). Since this study the traditional steps (e.g., schematic design, design development, construction documents, and construction process) have changed little from the time of their first publication. Many pre-design tools have been developed in order to help architects design buildings in the schematic design stage. These pre-design tools include a series of “Bioclimatic Charts” by Olgyay (1963), Givoni (1976, 1994, and 1998), Givoni-Milne (Milne and Givoni, 1979), the extended applications of the Givoni-Milne chart by Watson and Labs (1983), Lechner (1991), as well as other pre-design tools listed in Section 2.2.3.

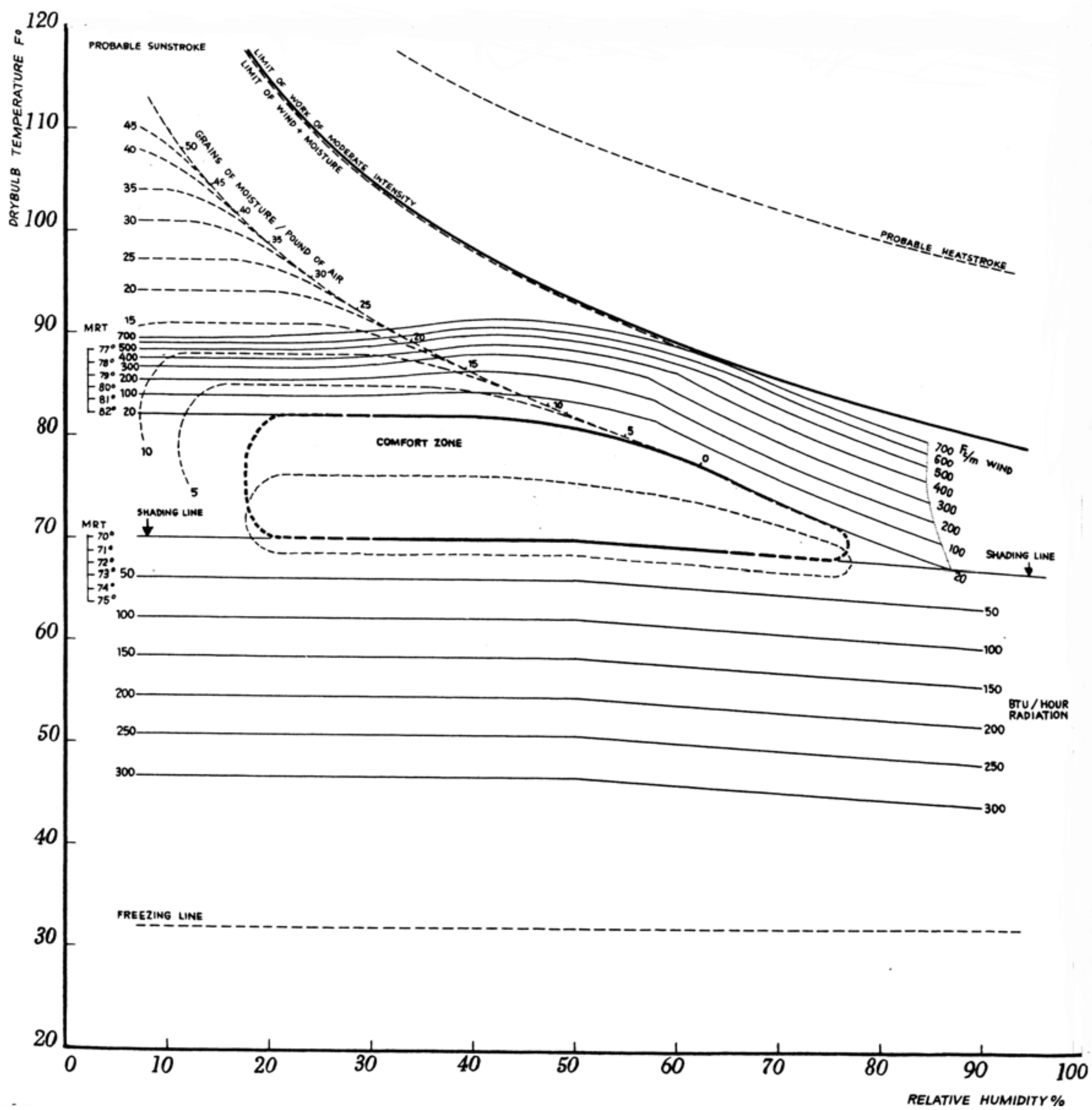


Figure 2.9 *Olgyay's bioclimatic chart (Olgyay 1963, p.22). Copyright © 1963 by Princeton University Press (Reprinted with permission).*

2.2.2 Bioclimatic Chart

"Bioclimatic" design is the phase that is used to define potential building design strategies that utilize natural energy resources and minimize conventional energy use.

"The Building Bioclimatic Chart indicates that whenever ambient outdoor temperature and humidity conditions fall within the designated limits of a control strategy, then the interior of a building designed to effectively execute that strategy will remain comfortable." (Watson and Labs, 1983, p.33). This approach to designing buildings to maintain indoor comfort conditions has been developed and updated many times since its original creation, including: Olgyay (1963), Arens et al., (1980), Givoni (1976, 1994, and 1998), and Milne and Givoni (1979).

In the 1950s, bioclimatic designs were first used by Victor and Aladar Olgyay who published a series of articles and books on this topic. In 1963, Victor Olgyay developed the first bioclimatic chart based on outdoor conditions (Olgyay, 1963, p. 22) (see Figure 2.9). The chart shown here was suggested for lightweight buildings (i.e., plywood or gypsum on wood or metal stud walls and floors) in humid regions where ventilation is utilized during the day, and the indoor temperatures range is very close to the outdoor temperatures. Unfortunately, the chart is inappropriate for use in hot and dry regions where the indoor temperatures are significantly different from the outdoor temperatures (Givoni, 1976, pp. 310-311). Arens et al. (1980; ref. Watson and Labs, 1983, pp. 33-34) update the chart using the original format of the Olgyay's chart. This chart was based on a comfort model developed by the J.B. Pierce Foundation.

In 1969, a significant improvement of the bioclimatic chart was proposed by Baruch Givoni (Givoni, 1976). To address the problems of the Olgyay chart, Givoni developed the building bioclimatic charts for "envelope-dominated buildings" with no mechanical system. His charts were based on indoor temperature. He used his Index of Thermal Stress (I.T.S.) index to identify the limits of external climate conditions for each effective design strategy boundary that would be used to attain indoor comfort conditions (Givoni, 1976). Givoni's bioclimatic charts have been widely referenced by many studies.

In 1979, Milne and Givoni combined the different design strategies into the same chart (see Figure 1.2). They determined the limits of effectiveness for each design strategy in order to meet the needs of indoor comfort. Their chart is based upon the previous study conducted by Givoni (1976). The G-M bioclimatic chart (Milne and Givoni, 1979) is currently used by many architects in the U.S.; hence, the motivation for

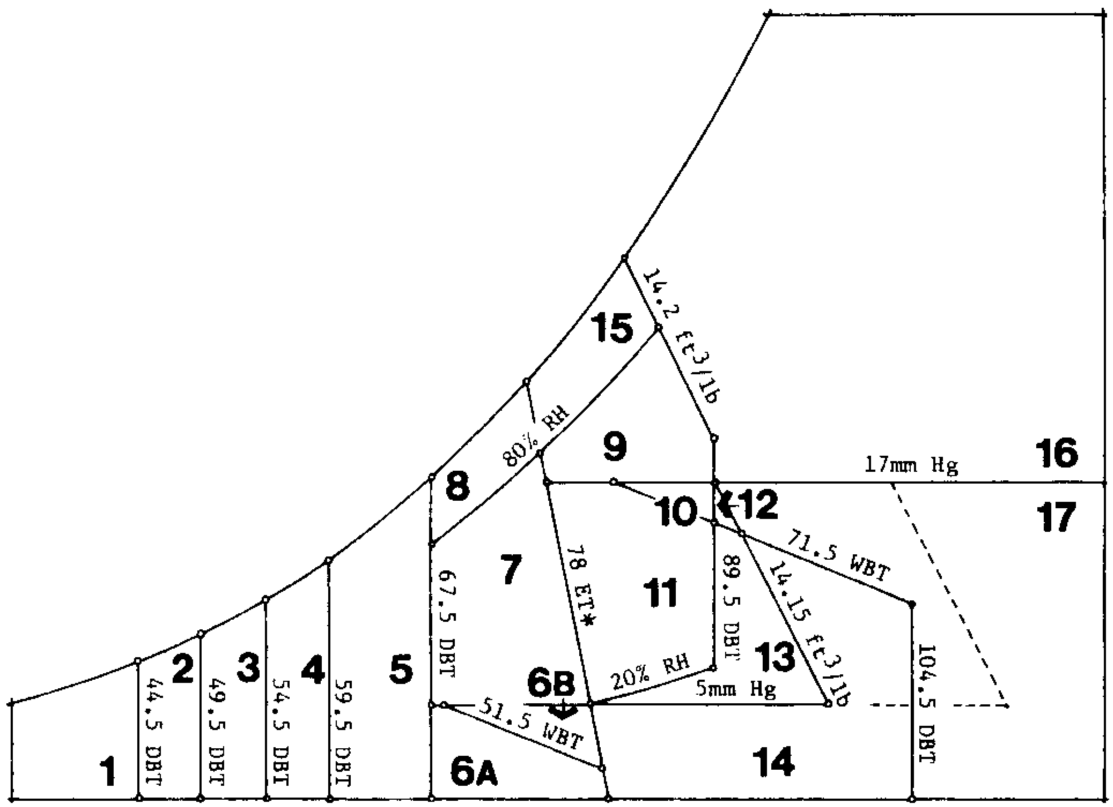


Figure 2.10 *Building bioclimatic chart (after Givoni) (Watson and Labs, 1983, p. 206).Copyright © 1983 by McGraw-Hill, Inc. (Reprinted by permission).*

this study. In Figure 1.2, the G-M Chart determines for each design strategy the limits of their effectiveness to meet the needs of indoor comfort conditions. It should be noted that Milne and Givoni considered the boundaries to be fuzzy, and even ambiguous. This is indicated by the arrows that they frequently include on their chart.

In one of the ways to use their chart, hourly weather data for a location can be superimposed onto the chart to calculate the number of hours that fall into each design strategy in order to find the appropriate design strategies for that location. A detailed description of the G-M Chart design strategy boundary delineations that was used in this research can be found in “Climatic Design” (Watson and Labs, 1983, p.206) (see Figure 2.10 and Table 2.1).

Table 2.1 *Control strategies (Watson and Labs 1983, p. 206). Copyright © 1983 by McGraw-Hill, Inc. (Reprinted with permission).*

Identification of climate control strategies on the Building Bioclimatic Chart (adapted after Givoni).	
BIOCLIMATIC NEEDS ANALYSIS	
Total heating (< 68F)	1-5
Total cooling (> 78ET*)	9-17
Total comfort (68F – 78ET*, 5mm Hg – 80% RH)	7
Dehumidification (> 17mm Hg or 80% RH)	8-9, 15-16
Humidification (< 5mm Hg)	6A, 6B (14)
STRATEGIES OF CLIMATE CONTROL	
Restrict conduction	1-5; 9-11, 15-17
Restrict infiltration	1-5; 16-17
Promote solar gain	1-5
Restrict solar gain	6-17
Promote ventilation	9-11
Promote Evaporative cooling	11, 13-14 (6B)
Promote radiant cooling	10-13
Mechanical cooling	17
Mechanical cooling & dehumidification	15-16

Lechner (1991) divided the United States into 17 climate regions. For each region, he recommended a set of specific priority design strategies. These included examples of appropriate residential building drawings, maps, climate data for the U.S. by representative cities, and a building bioclimatic chart (Lechner, 1991, p.41). The climate data is presented on the Givoni-Milne bioclimatic chart by 12 straight lines. Each line is the connection of two points which mark the monthly normal daily minimum and maximum temperatures and their corresponding relative humidity. His method of presenting the building design strategy recommendations is both useful and convenient to use. Therefore, it was considered in this research.

In summary, the Givoni-Milne bioclimatic chart (Milne and Givoni, 1979) has been widely used. Therefore, their chart will be tested and evaluated in this research.

Other methods of climatic analysis and data presentation from the studies in this literature review were also considered.

2.2.3 Other Pre-Design Tools

Other pre-design tools and methods of climatic analysis and graphical presentations that are very useful include the “Shading Mask Protractor” (Olgyay and Olgyay, 1957), the “Timetable of climatic needs” (Olgyay, 1963), the “Horizontal sun path diagrams” (Hand, 1948; ref. Olgyay and Olgyay, 1957), the “Vertical sun path diagrams” (Bennett, 1978 and Mazria, 1979), and the “Sundial diagrams” (Watson and Glover, 1981). Several other software design tools and methods of climatic analyses and graphical presentations that are very useful and that are considered in this research include: “CLIMATE CONSULTANT” (Clayton, 1987; Acenas, 1989; Li and Milne, 1994), “SOLAR-2” (Milne, 1978; Sheu, 1986), “SOLAR-5” (Milne and Yoshikawa, 1979; Milne and Yoshikawa, 1979; Milne et al., 1986a), “DAYLIT” (Milne et al., 1986b), “OPAQUE” (Hwang, 1987; Abouella and Milne, 1990), “Energy Scheming” (Brown; 1989, 1991, and 1997), “Radiance” (Ward, 1996), “The Weather Tool” (Marsk and Raines, 1998), and “Shaded Fenestration Design” (Oh and Haberl, 1997; Oh, 2000).

In summary, in this study the Givoni-Milne bioclimatic chart (1979) will be tested and evaluated for thermostatically-controlled residence in selected climates using simulation. Selected graphical presentation techniques from the previously mentioned design tools and computerized programs were also considered in this research.

2.3 CLIMATE-CONTROLLED DESIGN STRATEGIES FOR RESIDENTIAL BUILDINGS

2.3.1 Introduction

Climate-controlled design strategies are procedures used to avoid unwanted heat gain in the summer or reduce heat loss in the winter. In those buildings that are thermostatically-controlled, the desirable method is not to work against but to work with

Table 2.2 *Psychrometric chart-processes (Willman et al. 1993, p.236). Copyright © 1993 by AIA (Reprinted with permission).*

- *Cooling and Dehumidification* is accomplished by passing air over a cold surface that has a temperature below the dew point of the air.
- *Dehumidification (only)* can be accomplished by passing the cooled, dehumidified air through a heat exchanger to precool incoming air, which in turn heats the outgoing air.
- *Sensible Cooling (only)* is accomplished by ensuring that the temperature of the cold surface is above the dewpoint of the air.
- *Evaporative Cooling* occurs when water is caused to evaporate into the air stream (the heat of vaporization being removed from the sensible heat content of the air).
- *Humidification* can be accomplished by passing the air over warmed water or by spraying either steam or a fine water mist into the airstream.
- *Heating and Humidification* is the humidification process with the addition of a hot surface to preheat the air.
- *Heating (only)* is accomplished by simply passing air over a hot surface.
- *Chemical Dehydration or Dehumidification* is accomplished by passing moist air through either beds of various desiccants or filters wetted with moisture-absorbing chemicals. A small decrease in enthalpy is caused by the heat of chemical mixing, but the large increase in sensible heat is caused by the heat of vaporization being released back into the airstream as the moisture condenses.

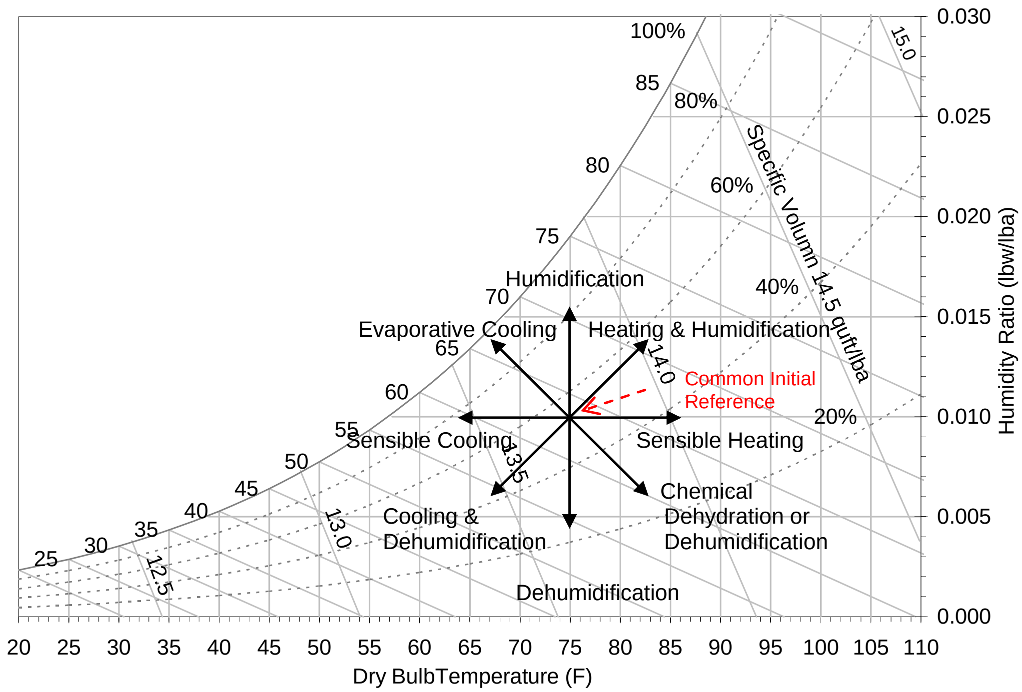


Figure 2.11 *Psychrometric chart- processes (Adapted from Eads, 1979; in Willman et al. 1993, p. 237).*

the natural climate resources. Therefore, building designers should begin their study with the processes that change the physical properties of moist air. “Psychometrics Chart-Processes” (Willman et al., 1993, p. 237) (see Table 2.2 and Figure 2.11) shows the various processes needed to change indoor temperature & humidity in order to accomplish comfort conditions. Although there is no comfort zone in this chart, the direction of movement of the in various processes is very helpful for understanding the movement on the bioclimatic chart. For example, to treat outside air in region 3 for use in the comfort zone one would use heating only. In most buildings, environmental systems are used to accomplish comfort conditions. Therefore, for building designers, it is very important to understand and determine the various processes used to change the physical properties of the air in the hopes of achieving comfort conditions.

The design strategies recommended in the Givoni-Milne bioclimatic chart that were investigated in this research are: passive solar heating, conventional heating, humidification, internal gains, shading, high thermal mass, evaporative cooling, ventilation, and air conditioning with conventional dehumidification (Milne and Givoni, 1979).

2.3.2 Passive Solar Heating

Around 50 A.D., the Romans first used glass in a greenhouse to trap heat radiated from the sun. In the seventeenth century, greenhouses became widely used for growing exotic plants and served as an additional sun space for the upper class in northern Europe, which by the eighteenth century became known as the “Age of Greenhouses”. In the 1920s, solar heating for everyone was first used in Europe. However, it was not until the 1930s that American architects began to use solar heating in a significant way. Solar heating later declined in the late 1950s (Lechner, 1991, pp. 104-105) when non-renewable fuel sources became both abundant and inexpensive. Passive solar heating can be used in several ways. A sunspace is the most common method, which has not only advantageous for its heating efficiency but also creates a pleasant living environment within a building.

Milne and Givoni suggested that the heating demand of a small 1,000 ft^2, well-insulated building with a 200 ft^2 south-facing glass could be achieved for one day without supplemental heating. This assumes clear sky conditions during the winter when the total daily insolation on each square foot of the south-facing glass would be about 1,700, 1,500, and 1,300 Btu at 32 ºN, 40 ºN, and 48 ºN, respectively, and would accommodate a maximum average daily temperature range above 43 ºF, 46 ºF, and 49 ºF at 32 ºN, 40 ºN, and 48 ºN, respectively. These values are based upon the overall solar heating system efficiency of 0.33 for the collection, storage, and distribution of passive solar heat (Milne & Givoni, 1979, p.102). Lechner (1991) suggested that the thickness of thermal mass (i.e., slabs, walls, concrete, and brick) for a direct gain system should be four to six inches. Anything over six inches of thickness is only slightly more helpful. South facing windows should be double-glazed except in very mild climates. Low-e coatings on the outside of the inside pane helps reduce nighttime heat loss. More information about passive solar design can be founded in Mazria (1979), Balcomb and Jones (ed.) et al. (1983), Balcomb (1986), and Balcomb (ed.) (1992). In this research, passive solar energy was not simulated; however, the effect from a combination of solar radiation availability and house mass will be considered.

2.3.3 Conventional Heating

In conventional heating, there are two major concerns with regards to system selection: the source of energy and the method of distribution. Possible sources of energy include: coal, gas, oil, wood, and electricity (Milne and Givoni, 1979). Heat can be distributed in a building by air or water by using a variety of devices (i.e., heat pump, boiler, furnace, etc.) More information about heating systems can be found in several books including: Lechner (1991), Stein and Reynolds (1992; 2000), Kreider and Rabl (1994), Moore (1993), McQuiston et al. (2000), and Ramsey and Sleeper (2000). In this study, a conventional heating system contained in the DOE-2 simulation program was considered for evaluation.

2.3.4 Humidification or Dehumidification

Humidification or dehumidification may be necessary when indoor temperatures are satisfactory but humidity levels may be different from that which is desired. In the humidification process moisture is added to the environment through evaporation. This is often accomplished through additional heating in order to counteract the sensible cooling that accompanies the evaporative process. Dehumidification usually accompanies the air-conditioning process when an air stream passes across air-conditioning coils that are below the dewpoint and water condenses on the cold surface of the air-conditioning coils. Dehumidification can also be accomplished through a chemical or desiccant process. In this research, both humidifying and dehumidifying design strategies were considered using simulation.

2.3.5 Internal Gains

Buildings experience internal heat gain from power consuming appliances, lighting, and from occupants. Internal heat gain reduces the fuel needed for heating during the cold weather season but increases the electric used for cooling during the warm weather season. More information about internal heating loads can be found in the ASHRAE Handbook of Fundamentals (2001b, Chapter 28). To determine the internal heat gain, the sources of internal heat (i.e., cooking, showering, lighting, equipment, and building occupants) should be identified as well as their schedules. In this study, an internal gain design strategy was carefully considered.

2.3.6 Shading

In the building bioclimatic chart, "The ideal shading device will block a maximum of solar radiation while still permitting views and breezes to enter a window." (Lechner, 1991, p.139) Watson and Labs (1983) suggested the need for shading devices when outdoor air temperature exceeds the lower limits of the comfort zone (68 ºF). Therefore, it is an important strategy to consider when outdoor air temperatures fall in the 68 ºF to 78 ET range and it becomes even more important for climate control when outdoor air temperatures exceed 78 ET. In a similar fashion, the “shadeline” in the Givoni-Milne chart is approximately 70 ºF. Therefore, if the outdoor temperature is above the shade line, then the windows need to be shaded. Finally, ASHRAE recommends shade line factors (SLFs) (ASHRAE, 2001b, p.28.4) for windows facing various directions in residential buildings in different latitudes. In summary, the functional advantages and aesthetic benefits of shading devices were also considered for this research by extending N, E, S, W building shades.

2.3.7 High Thermal Mass with and without Night Ventilation

Thermal mass (i.e., heavy masonry walls with exterior insulation, concrete floors, and concrete roofs) has the ability to temper or delay both heating and cooling loads. However, other factors also affect building performance. These factors include the orientation and aspect ratio, the color and texture of exterior surfaces, wind velocities, infiltration rates, shading, moisture in the walls, and thermal bridges (Demkin et al., 1993, p.50).

In hot and dry regions where the night temperature during the summer can fall below the comfort range, it is possible to store coolness in the building’s mass and use it to help maintain indoor comfort conditions during the daytime when the outdoor air rises above the comfort zone. This can be applied in those regions where the ambient vapor pressure is below 63.5 ºF (17.5 ºC) dewpoint (15 mmHg, 0.0125 lbw/lba) which represents the point where the human body can feel comfortable without air motion, at temperatures up to 77-80 ºF (25-27 ºC) (Givoni, 1981).

High thermal mass with night ventilation is a very effective technique used to reduce cooling loads in hot and dry regions. To achieve a high level of effectiveness in a hot climate, the building’s structure should satisfy the daily interior temperature range, be well shaded, and have a highly reflective outer surface (Watson, 1983). The dry-bulb temperature limit (in the Givoni-Milne chart, 1979) is high under these conditions. More information about high thermal mass can also be found in the study by Claridge, et al. (1992) as it relates to ASHRAE’s variable-based degree-day calculation. ASHRAE

Standards 90.1 (ASHRAE, 2004b) and 90.2 (ASHRAE, 2007) provide principle and standard for thermal mass performance, which is understandable and convenient to use for building design. The International Energy Conservation Code (IECC) (ICC, 2006) also implements a new climate zone system (Briggs et al., 2003a; 2003b), which encourages energy conservation through efficiency in envelope design. “ASHRAE GreenGuide” (ASHRAE, 2006) also included more information about “night precooling” as well as details on thermal mass concept on building loads. Therefore, a high thermal mass (without night ventilation) design strategy for building performance was investigated for this study by using high thermal mass walls and varying floor weight in the DOE-2 simulation.

2.3.8 Evaporative Cooling

Evaporative cooling is an adiabatic saturation process that increases moisture in the air to obtain a lower air temperature without changing the enthalpy or total heat content of the air (Stein and Reynolds, 1992). In the Psychrometric Chart-Processes, the direction of this process follows the wet-bulb line upward to the left (see Figure 2.11). The two main types of evaporative cooling are direct and indirect evaporative cooling. Evaporative cooling can be accomplished in several ways (i.e., spraying the moisture into the air stream or blowing air through a wetted mat). Extensive research into evaporative cooling in arid regions can be found in “Passive Cooling” (Yellott, 1989). The Zion National park Visitors Center is one of the examples that are successful in using evaporative cooling systems with natural downdraft cool-towers to reduce indoor temperature (Torcellini et al., 2005). Although direct evaporative cooling, which is referred to in the Givoni-Milne chart (1979) could be used by selecting the evaporative system available in the DOE-2 program, it was not included in this study.

2.3.9 Ventilation

“Ventilation comes from the Latin word, ventus, and means the movement of air.” (Watson & Labs, 1983, p.53). The basic idea with ventilation is to satisfy the fresh air required for building occupants, to increase the rate of evaporation and heat loss of the body, and to cool the building's interior by exchanging warm indoor air for cooler outdoor air. A significant study on ventilation was the study conducted by Chandra, who concluded that ventilative cooling has a significant potential for reducing air-conditioning costs even in a hot and humid climate such as Florida (Chandra, 1989).

In hot and humid regions where the diurnal temperature range is small, constant daytime ventilation across the skin, either naturally or mechanically, may not provide thermal comfort without additional assistance. In many cases, daytime ventilation alone cannot keep indoor temperatures below those of the outdoors (Givoni, 1981). In such regions, Watson and Labs (1983) recommended using lightweight structures to cool the building quickly at night and stated that the ideal structure would be no structure at all, except for a canopy to provide shading. According to Givoni (1976), the upper limit of the ventilation effectiveness boundary is a wind speed of 300 fpm (1.5 m/sec), which is the greatest wind speed that will not cause human annoyance. Dry-bulb temperatures of 89ºF are accepted as a limit for vapor pressures less than a 67 ºF (19.4 ºC) dewpoint (17 mm Hg, 0.014 lbw/lba). The most desirable range of wind velocities can be found in Stein and Reynolds (1992, p. 41).

In the DOE-2 program, thermostatically-controlled ventilation means economizer cooling that uses low temperature outside air to flush out internal heat gains. In the Givoni-Milne chart, ventilation refers to operable windows and wind-driven air movement. Therefore, the effect of ventilative cooling design strategies on building performance were investigated for this research using DOE-2 economizer cycle.

2.3.10 Air-Conditioning with Conventional Dehumidification

On the Givoni-Milne chart, beyond those regions where ventilation strategies could be used to create human comfort, air-conditioning (A/C) is quite often the only alternative for most buildings. Air-conditioning and dehumidification can be conventionally accomplished when air is passed across a cooling coil that is below the dewpoint temperature of the air stream in order to condense and drain away water

(Milne and Givoni, 1979). More information about A/C systems can be found in numerous books, including: Lechner (1991), Stein and Reynolds (1992; 2000), Kreider and Rabl, (1994), Moore (1993), and McQuiston et al. (2000). Therefore, a conventional cooling and dehumidification system was considered for this research from the DOE-2 program library of the system types.

In summary, the design strategies recommended in the G-M Chart (1979) which include passive solar heating, conventional heating, humidification, internal gains, shading, high thermal mass, evaporative cooling, ventilation using an economizer, and air-conditioning with conventional dehumidification were all investigated in this study.

There are several limitations to the G-M Chart, which were mentioned in Clayton (1987) and were considered in this research: 1) the chart does not incorporate solar radiation, which could lead to mistaken recommendations for active or passive solar design strategies when a climate has few solar resources; 2) the chart does not illustrate diurnal temperature swings, which may lead to misleading recommendations with respect to nighttime ventilation design strategies; and 3) the chart does not account for seasonal variations, where many buildings make use of different design strategies or different system operation strategies.

2.4 BUILDING SIMULATION PROGRAMS

2.4.1 Introduction

There are many well-documented energy simulation programs available around the world. The history of building energy simulation programs in the U.S. can be found in the publications by Kusuda (1999), and Ayres and Stamper (1995). These programs include: DOE-2 (Winkelmann, 1993a; 1993b), BLAST (BLAST Support Office, 1992), ENERGY-10 (Balcomb and Beeler, 1998), ECOTECH (Marsk, 1997; Marsk and Raines, 1998), EnergyPlus (Crawley et al., 2000), ENER-WIN (Degelman, 2002), eQUEST (Hirsch, J. J., 2003), TRNSYS (Klein et al., 2004), and MIT Design Advisor (Glicksman et al., 2005). Although numerous energy simulation programs have been developed, the DOE-2 program is the most wildly accepted public-domain simulation program. DOE-2.1e validation studies are found in the research of Lomas et al. (1994), Vincent and Huang (1996), and Meldem and Winkelmann (1998). The validations of several versions of the DOE-2 were documented in Sullivan (1998).

2.4.2 The DOE-2 Simulation Program

In the U.S., the DOE-2 program, developed by the Lawrence Berkeley National Laboratory (LBNL), has been updated and extensively used. The program was first called “CAL-ERDA”. In 1978, it was renamed DOE-1, and a year later it was updated to be DOE-2 (York & Tucker, 1980). The latest version is DOE-2.1e, Version 121 (Winkelmann, 1993a; 1993b), which will be used for this research.

DOE-2 consists of four FORTRAN-90 subprograms: LOADS, SYSTEMS, PLANT, and ECONOMICS. The LOADS sub-program calculates the hourly heating/cooling loads and passes the information to SYSTEMS. The SYSTEMS sub-program then simulates the internal equipment and HVAC air-side systems, including all HVAC equipment, lights, and appliances. It allows the user to specify various systems in order to accurately simulate interior conditions. After receiving the information from SYSTEMS, the PLANT sub-program then simulates all primary energy-using equipment such as chillers, boilers, etc. Finally, the ECONOMICS sub-program calculates utility and life cycle costs for a pre-specified period of time. (Bou-Saada and Haberl, 1994)

The building dimensions in a DOE-2 input file can be viewed using an architectural rendering package called DrawBDL (Huang, 1994). This program directly obtains building dimensions from the DOE-2 input file and creates an architectural rendering (2D and 3D) of the building. Related studies of graphical and building energy analysis can be found in Haberl et al. (1988a; 1988b; and 1995) and Haberl and Abbas (1998).

Therefore, in this study, the DOE-2 simulation program was used to determine the energy performance of the prototype house. The DrawBDL program was used to generate an architectural rendering of the building. Previous methods of presenting the DOE-2 hourly data were also considered.

2.5 CLIMATE CLASSIFICATIONS AND REPRESENTATIVE WEATHER DATA

2.5.1 Introduction

Climate affects building energy use in most buildings. There are two main types of climates, macroclimate and microclimate. For a particular location, environmental factors (i.e., elevation, land forms, soil types, vegetation, man-made structures) can change from climate to climate. Many procedures were previously used to classify these various climates into categories. This research focuses on those climate categories developed for building energy conservation designs. In the U.S., the National Oceanic and Atmospheric Administration (NOAA, 1980, and 1986) has collected and published extensive climatic weather data. These data have been used to develop several climatic data sets in different formats (i.e., TMY2, TRY2, WYEC2, CWEC, CTZ2, IWEC). These weather data sets are commonly used for energy simulation programs and therefore were reviewed in this research.

2.5.2 Climate Classifications

In the United States, many energy conservation design guidelines, standards and energy codes have been developed based on climate. Victor Olgyay classified climate into four categories: cool, temperate, hot-arid, and hot-humid (Olgyay, 1963). His classification system was based on the Köppen study (Köppen, 1924; Köppen and Geiger, 1930). In 1949, The American Institute of Architects (AIA) developed the House Beautiful Climate Control Project, which divided the U.S. into 15 regions and presented comprehensive climatic information for each representative city (Watson, 1993).

In 1978, the AIA Research Corporation developed 13 Regional Guidelines for Building Passive Energy Conserving Homes. The guidelines were based on heating and cooling needs, solar availability when temperatures ranged from 50-60°F, and the effect of diurnal temperature swings and humidity (Watson, 1993). Lechner (1991), using climatic information from the study conducted by the AIA, divided the U. S. climate into 17 regions. He proposed design guidelines and graphical climatic data for each region.

Briggs et al. (2003a; 2003b) developed a new climate classification system for building energy codes, standards, energy analysis, and design guidelines. This new climate classification was based on the widely accepted classification systems of world climates (Köppen and Geiger, 1930), and was meant to improve the implementation of building energy codes and standards. In order to accomplish this, Briggs et al. used a "hierarchical cluster analysis", which is a distance metric that represents the degree of similarity or dissimilarity between observations in a data set (Briggs et al., 2003a; 2003b), to classify the climate into 17 new climate zones (see Table 2.3 and Figure 2.12). These new climate classifications were considered in this research.

ASHRAE Standards 90.1 (ASHRAE, 2004b) and the International Energy Conservation Code (IECC) (ICC, 2006) both use four different methods for specifying climate-dependent requirements. In many situations, the climatic data needed to determine the requirements is not included in the standards or the code documents. The ASHRAE energy standards and the IECC were both considered for this research.

2.5.3 Representative Weather Data

There are two main categories of hourly weather data used in energy simulations: 1) actual year data and 2) typical year data. The actual hourly observations data are available from many sources, which include the U.S. National Climatic Data Center (NCDC, 1976, 1981, and 1993) and the Solar and Meteorological Surface Observational Network (SAMSON) (NCDC, 1993). A number of weather data sets for energy simulations (i.e. TRY, TMY, TMY2, WYEC, WYEC2, BIN, IWEC, etc.) have been developed by several groups for different purposes, which include the NCDC, Sandia

Table 2.3 *Climate zone definitions for new classification (Briggs et al. 2003b, p.124). Copyright © 2003 by ASHRAE (Reprinted with permission).*

B. Thermal Zone Definitions

Zone No.	Climate Zone Name and Type[2]	Thermal Criteria[1, 3, 8]	Representative U.S. City[4]	Köppen Class.[5]	Köppen Classification Description[6]
1A	Very Hot – Humid	5000 < CDD10°C	Miami, FL	Aw	Tropical Wet-and-Dry
1B[7]	Very Hot – Dry	5000 < CDD10°C	---	BWh	Tropical Desert
2A	Hot – Humid	3500 < CDD10°C _ 5000	Houston, TX	Caf	Humid Subtropical (Warm Summer)
2B	Hot – Dry	3500 < CDD10°C _ 5000	Phoenix, AZ	BWh	Arid Subtropical
3A	Warm – Humid	2500 < CDD10°C _ 3500 AND HDD18°C _ 3000	Memphis, TN	Caf	Humid Subtropical (Warm Summer)
3B	Warm – Dry	2500 < CDD10°C _ 3500 AND HDD18°C _ 3000	El Paso, TX	BSk/BWh/H	Semiarid Middle Latitude/Arid Subtropical/Highlands
3C	Warm – Marine	HDD18°C _ 2000	San Francisco, CA	Cs	Dry Summer Subtropical (Mediterranean)
4A	Mixed – Humid	CDD10°C _ 2500 AND HDD18°C _ 3000	Baltimore, MD	Caf/Daf	Humid Subtropical/Humid Continental (Warm Summer)
4B	Mixed – Dry	CDD10°C _ 2500 AND HDD18°C _ 3000	Albuquerque, NM	BSk/BWh/H	Semiarid Middle Latitude/Arid Subtropical/Highlands
4C	Mixed – Marine	2000 < HDD18°C _ 3000	Salem, OR	Cb	Marine (Cool Summer)
5A	Cool – Humid	3000 < HDD18°C _ 4000	Chicago, IL	Daf	Humid Continental (Warm Summer)
5B	Cool – Dry	3000 < HDD18°C _ 4000	Boise, ID	BSk/H	Semiarid Middle Latitude/Highlands
5C[7]	Cool – Marine	3000 < HDD18°C _ 4000	---	Cfb	Marine (Cool Summer)
6A	Cold – Humid	4000 < HDD18°C _ 5000	Burlington, VT	Daf/Dbf	Humid Continental (Warm Summer/ Cool Summer)
6B	Cold – Dry	4000 < HDD18°C _ 5000	Helena, MT	BSk/H	Semiarid Middle Latitude/Highlands
7	Very Cold	5000 < HDD18°C _ 7000	Duluth, MN	Dbf	Humid Continental (Cool Summer)
8	Subarctic	7000 < HDD18°C	Fairbanks, AK	Dcf	Subarctic

Notes:

1. Column 1 contains alphanumeric designations for each zone. These designations are intended for use when the zones are referenced in the code. The numeric part of the designation relates to the thermal properties of the zone. The letter part indicates the major climatic group to which the zone belongs; A indicates humid, B indicates dry, and C indicates marine. The climatic group designation was dropped for Zones 7 and 8 because we did not anticipate any building design criteria sensitive to the humid/dry/marine distinction in very cold climates. Zones 1B and 5C have been defined but are not used for the United States. Zone 6C (Marine and HDD18°C > 4000 (HDD65°F > 7200) might appear to be necessary for consistency. However, very few locations in the world are both as mild as is required by the Marine zone definition and as cold as necessary to accumulate that many heating degree-days. In addition, such sites do not appear climatically very different from sites in Zone 6A, which is where they are assigned in the absence of a Zone 6C.
2. Column 2 contains a descriptive name for each climate zone and the major climate type from Table 1A. The names can be used in place of the alphanumeric designations wherever a more descriptive designation is appropriate.
3. Column 3 contains definitions for the zone divisions based on degree-day cooling and/or heating criteria. The humid/dry/marine divisions must be determined first before these criteria are applied. The definitions in Table 1A and 1B contain logic capable of assigning a zone designation to any location with the necessary climatic data anywhere in the world. However, the work to develop this classification focused on the 50 United States. Application of the classification to locations outside of the United States is untested.
4. Column 4 contains the name of a SAMSON station found to best represent the climate zone as a whole (NCDC 1993). See discussion of the process used to select representative cities.
5. Column 5 lists abbreviations for the climate groups based on a simplified version of the Köppen system (Finch et al. 1957) that best match each zone. This information relates the climate zones to a widely used world classification system and may facilitate application outside the United States.
6. Column 6 contains a verbal description derived from Köppen's work that serves to explain the two- and three-letter codes in the previous column.
7. Zones 1B and 5C do not occur in the United States, and no representative cities were selected for these zones due to data limitations. Climates meeting the listed criteria do exist in such locations as Saudi Arabia, British Columbia, Canada, and Northern Europe.
8. SI to I-P Conversions:

2500 CDD10°C = 4500 CDD50°F	3000 HDD18°C = 5400 HDD65°F
3500 CDD10°C = 6300 CDD50°F	4000 HDD18°C = 7200 HDD65°F
5000 CDD10°C = 9000 CDD50°F	5000 HDD18°C = 9000 HDD65°F
2000 HDD18°C = 3600 HDD65°F	7000 HDD18°C = 12600 HDD65°F

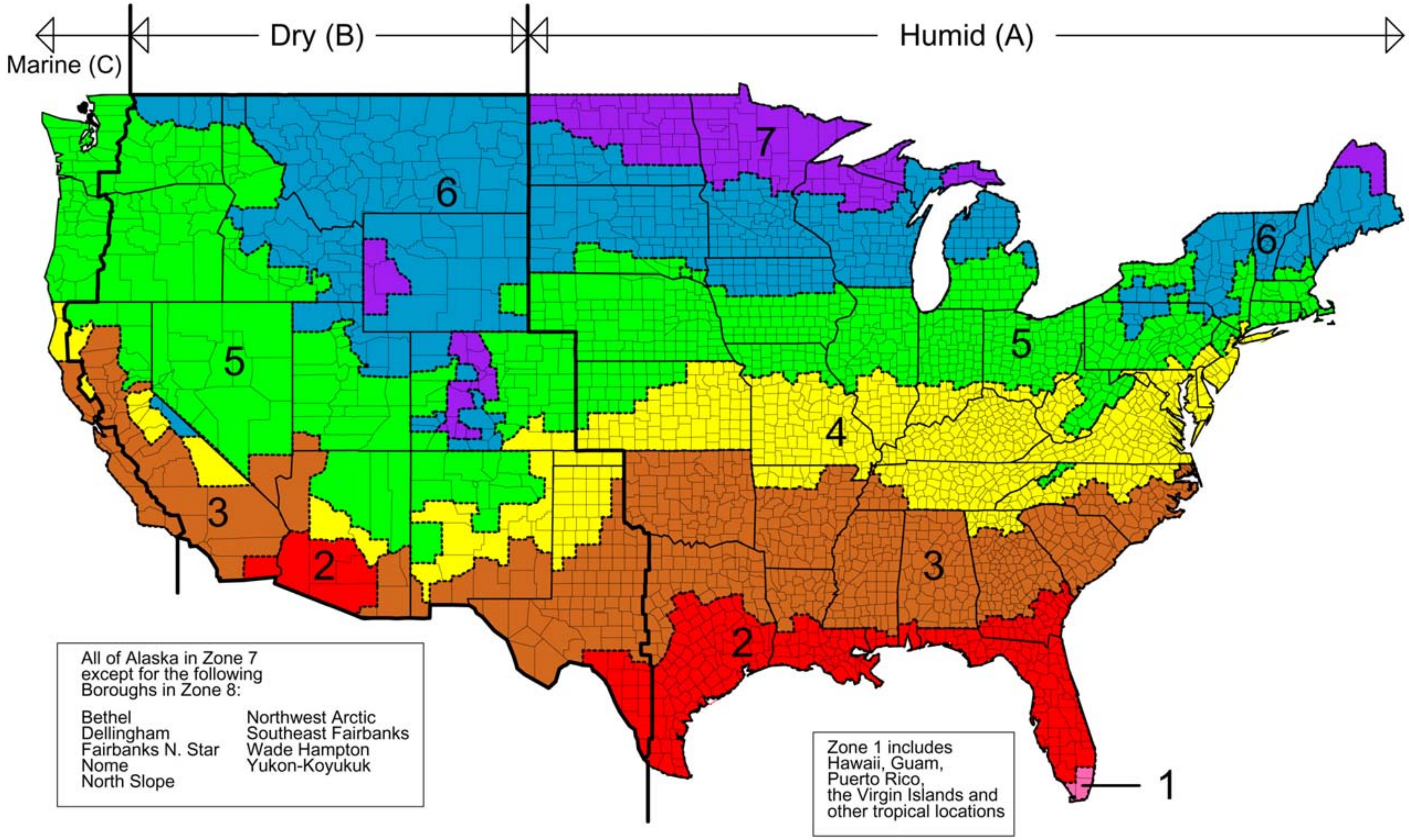


Figure 2.12 *Map of the United States showing the proposed new climate zone assignments under the new classifications (Briggs et al. 2003b, p.125). Copyright © 2003 by ASHRAE (Reprinted with permission).*

National Laboratory, ASHRAE, and the National Renewable Energy Laboratory (NREL). In 1976, the NCDC developed the Test Reference Year (TRY) weather data sets for use in energy simulations (NCDC, 1976). TRY weather data are from actual historic years. These years were selected by eliminating any year that had months with extreme conditions until only one suitable year remained. That year contained dry-bulb, wet-bulb, and dewpoint temperatures, wind speed and wind direction, relative humidity, barometric pressure, cloud cover and type, and a place holder for solar radiation, but no measured solar data (Huang et al., 1996).

To deal with the limitations of the TRY weather tape's lack of solar data, the NCDC and the Sandia National Laboratory developed a new data set, the Typical Meteorological Year (TMY), for 234 U.S. locations (NCDC, 1981). In 1995, NREL updated the TMY data set to TMY2 (Marion and Urban, 1995). The new TMY2 data utilized the Solar and Meteorological Surface Observational Network (SAMSON), which includes the published weather and the solar data from the National Solar Radiation Data Base (NSRDB) from 1961-1990, which was compiled by the NREL (NSRDB; 1992, 1995) and NCDC (1993).

In 1983, ASHRAE developed the Weather Year for Energy Calculations (WYEC) (Crow, 1983), which also included solar data. WYEC weather data was designated to represent more typical weather patterns than would occur in a single annual or monthly weather data set. ASHRAE sponsored research to update the solar insolation models (Perez et al., 1992) and worked with the NREL to update the WYEC data set (Stoffel, 1995). The new format is known as WYEC2. In 2001, ASHRAE developed a new typical meteorological year hourly weather data set, the International Weather for Energy Calculations (IWEC), for 227 locations outside the USA and Canada (ASHRAE, 2002). IWEC data were derived from up to 18 years of DATSAV3 hourly weather data originally archived at the NCDC. Solar radiation was calculated from cloud cover using a model calibrated on a station-by-station basis with measured solar radiation data collected from the World Radiation Data Center (ICSU, 1996).

Several studies have highlighted shortcomings in current weather files, including: Kusuda and Achenbach, 1965; Huang and Crawley, 1996; Crawley, 1998; and Haberl et al., 1995. Kusuda and Achenbach explained how to calculate ground temperatures, an item that is missing from most weather data sets. Huang and Crawley recommended that energy simulation users avoid using TRY and use TMY2 or WYEC2 weather files, which have more appropriate long-term weather data (Huang and Crawley, 1996, p.4.188; and Crawley, 1998). Haberl et al. compared measured weather data versus TMY weather data in the DOE-2 simulation. Their study showed that the measured data contains dryer conditions, lower temperatures, and less wind speed than appeared in the TMY weather data. Therefore, in this study, the TMY2 weather data was used with the DOE-2 program for all but one of the selected sites and ground temperatures are calculated with the Kusuda and Achenbach algorithms inside the DOE-2 program.

2.6 LITERATURE REVIEW SUMMARY

This research focuses on describing comfort in terms useful for the design of thermostatically-controlled residential heating and cooling systems. The goals include maintaining indoor thermal comfort and reducing energy use in buildings. In order to evaluate indoor comfort conditions, the ASHRAE Standard 55-1992 comfort chart was used. The Givoni comfort charts and the other factors that affect the limits of air temperature and humidity were also evaluated. The Givoni-Milne bioclimatic chart (1979) was tested and evaluated for climate-controlled residences in selected climates. The previous techniques of graphical presentation were all reviewed and the relevant graphical techniques were used. The design strategies recommended in the G-M chart, as well as the recommended techniques and design guidelines from the previous publications were all considered. The DOE-2 simulation program was used with the TMY2 weather data to determine the building energy performance of a prototypical residence in the selected climates. The DrawBDL program was used to generate architectural renderings of the building used in the DOE-2 simulation. Finally, representative cities for several climates were carefully selected.

CHAPTER III

SIGNIFICANCE OF THE STUDY

3.1 EXPECTED CONTRIBUTIONS OF THIS RESEARCH

This research is intended to contribute to the development of new methodologies using computer simulation and representative weather data to develop a new bioclimatic chart. This will be accomplished by testing and validating the original G-M bioclimatic chart. In the literature review, several pre-design tools were identified that used computer simulation. Many of the previous pre-design tools recommended potential design strategies for climate-controlled environments in order to maintain indoor comfort conditions, based on conclusion drawn from the previous bioclimatic charts and the G-M bioclimatic chart (1979) (see Bioclimatic Chart, Chapter II). Unfortunately, there have been no systematic efforts to use simulation programs and appropriate weather data to evaluate the effectiveness and improve the accuracy of the existing G-M chart for a thermostatically-controlled residence. Due to this concern, this research intends to provide the following contributions:

1) The development of new methodologies to simulate and test specific strategies for climate-controlled residences.
2) The evaluation of the effectiveness of the design strategy boundaries of the Givoni-Milne bioclimatic chart (1979), which can be applied to climate-controlled residential buildings in selected climates.
3) The identification of new regions on the bioclimatic chart that have not been previously identified.
4) The development of the climatic analysis on the psychrometric chart, which can be used in relation to the bioclimatic analysis and has not yet been demonstrated.
5) The development of a new bioclimatic chart that will be more accurate and powerful pre-design tool for architects and engineers during the early design stage.

3.2 SCOPE AND LIMITATIONS OF THIS RESEARCH

This research is limited to the following assumptions:

1) This research focuses on specific design strategies which are defined in the G-M bioclimatic chart (1979), and can be simulated using the DOE-2 program (Winkelmann, 1993a; 1993b). The design strategies included in the G-M chart that the DOE-2 can simulate and will be investigate in this study include: conventional heating and cooling, lightweight and heavyweight thermal mass structures, ventilation using an economizer, and internal gains.
2) This research focuses on a specific building type: a one-story, slab-on-grade single-family house (Haberl et al., 2003a; 2003b; and 2000c) that is compliant with the International Energy Conservation Code, 2000 (ICC, 1999; 2006).
3) This research focuses on a variety of specific conditions in terms of building envelope, building system, and operation in order to suite different design strategies.
4) In addition, this research includes a variety of building locations in terms of climate considerations, which can be applied to regions that have similar climate characteristics and geographic types.
5) This research does not include varying building conditions in terms of building size, shape, form, or orientation, with the exception of the modifications conducted for passive solar, shading, and thermal mass.
6) This research focuses on using a thermostat to control indoor comfort conditions based on the ASHRAE Standard 55-1992, which is assumed to be a universal code of human comfort. Humidity control is accomplished indirectly by means of controlling the cooling coil temperature and system runtime.
7) This research does not focus on comfort conditions for specific regions or occupancies within the building.

8) This research provides design guidelines and design strategy recommendations that maintain comfort conditions while reducing building energy use.
9) Finally, the building investments and economic analyses of those design strategies are not included.

CHAPTER IV

METHODOLOGY

This chapter describes the methodology used for testing and simulating specific design strategies for climate-controlled residences in selected climates. In general, various weather data were selected and prepared for use with the DOE-2 simulation program. Several prototype residences were developed for specific design strategies and were simulated with the prepared weather data using the DOE-2 program. A number of tools were developed to extract, analyze, and display the outcomes of the weather data and the DOE-2 simulations onto the Givoni-Milne bioclimatic chart (1979) as well as other graphical displays. The results extracted from the weather data are demonstrated and discussed in Chapter V, Section 5.1. The results extracted from the DOE-2 simulations are demonstrated, discussed, and compared with the results from the G-M chart in Chapter V, Section 5.2.

The processes used in this study includes: 1) a procedure for selecting and preparing representative weather data; 2) a procedure for simulating buildings based on selected design strategies; 3) a procedure for mapping TMY2 weather data onto the psychrometric chart; and 4) a procedure for analyzing and projecting the simulation results onto the psychrometric chart.

Figure 4.1 shows a flowchart of the whole process. Numbers 1 to 4 indicate the order of each process, and rectangular dotted lines indicate the scope of each process. Detailed descriptions of each process are explained in the next sections (Sections 4.1 to 4.4).

4.1 PROCEDURE FOR SELECTING AND PREPARING REPRESENTATIVE WEATHER DATA

This section describes the process (Figure 4.2) used to select and prepare representative weather data for the DOE-2 simulations. The process includes: 1) criteria

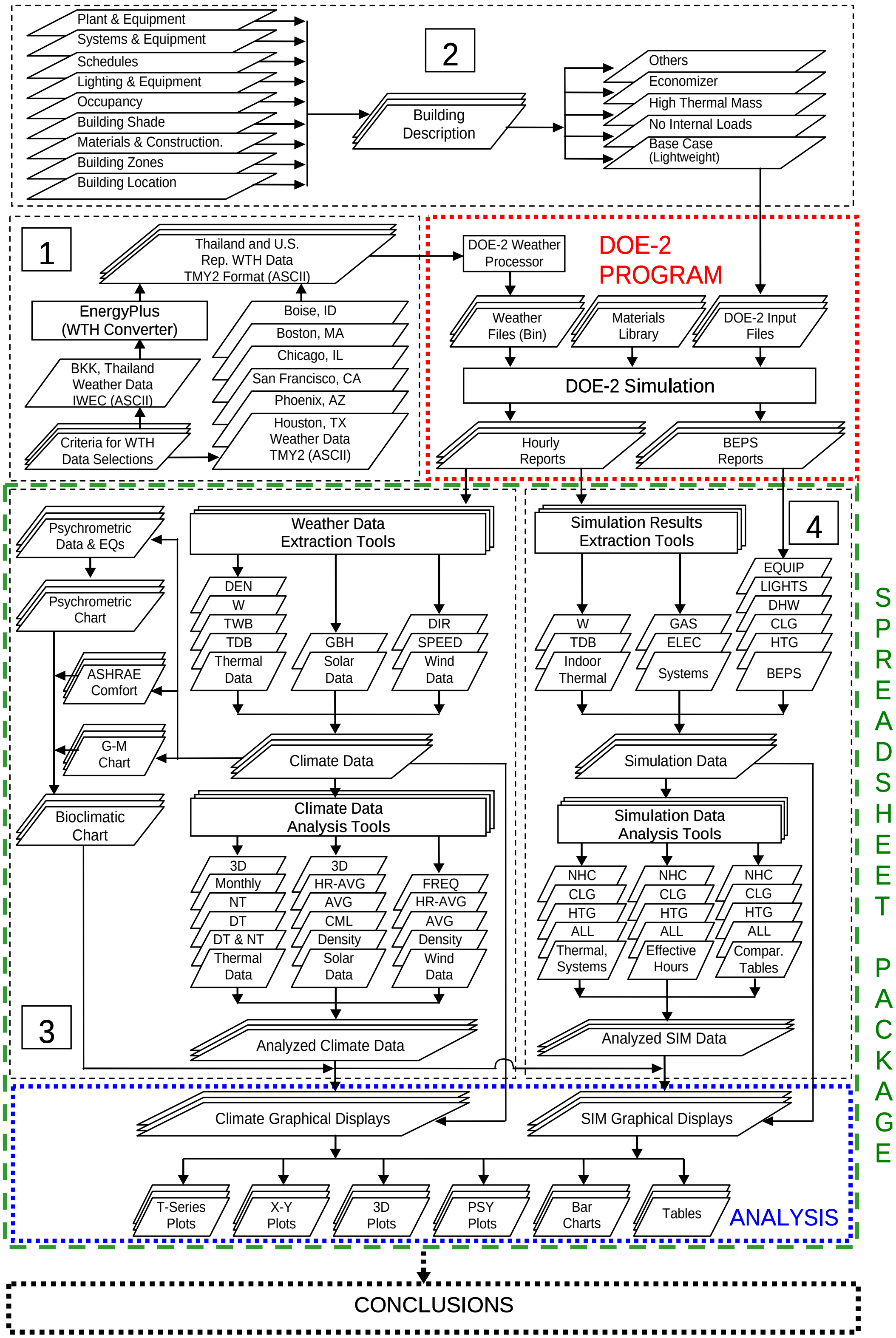


Figure 4.1 *Methodology flowchart of the whole process.*

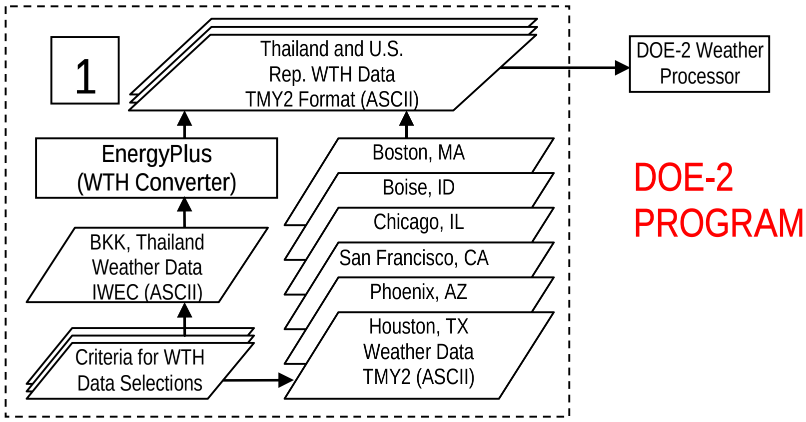


Figure 4.2 *Weather data selection and preparation flowchart.*

for climate and representative city selection, 2) selected climates and representative cities, and 3) weather data preparation and formats.

4.1.1 Criteria for Climate and Representative City Selections

The four criteria used to select representative climates are: 1) selected climate regions should cover the majority of the psychrometric chart, 2) the first group of climates and representative cities was selected from climates in the United States using recommendations from the new climate classification (Briggs et al., 2002), 3) the additional climate(s) outside the U.S. could be added to meet the first criterion, 4) the representative city(ies) of the additional climate(s) were selected from the city(ies) with larger populations.

4.1.2 Selected Climates and Representative Cities

The first group of the six selected climates in the U.S. covers the majority of the psychrometric chart. However, they do not cover the upper right part of the psychrometric chart. Therefore, to cover the upper right part of the psychrometric chart, an additional climate zone from Thailand is included. The seven selected climates and their representative cities in this research are: 1) very hot-humid (Bangkok, Thailand), 2) hot-humid (Houston, Texas), 3) hot-dry (Phoenix, Arizona), 4) warm-marine (San

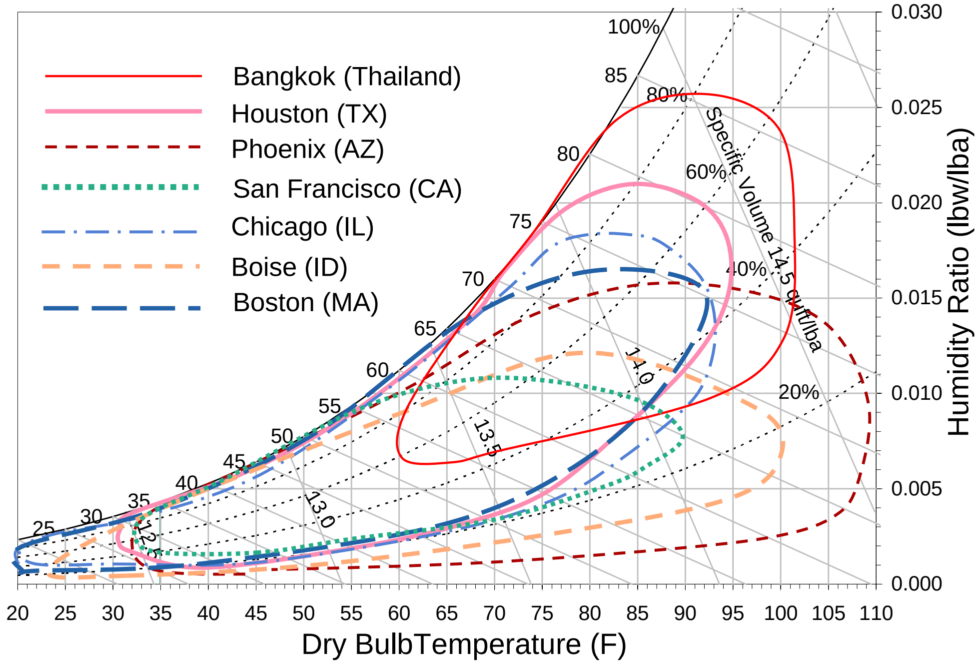


Figure 4.3 *The seven selected climate zones on the psychrometric chart.*

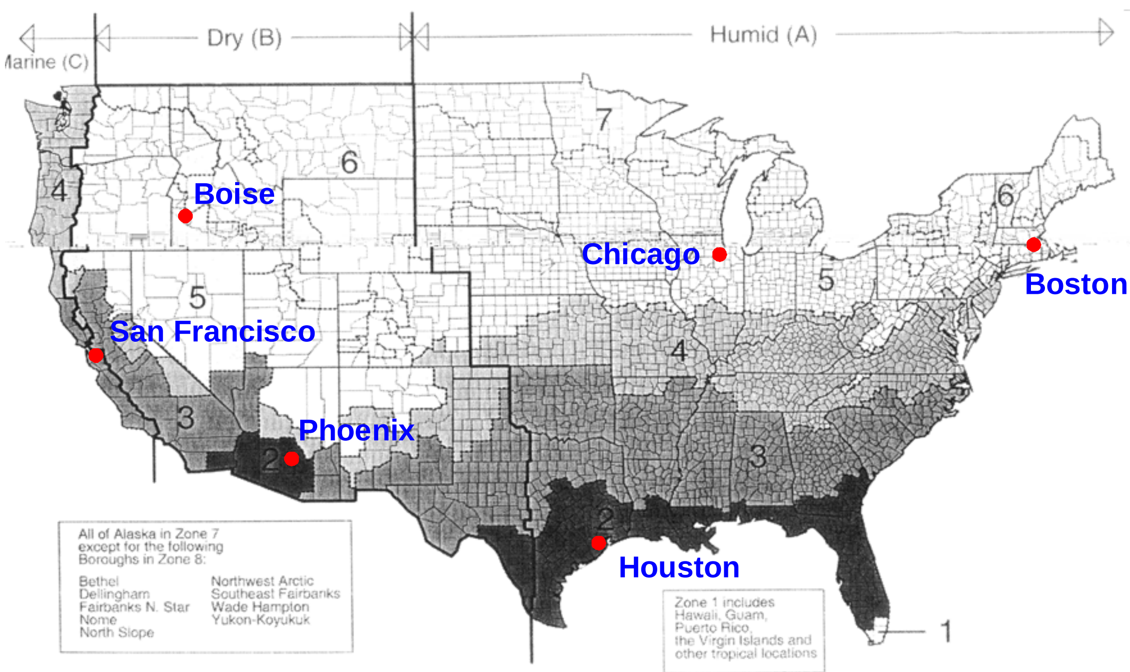


Figure 4.4 *Locations of the selected representative cities on the United States map (Briggs et al. 2003b, p.125). Copyright © 2003 by ASHRAE (Reprinted with permission).*

Francisco, California), 5) cool-humid (Chicago, Illinois), 6) cool-humid (Boston, Massachusetts), and 7) cool-dry (Boise, Idaho) (see Figure 4.3). Figure 4.4 is the new climate classification (Briggs et al., 2002) of the United States where all of the U.S. representative city locations are displayed as red dots. Figure 4.5 shows the location of Thailand which is located in Southeast Asia. Figure 4.6 shows the location of the capital city of Thailand, Bangkok (red dot). More information about the seven selected climates and the seven representative cities is given in Appendix A.1.

Figure 4.5 *Location of Thailand on Asia map (U.S. Central Intelligence Agency, 2000). Courtesy of the University of Texas Libraries, the University of Texas at Austin.*

Figure 4.6 *Location of Bangkok in Thailand (U.S. Central Intelligence Agency, 2006). Courtesy of the University of Texas Libraries, the University of Texas at Austin.*

4.1.3 Weather Data Preparation and Formats

As mentioned in Section 2.5.3, the TMY2 (Marion and Urban, 1995) and the WYEC2 (Stoffel, 1995) weather files have more appropriate long-term weather data (Huang and Crawley, 1996, p.4.188; and Crawley, 1998). Therefore, the TMY2 weather data is used in this study. For the U.S. locations, the TMY2 weather data of the selected climates was obtained from the National Renewable Energy Laboratory (NREL) web site. These data were already in TMY2 format (Marion and Urban, 1995; see Appendix A.2). For Thailand, the weather data was obtained from the International Weather for Energy Calculations (IWEC) CD-ROM (ASHRAE, 2002). However, these data are in IWEC format (ASHRAE, 2002; see Appendix A.3). Therefore, in order to use the weather data with the DOE-2 program, the format of Thailand weather data needed to be converted to TMY2 format. Therefore, procedures listed in the "Weather Converter

Program" of the EnergyPlus program (Crawley et al., 2000) were used to convert weather data in IWEC format to TMY2 format, see "Getting Started with EnergyPlus" (UIC and LBNL, 2004b) and "Auxiliary EnergyPlus Programs" (UIC and LBNL, 2004a).

Figure 4.2 displays the flowchart of the simulation process that includes the weather data preparation. The DOE-2 Weather Processor, which is a batch or command-line program called "doewth" or "doewth.exe", is used to pack a weather data file (ASCII) in TRY, TMY2, WYEC2, or CD144 formats to a binary file (BIN). The packed binary file is then ready to use with the DOE-2 simulation. The "DOE-2 Weather Processor" (Buhl, 1999) contains instructions for packing TRY, TMY2, WYEC2, or CD144 weather data files using the "DOE-2 Weather Processor".

4.2 PROCEDURE FOR SIMULATING THE SELECTED DESIGN STRATEGIES

The DOE-2.1e (Winkelmann, 1993a, 1993b; LBNL, 2000a, 2000b, 2001) simulation program was used to simulate several prototype residences together with the TMY2-packed weather files prepared from the previous step. The outcomes of the simulations were then used for further analysis. This section explains the process used to simulate the specific design strategies (Figure 4.7). The process includes: 1) developing DOE-2 input files for each design strategy, and 2) simulating performance of the prototype models using the representative weather data.

To begin, an input file was developed for each selected design strategy. The design strategies that are investigated in this study include: 1) lightweight house (base case), 2) lightweight house without internal loads, 3) high thermal mass house, and 4) lightweight house with an economizer. An input file consists of a series of building description variables and commands, which are assigned to the four main DOE-2 subprograms: LOADS, SYSTEMS, PLANT, and ECONOMICS. This research focuses on the analysis of weather data, thermal comfort, and building energy performance. The research does not focus on economics analysis; therefore only LOADS, SYSTEMS, and PLANT are included. The major building description variables of an input file in

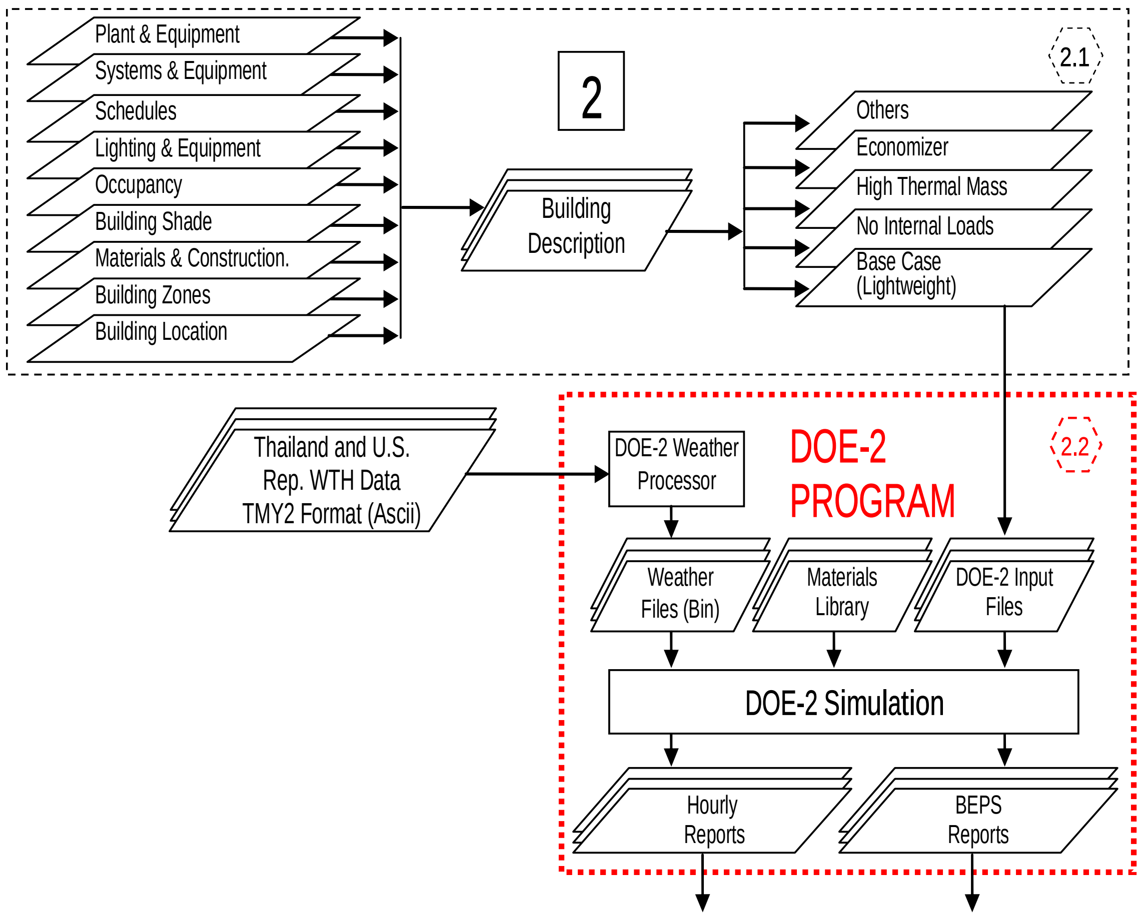


Figure 4.7 *Flowchart of the process for simulating the selected design strategies.*

this study include: building location, building zones, materials and construction, building shade, occupancy, light and equipment, schedules, systems and system equipment, and plant and plant equipment. DOE-2 employs the input file together with the DOE-2 materials library and the hourly weather file and then reports the outcomes that are specified in the input file. Numerous reports can be specified in the DOE-2 input files. However, the two important report types used for the analysis in this study are HOURLY-REPORT and BEPS report.

4.2.1 Developing DOE-2 Input Files for Each Design Strategy

This section (see label 2.1 in Figure 4.7) explains the important features of the DOE-2 input file of each design strategy. A traditional one-story, slab-on-grade single-family house input file (Haberl et al., 2003c; 2004) that is compliant with the 2000 International Energy Conservation Code (ICC, 1999) was used to develop a simple prototype model for each design strategy. The full version of the traditional house input file is available in the publications of Haberl et al. (2003c and 2004). Examples of the input file of each design strategy features are provided in Appendix B.1.

4.2.1.1 Lightweight house (base case)

A prototype model for the lightweight house, the base case in this study, is similar to the traditional single-family house (Haberl et al., 2003c; 2004), which the file name is “sngfam2st”, except for: 1) replacing the slab floor with a wood stud floor with a crawl space, 2) replacing the residential system (RESYS) with a single zone reheat system (SZRH), and 3) removing the temperature setback schedules.

Table 4.1 provides a brief description of the base-case house which is for two occupants with an area of 2,500 ft^2. The house consists of a conditioned living space (50’ x 50’ x 8’) and an unconditioned garage (22’ x 22’ x 8’). The front of the house faces south and each side of the house has a window with an area equals to 15% of the external wall area. The windows have aluminum frames with double pane low-e glazing (U-value = 0.75, SHGC = 0.4). The walls consist of asbestos vinyl siding, ½” plywood, R-15 mineral wool/fiber insulation, and ½” gypsum boards on 2 x 4 wood studs. The floor with a crawl space is 1” thick hardwood sub floor on 2 x 8 hardwood joists and R-7 mineral wool/fiber insulation. The crawl space wall is 1.5 ft above the ground and 1 ft under the ground. The roofs and ceilings consist of asphalt siding, ½” plywood, 24” air gap, R-26 mineral wool/fiber insulation, and ½” gypsum boards on 2 x 10 wood studs. Figure 4.8 displays the base-case house using the DrawBDL program (Huang, 1994), which represents an exact architectural rendering of the DOE-2 input file.

Table 4.1 *The building components, the thermal properties, the construction materials, the HVAC systems and the equipment of the IECC (2000) code compliant house.*

Building	Value & Type	Description
House	50' x 50' x 8'	Conditioned (1 bedroom, 2 occupants)
Garage	22' x 22' x 8'	Unconditioned
Window	U = 0.75	Double Pane (Low-E), 15% of external wall area
Wall	R = 13	Asbestos vinyl siding, plywood, R-15 insulation, Gypsum Board, Wood Stud
Floor(with crawl space)	R = 7	Wood Stud and Subfloor (Hard wood)
Roof	R = 26	Asphalt siding, plywood, air-gap, R-27 insulation, Gypsum Board, Wood Stud
HVAC	Single Zone Reheat	Gas Furnace and Electric Herm. Reciprocating Chiller
T-set point (Winter)	68 F	No temperature setback
T-set point (Summer)	78 F	No temperature setback

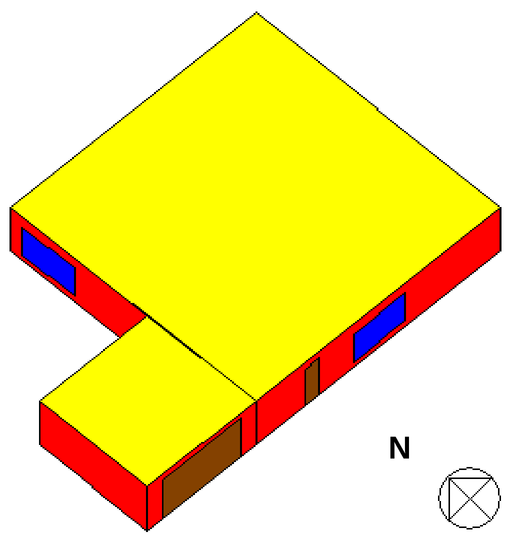


Figure 4.8 *The prototype model of the single-family house used in the DOE-2 program, generated using DrawBDL program. (Huang, 1994)*

Usually, a residential system (RESYS) would be used for simulating a residential building. However, the indoor humidity ratios from the DOE-2 HOURLY-REPORT, which are used to evaluate indoor comfort conditions on the psychrometric chart, are not applicable to RESYS. Therefore, a single zone reheat system (SZRH) for which the indoor humidity ratios were obtainable, was selected to simulate the case study house. The SZRH system provides a constant volume forced-flow heating and cooling from an air-handling unit to the zone. The discharge temperature is controlled from a thermostat in the conditioned space. The space temperature is controlled by a reheat coil installed in the supply air distribution duct (Winkelmann et al.; 1993a; 1993b). In this study, the reheat coil was enabled and the maximum increased temperature for supply air passing through the reheat coil is set at 55 °F (12.8 °C). The heating equipment is a gas furnace and the cooling equipment is an electric hermetically-sealed reciprocating chiller. The temperature set points of the conditioned space are set at 78 °F (25.6 °C) for the summer and 68 °F (20.0 °C) for the winter. There is no temperature setback for either summer or winter. The heating, cooling, and fan schedules are "on" all the time. The custom weighting factors (CWFs) are in thermal mass mode, which are set to be calculated. The important parts of the base-case input file that are different from the traditional house input file (Haberl et al., 2003c; 2004) are demonstrated in Appendix B.1.

4.2.1.2 Lightweight house without internal loads

A prototype model for the lightweight house without internal loads is similar to the base-case house except there are no internal loads, which include occupants, lights, and equipment. In the DOE-2 input file, the internal loads are removed by setting the schedule of occupants, lights, and equipment equal to "0". Appendix B.1 shows the changes to the input file (i.e., lightweight without internal loads) that are different from the base-case input file.

4.2.1.3 High thermal mass house

A prototype model for a high thermal mass house is similar to the base-case house except the walls and floor have been replaced with high mass materials. The materials of the wall from outside to inside, respectively, are 1" thick stucco, 3" thick rigid insulation (R-10.3), and 6" thick heavy weight concrete block filled. The floor is 4" thick concrete slab on grade. Appendix B.1 shows the changes to the high thermal mass input file that are different from the base-case house.

4.2.1.4 Lightweight house with an economizer

A prototype model for the lightweight house with an economizer is similar to the lightweight house (base case) except an economizer system is added. In the DOE-2 input file, an economizer system is turned on by setting the outside air (OA) control equal to "TEMP", which is a temperature-controlled economizer. In this study, the dry-bulb limit temperature was set at 65 °F (18.3 °C). This means, in the cooling mode, the economizer is activated when the outside air is cooler than 65 °F (18.3 °C). Appendix B.1 shows the changes used in this input file (ventilative cooling using economizer), which are different from the base-case input file.

4.2.2 Simulating Performance of the Prototype Models Using the Representative Weather Data

The DOE-2 input files of the conventional heating and cooling system (SZRH) for the prototype buildings, the DOE-2 materials library, and the packed weather data are passed into the LOADS simulation, then to the SYSTEMS simulation and finally to the PLANT simulation(see label 2.2 in Figure 4.7). For this research, the important outcomes can be divided into two main parts: 1) the outcomes from the selected weather data and 2) the outcomes from the DOE-2 simulation. Appendix B.2 contains examples of the HOURLY-REPORT. Appendix B.3 contains the BEPS report for each simulation.

4.2.2.1 The outcomes from the selected weather data

Weather data outcomes used for further analysis are obtained from the HOURLY-REPORT. The data needed for the analysis include: 1) thermal data (dry-bulb temperature, wet-bulb temperature, humidity ratio, and density of the air), 2) solar data (global horizontal solar radiation), and 3) wind data (wind speed and direction). This data is largely passed through DOE-2 without change from the TMY2 input files.

4.2.2.2 The outcomes from the DOE-2 simulation

The simulation outcomes used for the analysis are from the HOURLY-REPORT and the BEPS report. The hourly data needed for the analysis include: 1) indoor thermal data (dry-bulb temperature and humidity ratio), and 2) systems data (heating and cooling energy use). The BEPS report includes data for the whole year, which includes: 1) domestic hot water (DHW), 2) space heat, 3) space cooling, 4) ventilation fans, 5) pump and miscellaneous, 6) heat rejection, 7) miscellaneous equipment, and lights.

4.3 PROCEDURE FOR MAPPING TMY2 WEATHER DATA ONTO THE PSYCHROMETRIC CHART

A psychrometric chart is a useful graphical display to present the properties of moist air and to display different types of weather data and other corresponding data points. New techniques for using a psychrometric chart to present solar data and wind data are also presented in this section. The weather data used for the analysis are obtained from the DOE-2 hourly reports. Figure 4.9 shows the flowchart diagram of the process for mapping TMY2 weather data onto the psychrometric chart. The process includes: 1) developing a psychrometric chart model for each climate, 2) identifying and extracting appropriate weather data, and 3) analyzing and projecting the weather data onto the psychrometric chart. Most of the data analysis tools and graphical displays in this study were developed using a customized spreadsheet package, MS Excel (Microsoft Office, 2003).

4.3.1 Developing a Psychrometric Chart Model for Each Climate

In order to evaluate indoor comfort conditions and to validate the Givoni-Milne design chart (1979), the ASHRAE comfort chart (1992) and the G-M bioclimatic chart (1979) are combined onto the psychrometric chart. Since the atmospheric pressure affects the properties of the air and the atmospheric pressure changes as the altitude of a location changes, a psychrometric chart for the locations with different altitudes was developed. On the left of Figure 4.9 (see label 3.1) shows the process that a

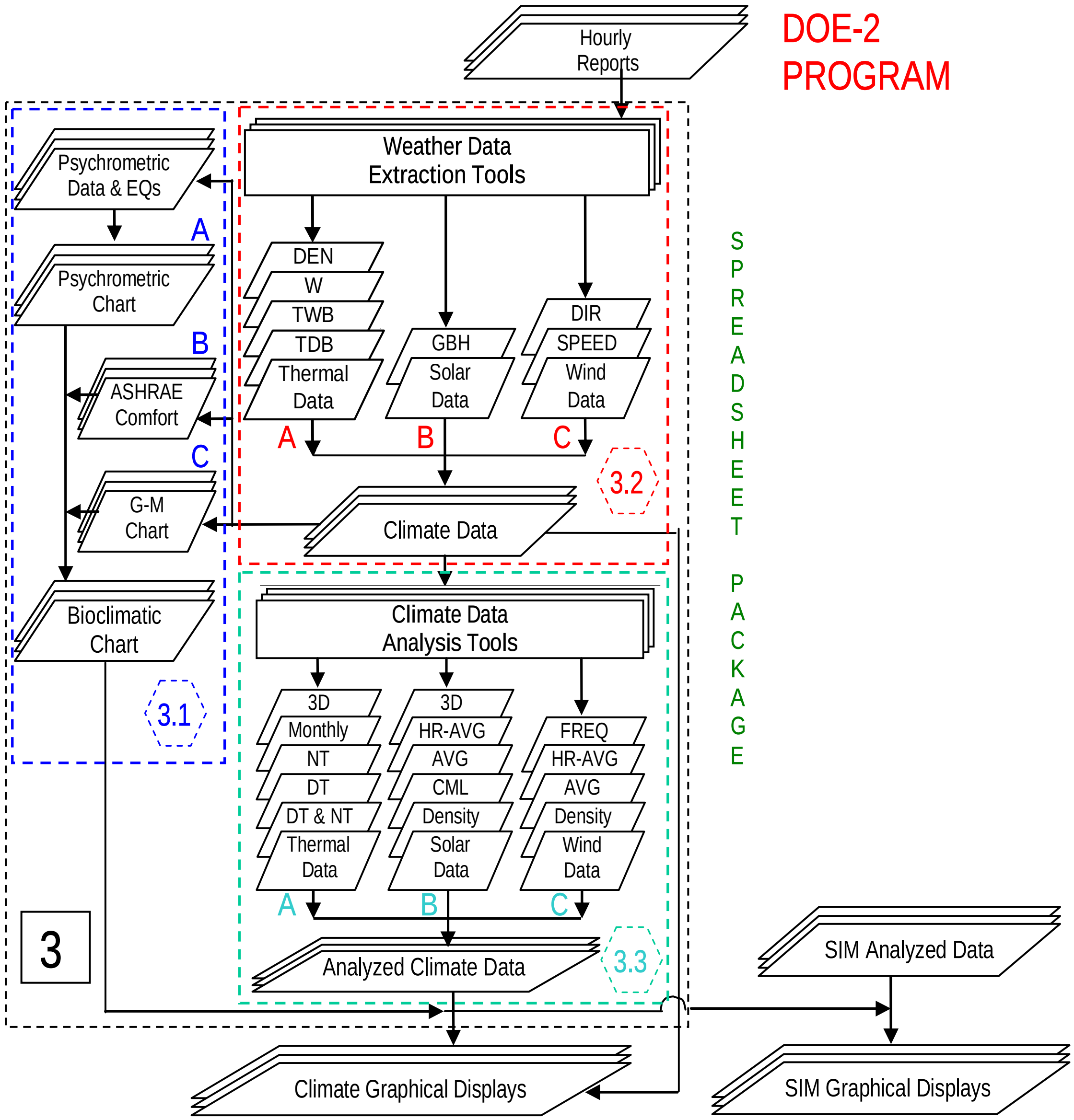


Figure 4.9 *Flowchart of the process for mapping TMY2 weather data onto the psychrometric chart.*

psychrometric chart for a representative city is developed using the combination of equations and weather data of the representative city. A number of equations and weather data are also used to develop the ASHRAE comfort chart and the G-M chart which are overlaid onto the psychrometric chart. The chart then becomes a model for that representative city to use to present different types of the outcomes from weather data and the DOE-2 simulation.

4.3.1.1 Display of the psychrometric chart

A psychrometric chart is plotted as an x-y plot where the x axis represents the dry-bulb temperature (*Tdb*) and the y axis represents the humidity ratio (*W*). Figure 4.10 shows psychrometric chart lines of relative humidity, dry-bulb temperature, wet-bulb temperature, humidity ratio, and specific volume for the normal temperature range of a representative city (Houston, Texas) in USCS (U.S. Customary System or IP) units. In order to avoid confusion and since the line of the enthalpy is very close to the wet-bulb line, the enthalpy line was not included in the chart. Examples of the spreadsheets used to develop the psychrometric chart are demonstrated in Appendix C.1. The equations used to develop each variable and the definitions of variables in this section are from publications by ASHRAE (1977), Kreider and Rabl (1994), and McQuiston et al. (2000).

Figure 4.10a shows the curve lines of the constant relative humidity (ϕ) where the increment of each line is 20%. Relative humidity is used to measure the moisture contained in the air. The relative humidity is the ratio of partial pressure of water vapor (*Pw*) to saturation pressure of water vapor (*Psat*) at the same dry-bulb temperature,

$$\phi = \frac{Pw}{Psat}. \tag{4.1}$$

The humidity ratio (*W*) is the ratio of mass of water vapor to the mass of dry air, which can be expressed using the ideal gas law and replacing the fraction of the mass with a ratio of pressures,

$$W = \frac{Pw}{Pda}\left(\frac{18.02}{28.96}\right) = 0.622\frac{Pw}{Pda}. \tag{4.2}$$

By Daltons's law, the Pda in Equation (4.2) can be replaced as,

$$W = 0.622\frac{Pw}{P - Pw}. \tag{4.3}$$

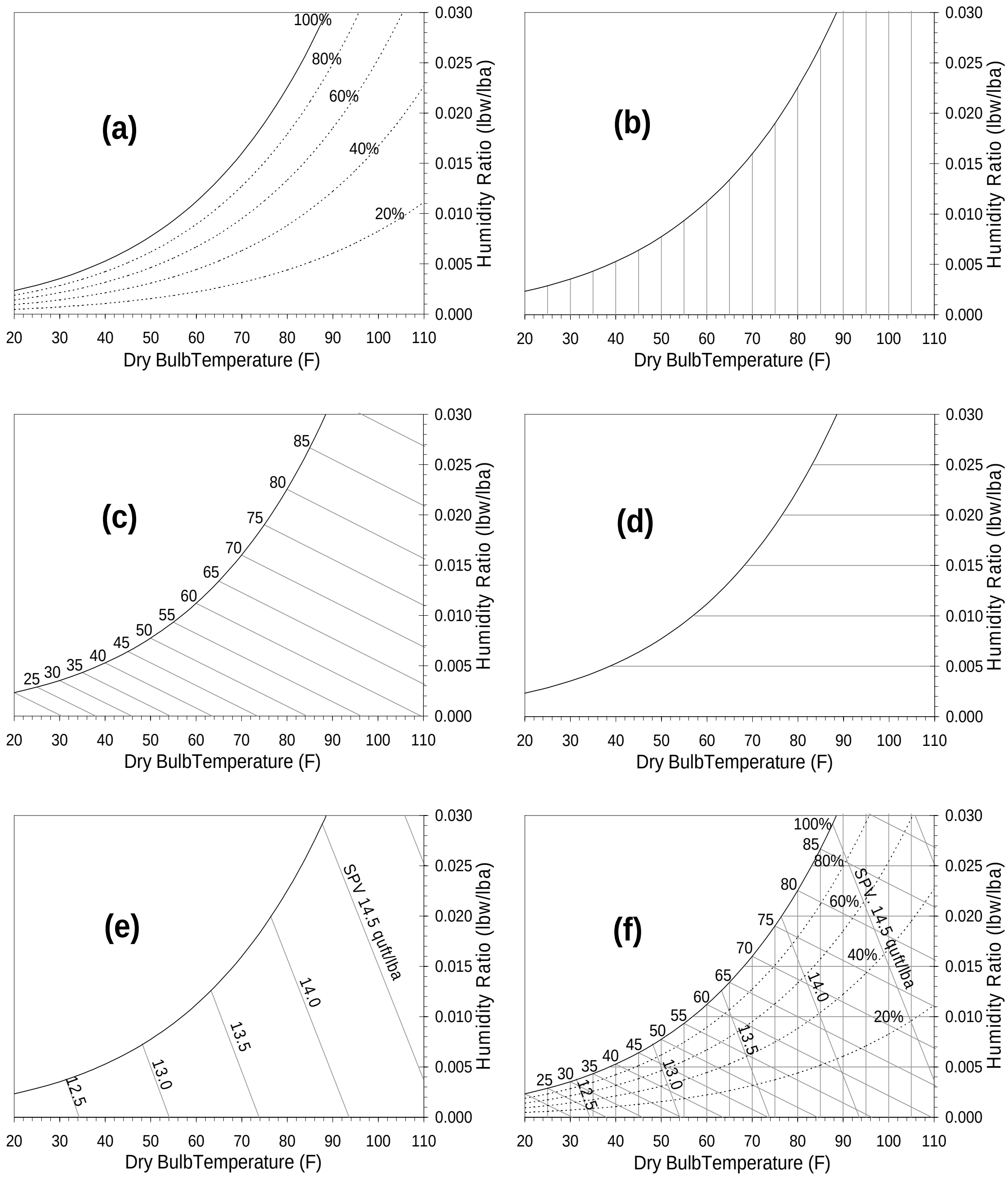


Figure 4.10 *Psychrometric chart lines. (a) Relative humidity, (b) Dry-bulb temperature, (c) Wet-bulb temperature, (d) Humidity ratio, (e) Specific volume, (f) Psychrometric chart.*

To find the corresponding humidity ratio (y-coordinate) of a given temperature (x-coordinate) for a specific humidity line, the *Pw* in Equation (4.3) can be defined as Equation (4.4) using Equation (4.1),

$$W = 0.622\frac{\phi Psat}{P - \phi Psat}. \tag{4.4}$$

The *Psat* at temperature T is

$$Psat(T) = Pc10^{K(1-Tc/T)}, \tag{4.5}$$

where the critical pressure of water (*Pc*) is 3226 psia, the critical temperature (*Tc*) is 1165.67 °R, and the parameter K is given by

$$K = 4.39553 - 3.469\left(\frac{T}{1000}\right) + 3.072\left(\frac{T}{1000}\right)^2 - 0.8833\left(\frac{T}{1000}\right)^3. \tag{4.6}$$

Figure 4.10b displays the vertical lines of the constant dry-bulb temperature (*Tdb*). At a given temperature (x-coordinate), a dry-bulb line can be drawn from the point where the humidity ratio equals zero to the upper part at the same temperature when the relative humidity ratio equals 100%. The corresponding humidity ratio of the 100 % relative humidity ratio can be calculated using Eqs (4.4 to 4.6).

In Figure 4.10c, the diagonal lines are the constant wet-bulb temperature (*Twb*). The concept of adiabatic saturation can be used to find a web bulb temperature. In this study, a wet-bulb line is drawn between the two coordinates. Assuming the first coordinate (*T1, W1*) is a coordinate of a dry-bulb temperature with the corresponding humidity ratio very close to zero. The second coordinate (*T2, W2*) is the coordinate of a given dry-bulb temperature with the corresponding humidity ratio at 100% relative humidity. Therefore, *W1* is an assumed number that is very close to zero. Equation (4.4) can be used to find W2. T1 can be found by solving the Equation,

$$W_1 = \frac{(1093 - 0.556T_2)W_2 - 0.24(T_1 - T_2)}{1093 - 0.444T_1 - T_2} \quad . \tag{4.7}$$

Figure 4.10d displays the horizontal lines of the constant humidity ratio (*W*). A humidity ratio line can be drawn from the point of a given humidity ratio with a maximum corresponding dry-bulb temperature in the chart to the point that the RH reaches 100% and find the corresponding dry-bulb temperature by solving the Equations (4.4 to 4.6).

In Figure 4.10e, the diagonal lines are the constant specific column (υ). A specific volume line of a specific volume value can be drawn by assuming dry-bulb temperature and finding its corresponding humidity ratio using Equation,

$$\upsilon = \frac{R_a T}{P - P_w} \, . \tag{4.8}$$

Where *Ra* is the dry air gas constant (53.35 ft/lb), *P* is total pressure of the air which can be found using Equation,

$$P = a + bH \, . \tag{4.9}$$

Where *H* is the elevation above sea level and the constants *a* and *b* are as follows:

If $H \leq 4000$ ft, a = 29.92. (4.10)

If $H > 4000$ ft, a = 29.42. (4.11)

The partial pressure of water vapor (*Pw*) can be found by solving Equation (4.3).

Figure 4.10f shows a psychrometric chart for the normal temperature range of a representative city (Houston, Texas) in USCS (U.S. Customary System) units.

4.3.1.2 Overlaying the ASHRAE comfort chart (1992)

The ASHRAE comfort zone (1992) is used to evaluate indoor comfort conditions in this research and is overlaid onto the psychrometric chart prepared in Section 4.3.1.1. Due to the difference in summer clothing (0.35 to 0.6 clo) and winter clothing (0.8 to 1.2 clo), the comfort zone consists of two zones (summer and winter). Figure 4.11 displays the summer and winter comfort ranges which are based on 10% dissatisfaction. The summer comfort region, which is higher than winter period, is displayed in red. The winter comfort region is displayed in blue. The coordinates of the summer and winter comfort zones are defined as follows:

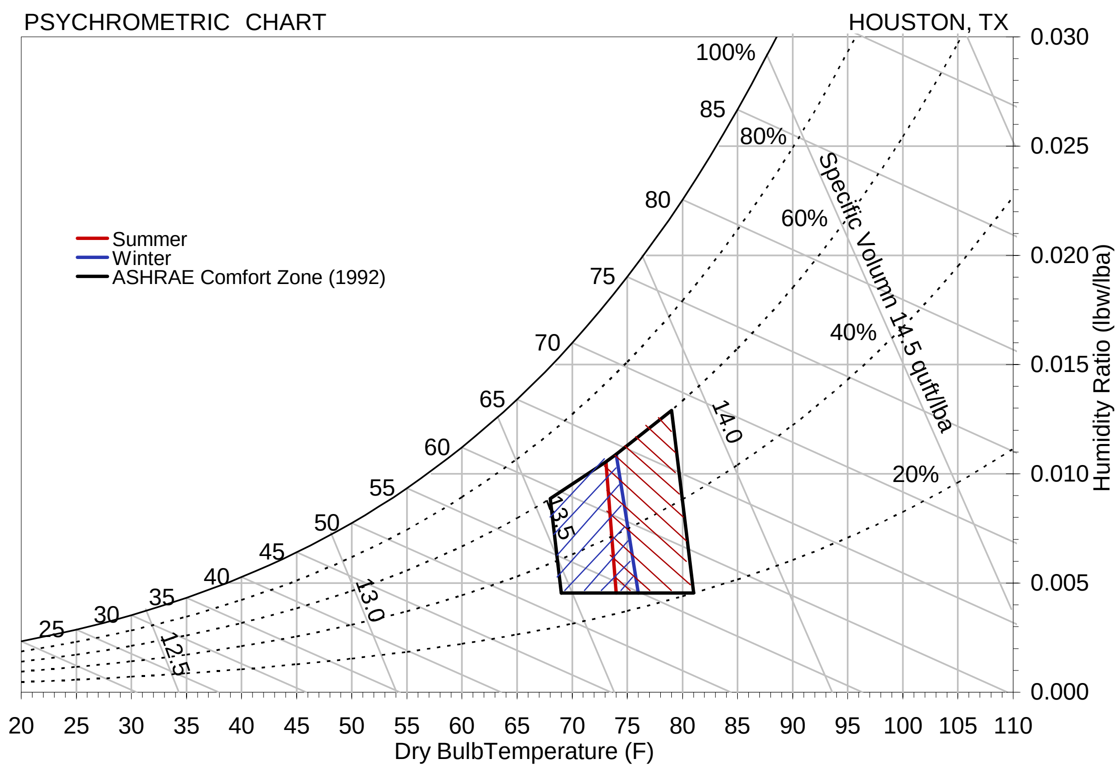


__Figure 4.11__ ASHRAE comfort zone (1992): Summer and winter comfort zones.

Winter comfort zone: the operative temperatures (t_0) is equal to the 68 to 74 °F (20 to 23.5 °C) at 60% RH and the t_0 is equal to 69 to 76 °F (20.5 to 24.5 °C) at 36 °F (2 °C) dewpoint temperature. These limits of t_0 correspond to 68 °F and 74 °F (20 °C and 23.5 °C) effective temperature (ET*) lines (ASHRAE, 1992).

Summer comfort zone: the operative temperatures (t_0) is equal to the 73 to 79 °F (22.5 to 26 °C) at 60% RH and the t_0 is equal to 74 to 81 °F (23.5 to 27 °C) at 36 °F (2 °C) dewpoint temperature. These limits of t_0 correspond to 73 °F and 79 °F (23 °C and 26 °C) ET* lines (ASHRAE, 1992).

The winter and summer comfort ranges overlap at 73 to 74 °F (23 to 23.5 °C) ET*. The upper and lower limits of relative humidity (RH) are based on health and indoor air quality (IAQ) considerations. This research combines the summer and winter comfort zones. In order to avoid problems with air properties that vary from one location to another due to differences in elevation, the y-coordinates or the humidity ratio (W) of the 60% RH (upper limit) should not be set as a fixed value but should be set as a function in Equation (4.4). Examples of the spreadsheets using to develop the ASHRAE comfort chart on a psychrometric chart are demonstrated in Appendix C.2.

4.3.1.3 Overlaying the Givoni-Milne bioclimatic chart

The Givoni-Milne bioclimatic chart (1979), which has been widely used in the U.S., will be tested and validated in this study. Therefore, their design strategy boundaries were overlaid onto the psychrometric chart for further analysis. The "Climatic Design" by Watson and Labs (1983, p. 206; see Figure 2.10 and Table 2.1) contains the detailed description for drawing the design strategy boundaries of the G-M chart (1979) in this research.

Figure 4.12 displays regions of the G-M design strategies (1979). The design strategies in the chart include: conventional heating (region 0), active solar (region 1), passive solar (regions 2 to 4), internal gains (region 5), humidification (regions 6a and 6b), comfort zone (region 7), dehumidification (region 8), ventilation (regions 9 to 11), evaporative cooling (regions 6b, 11, 13, 14a, and 14b), high thermal mass (regions 10 to 13), high thermal mass with night ventilation (regions 14b and 16), air-conditioning (regions 17a and 17b) , and air-conditioning with conventional dehumidification (regions 15a and 15b). Eqs (4.1 through 4.12) are used to find the coordinates of each region. Examples of the spreadsheets using to delineate the G-M design chart are available in Appendix C.3. The detailed descriptions used for overlaying each design strategy region onto the chart developed from the previous stages are as follows (see Figure 4.13 to Figure 4.14):

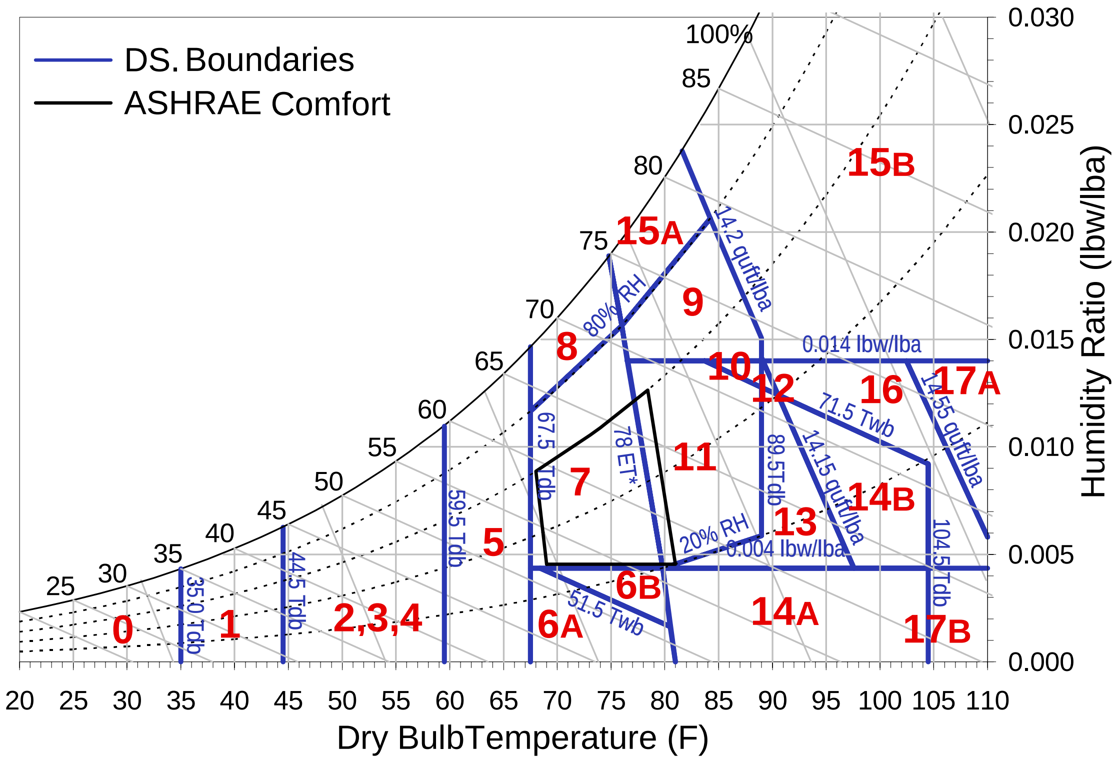


Figure 4.12 *Givoni-Milne design strategy boundaries (1979). (Adapted from Watson and Labs, 1983, p. 206) Conventional heating = 0; Active solar = 1; Passive solar = 2,3,4; Internal gains = 5; Humidification = 6a, 6b; Comfort zone = 7; Dehumidification = 8; Ventilation = 9, 10, 11; Evaporative cooling = 6b, 11, 13, 14a, 14b; High thermal mass = 10, 11, 12, 13; High thermal mass with night ventilation = 14b, 16; Air-conditioning = 17a, 17b; Air-conditioning with conventional dehumidification = 15a, 15b.*

Figure 4.13a shows the psychrometric chart and the ASHRAE comfort chart (1992), which is used as the base drawing for overlaying the Givoni-Milne design strategy boundaries in the next steps.

Figure 4.13b displays the design strategy boundary of the “conventional heating” (region 0). In this region, which includes all humidity conditions, the dry-bulb temperature is less than 35 °F.

In Figure 4.13c, the design strategy boundary of the “active solar” is region 1. In this region, the dry-bulb temperature is more than or equal to 35F and less than 44.5 °F, for all humidity conditions.

Figure 4.13d shows the design strategy boundary of the “passive solar” (regions 2, 3, and 4). The dry-bulb temperature in this region is more than or equal to 44.5 °F and less than 59.5 °F, for all humidity conditions.

Figure 4.13e, this figure displays the design strategy boundary of the “internal gains” (region 5), in which the dry-bulb temperature is more than or equal to 59.5 °F and less than 67.5 °F, for all humidity conditions.

Figure 4.13f demonstrates the design strategy boundary of the “humidification” (regions 6a and 6b). The limits of the design strategy are at the dry-bulb temperature more than or equal to 67.5 °F and less than or equal to 78 °F EF* and the humidity ratio less than 0.004 lbw/lba (5mm Hg or 36 °F dewpoint temperature). For region 6a, the wet-bulb temperature is less than or equal to 51.5 °F. For region 6b, the wet-bulb temperature is more than 51.5 °F.

In Figure 4.13g, the boundary of the “Givoni-Milne comfort zone” is region 7. In this region, the dry-bulb temperature is more than or equal to 67.5 °F and is less than or equal to 78 °F EF*. The humidity ratio is more than or equal to 0.004 lbw/lba (5mm Hg) and the relative humidity (RH) is less than or equal to 80%.

Figure 4.13h shows the design strategy boundary of the “dehumidification” (region 8), in which the dry-bulb temperature is more than or equal to 67.5 °F and less than or equal to 78 °F EF* and the humidity level is very high (more than 80% of RH).

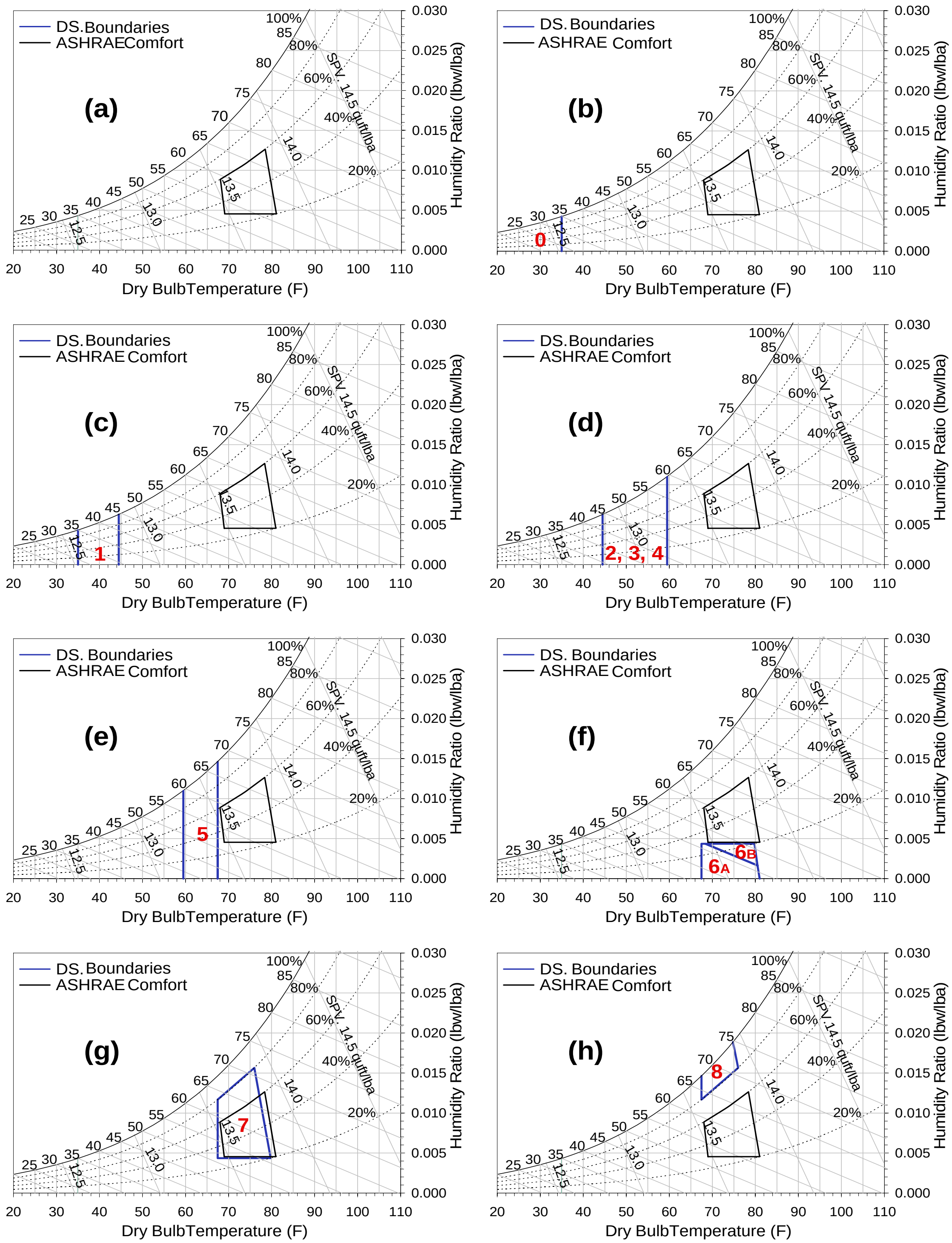


Figure 4.13 *G-M bioclimatic chart (2). (a) ASHRAE comfort zone (1992), (b) Conventional heating, (c) Active solar, (d) Passive solar, (e) Internal gains, (f) Humidification, (g) Comfort zone, (h) Dehumidification.*

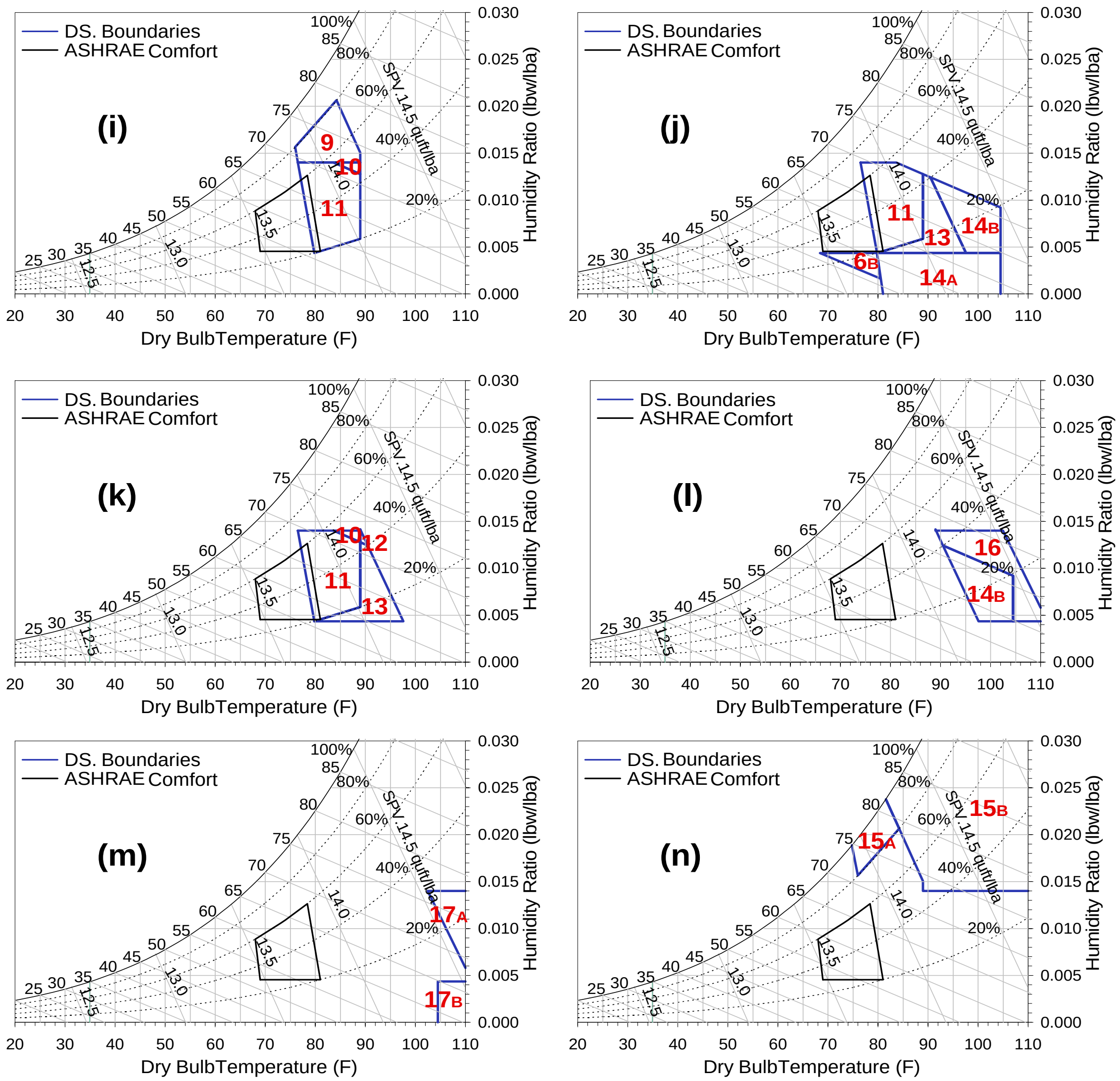


Figure 4.14 *G-M bioclimatic chart (3). (i) Ventilation, (j) Evaporative cooling, (k) High thermal mass, (l) High thermal mass with night ventilation, (m) Air-conditioning (n) Air-conditioning with conventional dehumidification.*

Figure 4.14i displays the design strategy boundary of the "Ventilation" (regions 9, 10, and 11). In these regions, the dry-bulb temperature is more than or equal to 78 °F EF* and less than or equal to 89.5 °F. The specific volume is less than or equal to 14.2 ft²/lb. The RH is more than or equal to 20% and is less than or equal to 80%.

Figure 4.14j shows the design strategy boundary of the “evaporative cooling” (regions 6b, 11, 13, 14a, and 14b). In region 6b, the dry-bulb temperature is more than or equal to 67.5 °F and less than or equal to 78 °F EF*, the humidity ratio is less than 0.004 lbw/lba (5mm Hg), and the wet-bulb temperature is more than 51.5 °F. In regions 11, 13, 14a, and 14b; the dry-bulb temperature is more than the 78 °F EF* and less than or equal to 104.5 °F, the wet-bulb temperature is less than or equal to 71.5 °F and the humidity ratio is less than or equal to 0.014 lbw/lba (17 mm Hg).

Figure 4.14k displays the design strategy boundary of the “high thermal mass” (regions 10, 11, 12, and 13). In these regions, the dry-bulb temperature is more than the 78 °F EF*. The specific volume is less than or equal to 14.15 ft^2/lb. The humidity ratio is more than or equal to 0.004 lbw/lba (5 mm Hg) and less than or equal to 0.014 lbw/lba (17 mm Hg).

Figure 4.14l, this figure displays the design strategy boundary of the “high thermal mass with night ventilation” (regions 14b and 16). In these regions, the specific volume is more than 14.15 ft^2/lb and less than or equal to 14.55 ft^2/lb. The humidity ratio is more than 0.004 lbw/lba (5 mm Hg) and less than or equal to 0.014 lbw/lba (17 mm Hg).

Figure 4.14m demonstrates the design strategy boundary of the “air-conditioning” (region 17a and 17b). In region 17a, the specific volume is more than 14.55 ft^2/lb. The humidity ratio is more than or equal to 0.004 lbw/lba (5 mm Hg) and less than or equal to 0.014 lbw/lba (17 mm Hg). In region 17b, the dry-bulb temperature is more than 104.5 °F and the humidity ratio is less than 0.004 lbw/lba (5mm Hg).

Figure 4.14n shows the design strategy boundary of the “air-conditioning with conventional dehumidification” (regions 15a and 15b). In region 15a; the dry-bulb temperature is more than 78 °F EF*, the RH is more than 80%, and the specific volume is less than or equal to 14.2 ft^2/lb. In region 15b; the dry-bulb temperature is more than 89.5 °F, the humidity ratio is more than 0.014 lbw/lba (17 mm Hg), the dry-bulb temperature is less than or equal to 89.5 °F, and the specific volume is more than 14.2 ft^2/lb.

It is important to note that, in the original G-M bioclimatic Chart (1980), the portions of the regions 0 (conventional heating), 1 (active solar), 2 to 4 (passive solar), and 5 (internal gains) that the humidity ratio less than 0.004 lbw/lba (5mm Hg or 36 °F dewpoint temperature) will need some humidification. In regions 7 (G-M comfort zone) and 9 (ventilation), the humidity level of area above 60% relative humidity (RH) is very high, which is beyond the upper humidity constraints of the ASHRAE comfort zone (1992).

4.3.2 Identifying and Extracting Appropriate Weather Data

The DOE-2 simulation reports the hourly weather data (Section 4.2.2.1, label 3.2 in Figure 4.9), which were used for the graphical displays and the analysis in this study. Unfortunately, the data are not in a format that can be used directly in this study (see Figure 4.15 and Appendix B.2). Therefore, in order to display and analyze the TMY2

```
MMDDHH RM-1      SYSTEM-1  GLOBAL    GLOBAL     GLOBAL     GLOBAL

       ZONE      RETURN    WET BULB  DRY BULB   HUMIDITY   DENSITY
       TEMP      HUMIDITY  TEMP      TEMP       RATIO      OF AIR
       F         LBS/LB    F         F          FRAC.OR    LB/CUFT
                           MULT.
       ----( 6)  ----(35)  ----( 7)  ----( 8)   ----(10)   ----(11)
1 1 1     70.4    0.0090      51.0      51.0      0.0079      0.077
1 1 2     70.4    0.0078      47.0      48.0      0.0066      0.077
1 1 3     70.4    0.0075      46.0      47.0      0.0063      0.077
1 1 4     70.4    0.0076      45.0      46.0      0.0061      0.078
1 1 5     70.4    0.0088      45.0      45.0      0.0063      0.078
1 1 6     70.4    0.0075      45.0      45.0      0.0063      0.078

1 118     70.5    0.0094      54.0      55.0      0.0086      0.076
1 119     70.5    0.0090      54.0      56.0      0.0084      0.076
1 120     70.5    0.0090      54.0      56.0      0.0084      0.076
1 121     70.5    0.0097      55.0      56.0      0.0090      0.076
1 122     70.5    0.0098      55.0      56.0      0.0090      0.076
1 123     70.4    0.0096      55.0      56.0      0.0090      0.076
1 124     70.5    0.0098      55.0      56.0      0.0090      0.076
        0 DAILY SUMMARY (JAN  1)
   MN     70.4    0.0074      44.0      44.0      0.0061      0.076
   MX     71.0    0.0099      55.0      56.0      0.0090      0.078
   SM   1692.2    0.2090    1211.0    1232.0      0.1837      1.842
   AV     70.5    0.0087      50.5      51.3      0.0077      0.077
```

Figure 4.15 *DOE-2 HOURLY-REPORT of indoor and outdoor conditions on January 1st.*

weather data of the representative cities, the data from the DOE-2 hourly report had to be identified, extracted, and rearranged into the appropriate format. The weather data used in this research includes: 1) thermal data (dry-bulb temperature, wet-bulb temperature, humidity ratio, and density of the air), 2) solar data (global horizontal solar radiation), and 3) wind data (wind speed and directions). Weather data extraction tools were developed to extract and rearrange the data. The process to develop the weather data extraction tools for thermal, solar, and wind are explained in this section.

4.3.2.1 Thermal data extraction tool

A spreadsheet program, Excel (MS Office, 2003), was used in this research to develop the weather data extraction tools (see label 3.2A in Figure 4.9). The steps used to develop the tools are as follows:

a. Open the DOE-2 output file (filename.out) using the Excel program.
b. Set the original data type to "Fixed width" and go to the next step.
c. In data preview, scroll down to the data that need to be extracted and double click at the desired positions to divide the data into columns and then go to the next step.
d. In columnar data format, select "General" and then finish the step of extracting the data.
e. Create a new spreadsheet so the weather data looks similar to Figure 4.16. Columns A through E are for the extracted data from the DOE-2 HOURLY-REPORT and columns F through K are for the rearranged data. Columns A and G are the hour of the year, columns B and H are the wet-bulb temperature, columns C and I are the dry-bulb temperature (Tdb), columns D and J are the humidity ratio (W), columns E and K are the density of the air, and column F is the date.
f. Copy and paste the extracted data for the whole year from the previous steps into the appropriate positions of the new spreadsheet (start at cell B6).

	A	B	C	D	E	F	G	H	I	J	K
1	RAW DATA					REARRANGED DATA					
2	VARIABLE NO.	7	8	10	11		VARIABLE NO.	7	8	10	11
3	HOUR	WET BULB	DRY BULB	HUMIDITY	DENSITY		HOUR	WET BULB	DRY BULB	HUMIDITY	DENSITY
4	OF	TEMP	TEMP	RATIO		DATE	OF	TEMP	TEMP	RATIO	
5	YEAR	(F)	(F)	(LBS/LB)	(LB/CUFT)		YEAR	(F)	(F)	(LBS/LB)	(LB/CUFT)
6	1	51	51	0.0079	0.077	1/1/01 0:00	1	51	51	0.0079	0.077
7	2	47	48	0.0066	0.077	1/1/01 1:00	2	47	48	0.0066	0.077
8	3	46	47	0.0063	0.077	1/1/01 2:00	3	46	47	0.0063	0.077
9	4	45	46	0.0061	0.078	1/1/01 3:00	4	45	46	0.0061	0.078
10	5	45	45	0.0063	0.078	1/1/01 4:00	5	45	45	0.0063	0.078
11	6	45	45	0.0063	0.078	1/1/01 5:00	6	45	45	0.0063	0.078
8748		1859	2037	0.4506	1.69	12/31/01 6:00	8743	46	46	0.0066	0.077
8749		77.5	84.9	0.0188	0.07	12/31/01 7:00	8744	41	41	0.0054	0.079
8750		INGS IN V/	RIORESIDE	IAL BUILDI	G	12/31/01 8:00	8745	42	42	0.0056	0.078
8751			SINGLE Z	ONE WITH	TIONAL S	12/31/01 9:00	8746	46	46	0.0066	0.078
8752		EPORT			PAGE219	12/31/01 10:00	8747	46	47	0.0063	0.078
8753		----------	-----------	-----------	--------------	12/31/01 11:00	8748	47	48	0.0066	0.077
8754		GLOBAL	GLOBAL	GLOBAL	GLOBAL	12/31/01 12:00	8749	46	46	0.0066	0.078
8755						12/31/01 13:00	8750	44	44	0.0061	0.078
8756		WET BULI	DRY BULB	HUMIDITY	DENSITY	12/31/01 14:00	8751	43	43	0.0058	0.078
8757		TEMP	TEMP	RATIO	OF AIR	12/31/01 15:00	8752	43	43	0.0058	0.078
8758		F	F	FRAC.OR	LB/CUFT	12/31/01 16:00	8753	42	42	0.0056	0.078
8759				MULT.		12/31/01 17:00	8754	41	41	0.0054	0.079
8760		7	8	10	11	12/31/01 18:00	8755	40	40	0.0052	0.079
8761	5233	77	79	0.0197	0.071	12/31/01 19:00	8756	39	39	0.005	0.079
8762	5234	76	78	0.019	0.071	12/31/01 20:00	8757	39	39	0.005	0.079
8763	5235	76	77	0.0193	0.071	12/31/01 21:00	8758	38	38	0.0048	0.079
8764	5236	76	77	0.0193	0.071	12/31/01 22:00	8759	37	37	0.0046	0.079
8765	5237	75	76	0.0186	0.072	12/31/01 23:00	8760	36	36	0.0044	0.08
14637	8753	42	42	0.0056	0.078						
14638	8754	41	41	0.0054	0.079						
14639	8755	40	40	0.0052	0.079						
14640	8756	39	39	0.005	0.079						
14641	8757	39	39	0.005	0.079						
14642	8758	38	38	0.0048	0.079						
14643	8759	37	37	0.0046	0.079						
14644	8760	36	36	0.0044	0.08						

Outdoor / Wind & Sun / Indoor & Energy

Figure 4.16 *Extraction spreadsheet for the outdoor thermal data for the hot-humid climate of Houston, Texas.*

g. In columns A and G, assemble the whole year from 1 through 8760 at the appropriate positions.

h. Using the function "LOOKUP" in Excel program to look up and match the hours of the year in columns A and G and provide the compatible data from the extracted data to the rearranged data (see Figure 4.16). An example of the function used to insert the Tdb extracted data (51 °F, cell B6 in Figure 4.16) into new rearranged data (H6 cell in Figure 4.16) is

Tdb = Look up hour (1, rearranged data) to match with hour (1, extracted data) and then provide Tdb (51, extracted data in hour 1),

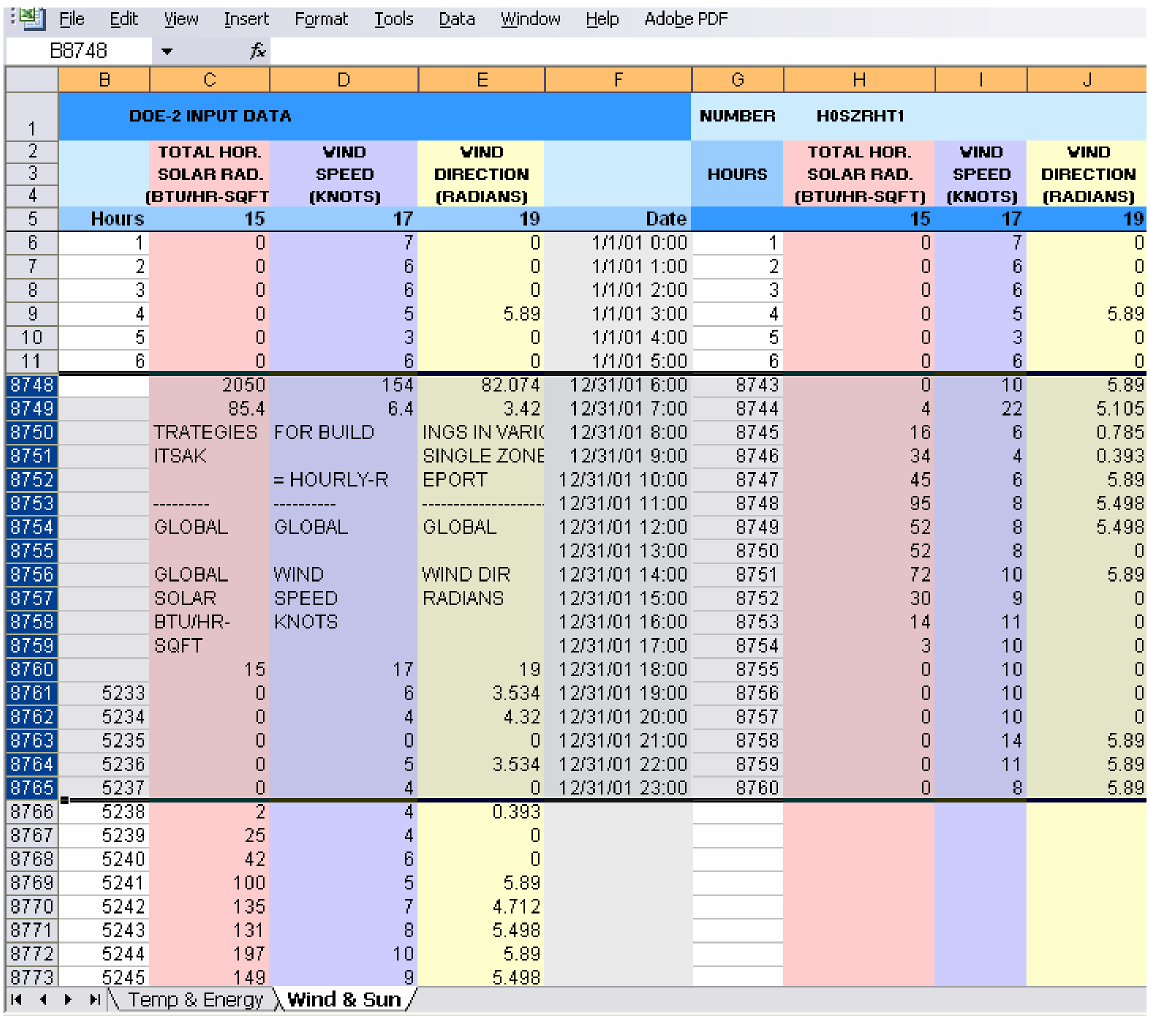
which in Excel is

H6 = LOOKUP(G6,$A$6:$A$15005,$B$6:$B$15005).

i. Similar functions are used to insert the other extracted data into the new rearranged data.

j. Copy the functions to the end of the data.

Figure 4.16 shows parts of the spreadsheet used for extracting and rearranging the outdoor thermal data for the hot-humid climate of Houston, Texas.



	B	C	D	E	F	G	H	I	J
1	DOE-2 INPUT DATA					NUMBER	H0SZRHT1		
2–4		TOTAL HOR. SOLAR RAD. (BTU/HR-SQFT	WIND SPEED (KNOTS)	WIND DIRECTION (RADIANS)		HOURS	TOTAL HOR. SOLAR RAD. (BTU/HR-SQFT)	WIND SPEED (KNOTS)	WIND DIRECTION (RADIANS)
5	Hours	15	17	19	Date		15	17	19
6	1	0	7	0	1/1/01 0:00	1	0	7	0
7	2	0	6	0	1/1/01 1:00	2	0	6	0
8	3	0	6	0	1/1/01 2:00	3	0	6	0
9	4	0	5	5.89	1/1/01 3:00	4	0	5	5.89
10	5	0	3	0	1/1/01 4:00	5	0	3	0
11	6	0	6	0	1/1/01 5:00	6	0	6	0
8748		2050	154	82.074	12/31/01 6:00	8743	0	10	5.89
8749		85.4	6.4	3.42	12/31/01 7:00	8744	4	22	5.105
8750		TRATEGIES	FOR BUILD	INGS IN VARI(	12/31/01 8:00	8745	16	6	0.785
8751		ITSAK		SINGLE ZONE	12/31/01 9:00	8746	34	4	0.393
8752			= HOURLY-R	EPORT	12/31/01 10:00	8747	45	6	5.89
8753		---------	----------	------------------	12/31/01 11:00	8748	95	8	5.498
8754		GLOBAL	GLOBAL	GLOBAL	12/31/01 12:00	8749	52	8	5.498
8755					12/31/01 13:00	8750	52	8	0
8756		GLOBAL	WIND	WIND DIR	12/31/01 14:00	8751	72	10	5.89
8757		SOLAR	SPEED	RADIANS	12/31/01 15:00	8752	30	9	0
8758		BTU/HR-	KNOTS		12/31/01 16:00	8753	14	11	0
8759		SQFT			12/31/01 17:00	8754	3	10	0
8760		15	17	19	12/31/01 18:00	8755	0	10	0
8761	5233	0	6	3.534	12/31/01 19:00	8756	0	10	0
8762	5234	0	4	4.32	12/31/01 20:00	8757	0	10	0
8763	5235	0	0	0	12/31/01 21:00	8758	0	14	5.89
8764	5236	0	5	3.534	12/31/01 22:00	8759	0	11	5.89
8765	5237	0	4	0	12/31/01 23:00	8760	0	8	5.89
8766	5238	2	4	0.393					
8767	5239	25	4	0					
8768	5240	42	6	0					
8769	5241	100	5	5.89					
8770	5242	135	7	4.712					
8771	5243	131	8	5.498					
8772	5244	197	10	5.89					
8773	5245	149	9	5.498					

Figure 4.17 *Extraction spreadsheet for the solar and wind data for the hot-humid climate of Houston, Texas.*

4.3.2.2 Solar data extraction tool

In similar method was used for developing the thermal data extraction tool is used to develop solar data extraction tool (see label 3.2B in Figure 4.9). Figure 4.17 shows a spreadsheet for the solar data for the hot-humid climate of Houston (Texas), which column C is the extracted global horizontal solar radiation (Bth/hour-ft^2) from the DOE-2 HOURLY-REPORT. Columns B and G are the hour of the year, column F is the date, and column H is the rearranged global horizontal solar radiation, which will be used for further analysis.

4.3.2.3 Wind data extraction tool

Similar method used for developing the thermal data extraction tool is used to develop wind data extraction tool (see label 3.2C in Figure 4.9). Figure 4.17 also shows the extracted wind data from the DOE-2 HOURLY-REPORT, which column D is the wind speed data (knots) and column E is the wind direction (radians). These data were rearranged and placed into columns I and J; respectively.

4.3.3 Analyzing and Projecting the Weather Data onto the Chart

In this step, the data from the previous step (Section 4.3.2, see label 3.3 in Figure 4.9) are analyzed and displayed in several plots such as time-series plots, x-y plots, three-dimensional plots, bar charts, and psychrometric plots. This research also uses new techniques to present the weather data on the psychrometric chart. Several data analysis tools, which were developed using the Excel spreadsheet to present the weather data on the psychrometric chart, are demonstrated in this section. The types of the weather data included in the analysis are: thermal data, solar data, and wind data.

4.3.3.1 Thermal data analysis tools

The thermal data used for the analysis in this section include: dry-bulb temperature and humidity ratio. The data analysis tools were developed to find the density of the data which is the frequency of occurrence of the outdoor conditions. The tools arranged the data density to be displayed on the psychrometric chart. The steps for developing the thermal data analysis tools for the whole year (daytime and nighttime), daytime, and nighttime are explained (see label 3.3A in Figure 4.9).

4.3.3.1.1 Daytime and Nighttime Data Density

The process to develop a tool for daytime and nighttime or a whole year data density analysis and display (Figure 4.18) include: obtaining the extracted dry-bulb temperature (Tdb) and humidity ratio (W) from the DOE-2 HOURLY-REPORT (see Section 4.3.2), inserting the extracted Tdb the appropriate range of W, counting the number of hours of each inserted Tdb in each range of W, rearranging the data (Tdb, range of W, and number of hours) into the appropriate range of frequency, and plotting the inserted x-y data points (Tdb, W) of each range of frequency onto the psychrometric chart using different colors. The detailed descriptions of the process are follows:

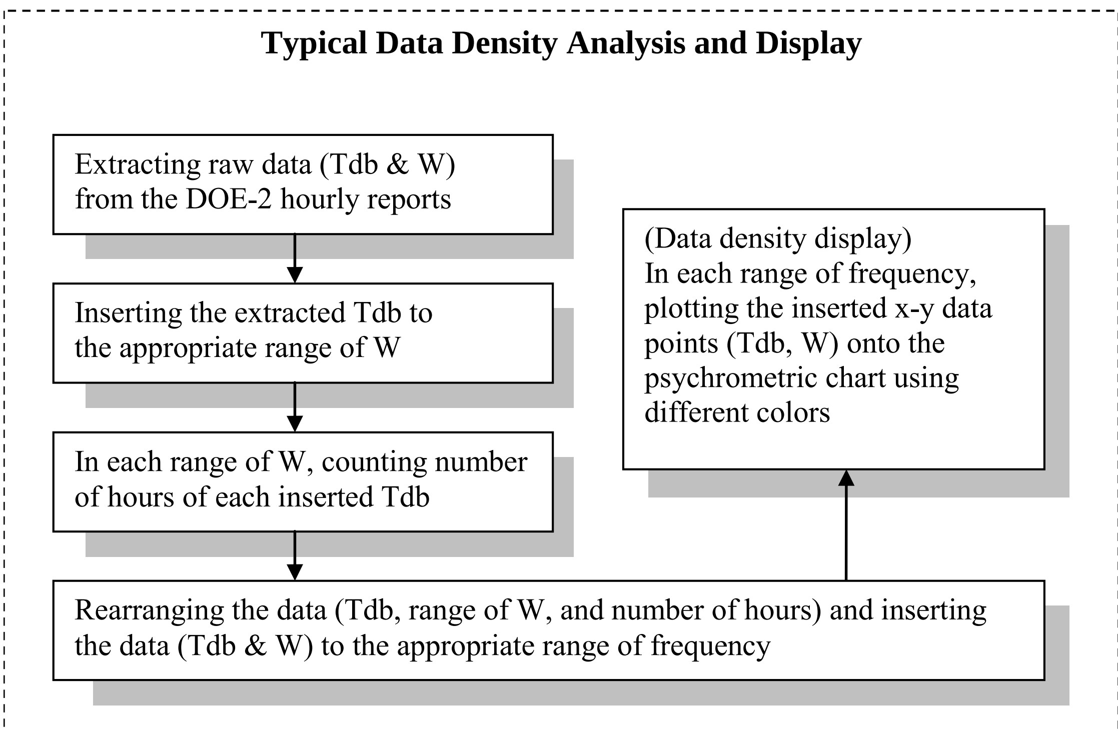


Figure 4.18 *Thermal data density analysis and display flowchart (daytime and nighttime).*

a. Create a new spreadsheet for the weather data to look similar to Figure 4.19, which columns A through E are date, time, hour of the year, dry-bulb temperature (Tdb), and humidity ratio (W); respectively.
b. Copy and paste one whole year of data (Tdb and W), which are extracted according to the Section 4.3.2.1, into the appropriate positions on the spreadsheet (start at D6 cell).
c. Create columns (F through BN) for the ranges of W from 0 to 0.03 lbw/lba (Figure 4.20). The increment of the range is 0.0005 lbw/lba (see row 8 in Figure 4.20).
d. Insert Tdb which are extracted from column D into the appropriate positions of the range of W (columns F through BN). An example (cell V9, Figure 4.20) of the functions used to extract the Tdb (51 °F) in relation with the corresponding W (0.0079 lbw/lba) to the appropriate range of W (0.008 lbw/lba) is

   Tdb = If 0.00775 < W (0.0079) ≤ 0.00825, then Tdb (51), other wise

   "blank";

   which in Excel is

   V9 = IF(AND(E9>U7,E9<=V7),D9,"").

e. Create a column (BP) for the Tdb from 20 to 110 °F and columns (BQ through DY) for the ranges of W from 0 to 0.03 lbw/lba (Figure 4.21). The increment of the range is 0.0005 lbw/lba (see row 8 in Figure 4.21).
f. In each range of W (columns F through BN), count number of hours of each Tdb which correspond to the Tdb in column BP and insert the number of hours into the appropriate ranges of W (columns BQ through DY). An example of the function used to count the number of hours of the Tdb at 20 °F in the 0.001 lbw/lba range of W and insert the number of hours into cell BS9 (Figure 4.21) is

	A	B	C	D	E	F	G	H	I	J	
5	Daytime & Nighttime										
6				Outdoor	Outdoor	Ranges of W and corresponding Tdb					
7	Date	Time	Hour	Temp	W	0.00025	0.00075	0.00125	0.00175	0.00225	0.(
8				(F)	(lbw/lbda)	0.000	0.0005	0.001	0.0015	0.002	0.
9	1/1/01	0:00	1	51	0.0079						
10	1/1/01	1:00	2	48	0.0066						
11	1/1/01	2:00	3	47	0.0063						
12	1/1/01	3:00	4	46	0.0061						
13	1/1/01	4:00	5	45	0.0063						
14	1/1/01	5:00	6	45	0.0063						
15	1/1/01	6:00	7	44	0.0061						
16	1/1/01	7:00	8	44	0.0061						
17	1/1/01	8:00	9	47	0.0063						
18	1/1/01	9:00	10	48	0.0066						
19	1/1/01	10:00	11	50	0.0071						
20	1/1/01	11:00	12	52	0.0077						
21	1/1/01	12:00	13	53	0.008						
22	1/1/01	13:00	14	54	0.0083						
8760	12/31/01	15:00	8752	43	0.0058						
8761	12/31/01	16:00	8753	42	0.0056						
8762	12/31/01	17:00	8754	41	0.0054						
8763	12/31/01	18:00	8755	40	0.0052						
8764	12/31/01	19:00	8756	39	0.005						
8765	12/31/01	20:00	8757	39	0.005						
8766	12/31/01	21:00	8758	38	0.0048						
8767	12/31/01	22:00	8759	37	0.0046						
8768	12/31/01	23:00	8760	36	0.0044						

Figure 4.19 *Spreadsheet of the thermal data density analysis (daytime and nighttime) for the hot-humid climate of Houston, Texas: raw data (Tdb and W)*

	F	O	P	Q	R	S	T	U	V	BN
5										
6	Ranges of W and corresponding Tdb									
7	0.00025	0.00475	0.00525	0.00575	0.00625	0.00675	0.00725	0.00775	0.00825	0.03025
8	0.000	0.0045	0.005	0.0055	0.006	0.0065	0.007	0.0075	0.008	0.03
9									51	
10						48				
11						47				
12					46					
13						45				
14						45				
15					44					
16					44					
17						47				
18						48				
19							50			
20								52		
21									53	
22										
8760					43					
8761				42						
8762				41						
8763			40							
8764			39							
8765			39							
8766			38							
8767		37								
8768		36								

Figure 4.20 *Spreadsheet of the thermal data density analysis (daytime and nighttime) for the hot-humid climate of Houston, Texas: range of W and corresponding Tdb.*

	BP	BQ	BR	BS	BT	BU	BV	BW	DX	DY
5										
6	Number of hours of each rannge of W and the corresponding Tdb									
7		W	(lbw/lbda)							
8	Temp (F)	0.0000	0.0005	0.0010	0.0015	0.0020	0.0025	0.0030	0.0295	0.0300
9	20	0	0	2	2	0	0	0	0	0
10	21	0	0	1	1	2	0	0	0	0
11	22	0	0	1	0	4	0	0	0	0
12	23	0	0	1	0	4	0	0	0	0
13	24	0	0	1	1	0	0	0	0	0
14	25	0	0	0	1	4	1	0	0	0
15	26	0	0	1	0	6	0	0	0	0
16	27	0	0	1	0	2	3	1	0	0
17	28	0	0	1	0	11	3	3	0	0
18	29	0	0	1	0	6	1	10	0	0
19	30	0	0	0	1	4	2	1	0	0
20	31	0	0	1	0	4	3	7	0	0
21	32	0	0	5	3	0	3	7	0	0
22	33	0	0	1	2	3	5	5	0	0
92	103	0	0	0	0	0	0	0	0	0
93	104	0	0	0	0	0	0	0	0	0
94	105	0	0	0	0	0	0	0	0	0
95	106	0	0	0	0	0	0	0	0	0
96	107	0	0	0	0	0	0	0	0	0
97	108	0	0	0	0	0	0	0	0	0
98	109	0	0	0	0	0	0	0	0	0
99	110	0	0	0	0	0	0	0	0	0
100	TOTAL	0	0	18	36	94	127	160	0	0

SOL_time(unused) / H_dt(DT) / H_dt(NT) / H_dt / C_dt(DT) / C_dt(NT) / C_dt / NHC_dt(DT) / NHC_dt(NT) / NHC_dt / DT_dt / NT_dt / ALL_dt

Figure 4.21 *Spreadsheet of the thermal data density analysis (daytime and nighttime) for the hot-humid climate of Houston, Texas: number of hours of each Tdb in each corresponding range of W.*

	EA	EB	EC	ED	EE	EF	EG	EH	EI	EZ	FA
5			COLUMN								
6	Temp	W	Frequen.	Tdb and the corresponding W in each range of frequency							UP
7					10		20		30		120
8	(F)	(lbw/lbda)	(hour)	T	W	T	W	T	W	T	W
9	20	0.0005	0	-99	-99	-99	-99	-99	-99	-99	-99
10	21	0.0005	0	-99	-99	-99	-99	-99	-99	-99	-99
11	22	0.0005	0	-99	-99	-99	-99	-99	-99	-99	-99
12	23	0.0005	0	-99	-99	-99	-99	-99	-99	-99	-99
13	24	0.0005	0	-99	-99	-99	-99	-99	-99	-99	-99
14	25	0.0005	0	-99	-99	-99	-99	-99	-99	-99	-99
15	26	0.0005	0	-99	-99	-99	-99	-99	-99	-99	-99
96	107	0.0005	0	-99	-99	-99	-99	-99	-99	-99	-99
97	108	0.0005	0	-99	-99	-99	-99	-99	-99	-99	-99
98	109	0.0005	0	-99	-99	-99	-99	-99	-99	-99	-99
99	110	0.0005	0	-99	-99	-99	-99	-99	-99	-99	-99
100	20	0.0010	2	20	0.001	-99	-99	-99	-99	-99	-99
101	21	0.0010	1	21	0.001	-99	-99	-99	-99	-99	-99
102	22	0.0010	1	22	0.001	-99	-99	-99	-99	-99	-99
103	23	0.0010	1	23	0.001	-99	-99	-99	-99	-99	-99
104	24	0.0010	1	24	0.001	-99	-99	-99	-99	-99	-99
105	25	0.0010	0	-99	-99	-99	-99	-99	-99	-99	-99
5463	105	0.0300	0	-99	-99	-99	-99	-99	-99	-99	-99
5464	106	0.0300	0	-99	-99	-99	-99	-99	-99	-99	-99
5465	107	0.0300	0	-99	-99	-99	-99	-99	-99	-99	-99
5466	108	0.0300	0	-99	-99	-99	-99	-99	-99	-99	-99
5467	109	0.0300	0	-99	-99	-99	-99	-99	-99	-99	-99
5468	110	0.0300	0	-99	-99	-99	-99	-99	-99	-99	-99

SOL_time(unused) / H_dt(DT) / H_dt(NT) / H_dt / C_dt(DT) / C_dt(NT) / C_dt / NHC_dt(DT) / NHC_dt(NT) / NHC_dt / DT_dt / NT_dt / ALL_dt

Figure 4.22 *Spreadsheet of the thermal data density analysis (daytime and nighttime) for the hot-humid climate of Houston, Texas: Tdb and the corresponding W in each range of frequency.*

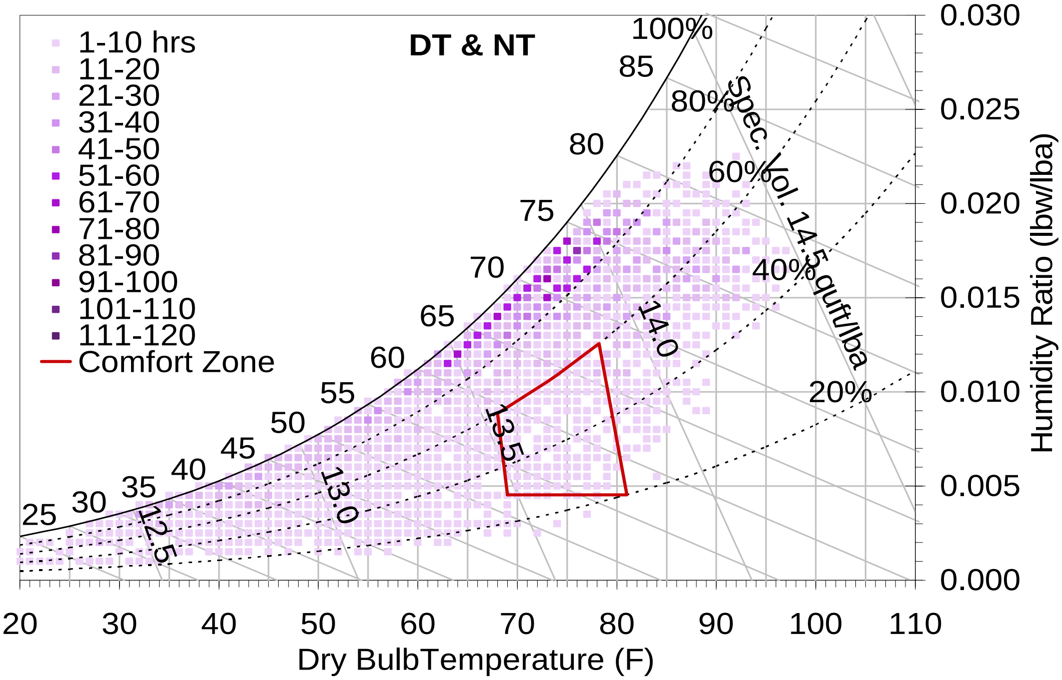


Figure 4.23 *Daytime and nighttime density plot of the thermal data for the hot-humid climate of Houston, Texas, on the psychrometric chart.*

Number of hours = Count number of hours of the Tdb (20, extracted data) in range of W (0.001, extracted data) that equal to Tdb (20, rearranged data) in range of W (0.001, rearranged data);

which in Excel is

BS9 = COUNTIF($H$9:$H$8768,BP9).

g. Rearrange the data extracted from the previous step (BP9 through DY99) to the new format by creating columns (EA through EC) for Tdb from 20 to 110 °F for each range of W, ranges of W from 0 to 0.03 lbw/lba, and the frequency of occurrence of the corresponding Tdb and W; respectively (Figure 4.22). Then create columns (ED through FA) for the ranges of the occurrence from 0 to 120 up (hours) for each corresponding Tdb and W. The increment of the frequency is 10 hours (see row 7 in Figure 4.22).

h. Extract the Tdb and W from column EA and EB and insert to the appropriate positions in columns (ED through FA), which correspond to the frequency of the occurrence in column EC. An example of the functions used to extract the 20 °F (Tdb), which has 2 hours of the occurrence, from cell EA100 (Figure 4.22) and insert into cell ED100 which is in the 10 hours of the range of frequency (Figure 4.22) is

   Tdb = If 0 < number of hours (2) ≤ 10, then Tdb (20), otherwise "-99";

   which in Excel is

   ED100 = IF(AND(EC100>0,EC100<=10),EA100,-99).

i. Plot the x-y data point (Tdb, W) of each range of the frequency, which are extracted from the previous step (ED9 through FA5468), on the psychrometric chart using different colors varying from light to dark. The lightest color represents 1 to 10 hours of frequency of the occurrence and the darkest color represents 111 to 120 hours of frequency of the occurrence in the year.

Figure 4.23 displays one year (daytime and nighttime) of thermal data density for the hot-humid climate of Houston (Texas), on the psychrometric chart.

4.3.3.1.2 Daytime Data Density

The process to develop a tool for daytime data analysis and display is similar to the process for developing a tool for one year of data except that the data are not the whole year, but are the data for daytime only. The daytime data are defined either by the availability of the sun or is the data during sunrise when the global horizontal solar radiation (GBH) is not equal to zero. The GBH is added into the spreadsheet (column C, Figure 4.24) to indicate the daytime period and uses functions to extract the daytime data (Tdb and W) from the whole year data, which in this study are located in the "Data" spreadsheet, columns Q and R (Data!Q-R). An example of the functions used to extract the Tdb (44 °F) with the corresponding GBH (8 Btu/hr-ft²) from the cell Q16 in the "Data" spreadsheet and insert the Tdb into cell D16 (Figure 4.24) is

Tdb = If GBH (8) > 0, then Tdb (44), otherwise "-99";

which in Excel is

D16 = IF(C16>0,Data!Q16,-99).

Figure 4.25 displays density plot of the daytime thermal data for the hot-humid climate of Houston, Texas, on the psychrometric chart.

4.3.3.1.3 Nighttime Data Density

The process for developing a tool for nighttime data analysis and display is similar to the process for developing a tool for a whole year of data except that the data are the data for nighttime only. Similar to the daytime data, the nighttime data are defined by the availability of the sun or are the data during sunset when the global horizontal solar radiation (GBH) is equal to zero. The GBH is added into the spreadsheet (column C, Figure 4.26) to indicate the nighttime period and uses functions to extract the nighttime data (Tdb and W) from the whole year data, which in this study are located in the "Data" spreadsheet, columns Q and R (Data!Q-R). An example of the functions used to extract the Tdb (44 °F) with the corresponding GBH (0 Btu/hr-ft²) from the cell Q15 in the "Data" spreadsheet and insert the Tdb into cell D15 is

Tdb = If GBH (0) = 0, then Tdb (44), otherwise "-99";

which in Excel is

D15 = IF(C15=0,Data!Q15,-99).

Figure 4.27 displays density plot of the nighttime thermal data for the hot-humid climate of Houston, Texas, on the psychrometric chart.

File Edit View Insert Format Tools Data Window Help

	A	B	C	D	E	F	R	S	T
5	DAYTIME								
6	Date	Time	Global Solar Rad. (hourly)	Outdoor Temp	Outdoor W	Db Temperature in each range of Humidity			
7						0.00025	0.00625	0.00675	0.0072
8			(BTU/Hr-Sqft)	(F)	(lbw/lbda)	0.0000	0.0060	0.0065	0.007[illegible]
9	1/1/01	0:00	0	-99	-99				
10	1/1/01	1:00	0	-99	-99				
11	1/1/01	2:00	0	-99	-99				
12	1/1/01	3:00	0	-99	-99				
13	1/1/01	4:00	0	-99	-99				
14	1/1/01	5:00	0	-99	-99				
15	1/1/01	6:00	0	-99	-99				
16	1/1/01	7:00	8	44	0.0061		44		
17	1/1/01	8:00	16	47	0.0063			47	
18	1/1/01	9:00	46	48	0.0066			48	
19	1/1/01	10:00	52	50	0.0071				
20	1/1/01	11:00	78	52	0.0077				
21	1/1/01	12:00	86	53	0.008				
22	1/1/01	13:00	78	54	0.0083				
8760	12/31/01	15:00	30	43	0.0058		43		
8761	12/31/01	16:00	14	42	0.0056				
8762	12/31/01	17:00	3	41	0.0054				
8763	12/31/01	18:00	0	-99	-99				
8764	12/31/01	19:00	0	-99	-99				
8765	12/31/01	20:00	0	-99	-99				
8766	12/31/01	21:00	0	-99	-99				
8767	12/31/01	22:00	0	-99	-99				
8768	12/31/01	23:00	0	-99	-99				

SOL_time(unused) / H_dt(DT) / H_dt(NT) / H_dt / C_dt(DT) / C_dt(NT) / C_dt / NHC_dt(DT) / NHC_dt(NT) / NHC_dt / DT_dt / NT_dt / ALL_dt /

Figure 4.24 *Spreadsheet of the density plot of the thermal data (daytime) for the hot-humid climate of Houston, Texas: raw data (Tdb and W).*

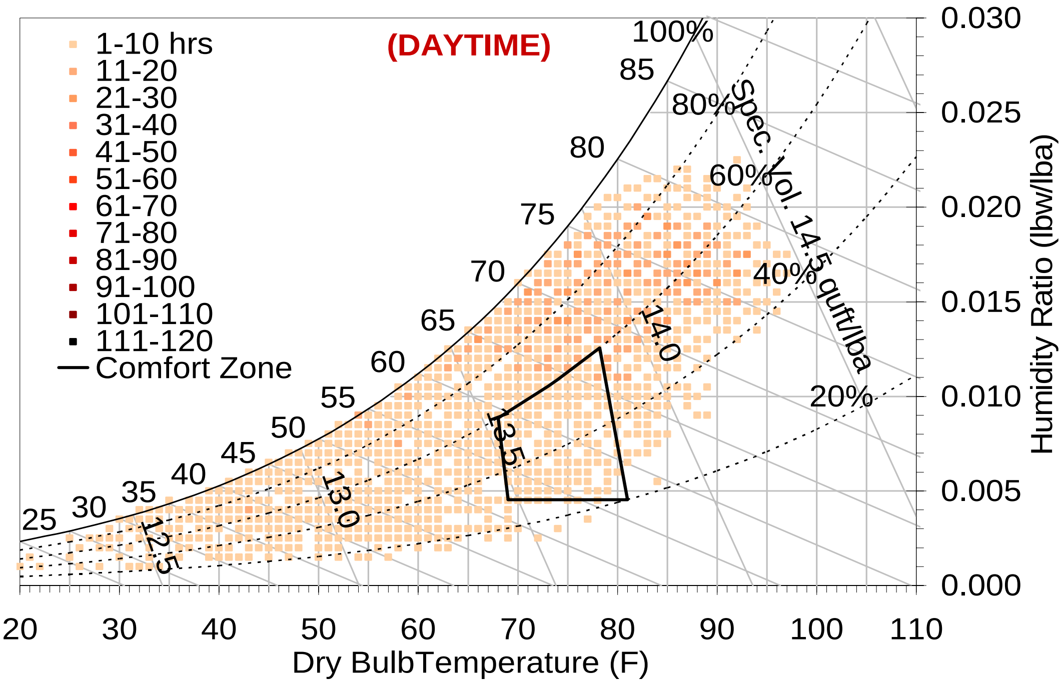
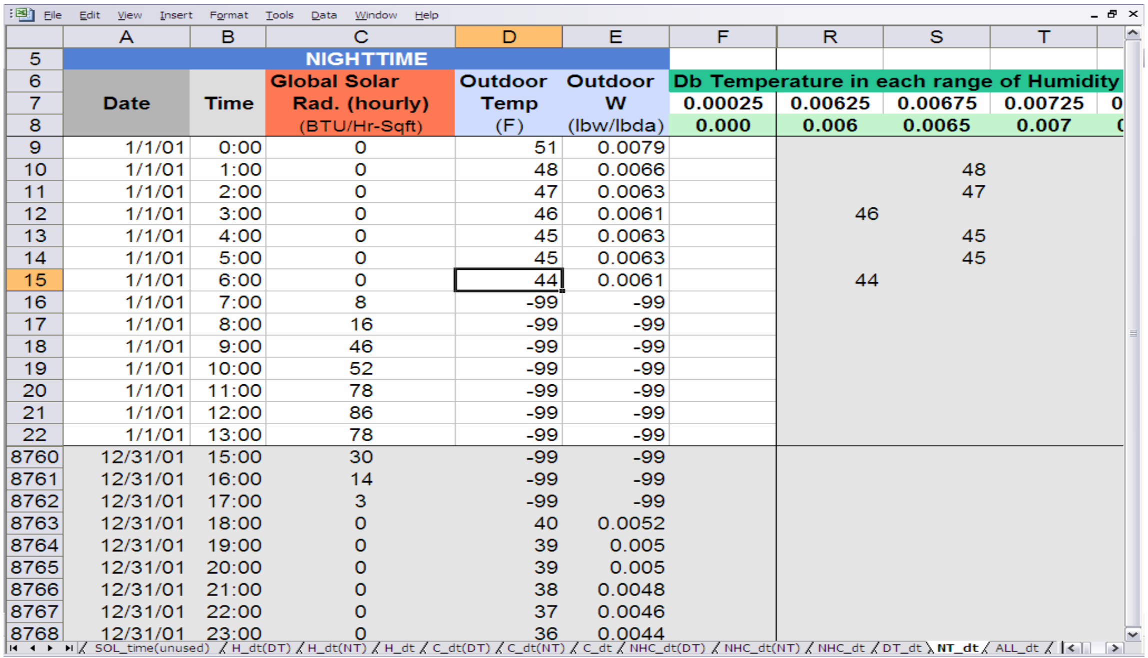


Figure 4.25 *Daytime density plot of the thermal data for the hot-humid climate of Houston, Texas, on the psychrometric chart.*



	A	B	C	D	E	F	R	S	T
5	NIGHTTIME								
6			Global Solar	Outdoor	Outdoor	Db Temperature in each range of Humidity			
7	Date	Time	Rad. (hourly)	Temp	W	0.00025	0.00625	0.00675	0.00725
8			(BTU/Hr-Sqft)	(F)	(lbw/lbda)	0.000	0.006	0.0065	0.007
9	1/1/01	0:00	0	51	0.0079				
10	1/1/01	1:00	0	48	0.0066			48	
11	1/1/01	2:00	0	47	0.0063			47	
12	1/1/01	3:00	0	46	0.0061		46		
13	1/1/01	4:00	0	45	0.0063			45	
14	1/1/01	5:00	0	45	0.0063			45	
15	1/1/01	6:00	0	44	0.0061		44		
16	1/1/01	7:00	8	-99	-99				
17	1/1/01	8:00	16	-99	-99				
18	1/1/01	9:00	46	-99	-99				
19	1/1/01	10:00	52	-99	-99				
20	1/1/01	11:00	78	-99	-99				
21	1/1/01	12:00	86	-99	-99				
22	1/1/01	13:00	78	-99	-99				
8760	12/31/01	15:00	30	-99	-99				
8761	12/31/01	16:00	14	-99	-99				
8762	12/31/01	17:00	3	-99	-99				
8763	12/31/01	18:00	0	40	0.0052				
8764	12/31/01	19:00	0	39	0.005				
8765	12/31/01	20:00	0	39	0.005				
8766	12/31/01	21:00	0	38	0.0048				
8767	12/31/01	22:00	0	37	0.0046				
8768	12/31/01	23:00	0	36	0.0044				

Figure 4.26 *Spreadsheet of the density plot of the thermal data (nighttime) for the hot-humid climate of Houston, Texas: raw data (Tdb and W).*

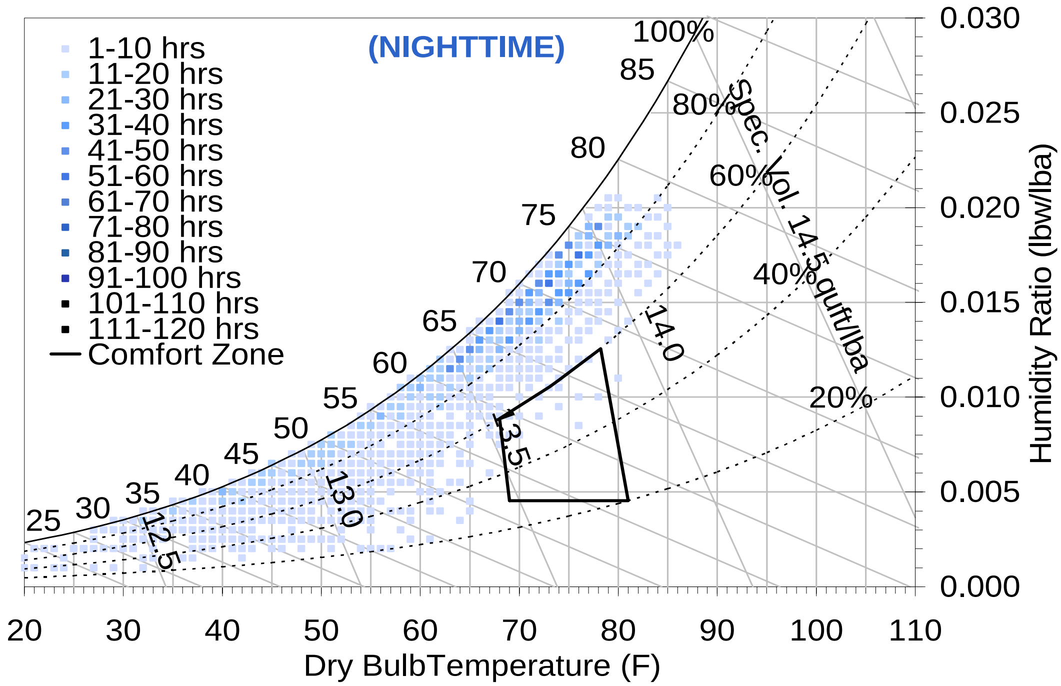


Figure 4.27 *Nighttime density plot of the thermal data for the hot-humid climate of Houston, Texas, on the psychrometric chart.*

4.3.3.2 Solar data analysis tools

The solar radiation used to indicate the availability of the sunlight in this study is the global horizontal solar radiation (GBH). Data analysis tools were developed using new techniques to find the relationship between the thermal data and the GBH data and to present the density, cumulative, average, and hourly average of the GBH onto the psychrometric chart (see label 3.3B in Figure 4.9). The process to develop these tools was tedious and time consuming. Therefore, to reduce the time to create these tools a "macro" subcommand in the Excel program was used. The following material provides an outline of how the "macro" tool functions.

4.3.3.2.1 GBH Data Density

The global horizontal solar radiation (GBH) density plot in this study is the number of hours of the GBH which occur in a year at any outdoor conditions. This type of data is exactly the same as the daytime density plot of the thermal data in Section 4.3.3.1 (Figure 4.25). Therefore, the tool for developing the analysis and display of daytime data density of thermal is also used to develop the GBH data density analysis and display. Figure 4.28 shows the part of the GBH data density tool which will be used to develop the average GBH data. Figure 4.29 displays the GBH density plot for a hot-humid climate of Houston, Texas, on the psychrometric chart.

4.3.3.2.2 Cumulative GBH Data

The cumulative global horizontal solar radiation (GBH) data in this study is the amount of the total GBH (Btu/ft^2-year) which occurs in one year at a specific outdoor condition. Although the process to develop a tool for data analysis and the display of the cumulative GBH data is different from the GBH data density, the idea used to develop both tools is similar. Figures 4.28 and 4.30 to 4.32 show the spreadsheet tools of the cumulative GBH. The steps to develop the tools include: obtaining the GBH, Tdb, and W extracted data from the DOE-2 HOURLY-REPORT (see Section 4.3.2.1), developing a spreadsheet for each Tdb and inserting the GBH data which occur at that Tdb into the

	BP	BQ	BR	BS	BT	BU	BV	BW	DX	DY
5										
6	Number of hours of GBH of each range of W and the corresponding Tdb									
7		W	(lbw/lbda)							
8	Temp (F)	0.0000	0.0005	0.0010	0.0015	0.0020	0.0025	0.0030	0.0295	0.0300
9	20	0	0	1	0	0	0	0	0	0
10	21	0	0	0	1	0	0	0	0	0
11	22	0	0	1	0	0	0	0	0	0
12	23	0	0	0	0	0	0	0	0	0
13	24	0	0	0	0	0	0	0	0	0
14	25	0	0	0	1	0	1	0	0	0
15	26	0	0	1	0	1	0	0	0	0
16	27	0	0	0	0	0	1	0	0	0
17	28	0	0	1	0	2	3	0	0	0
18	29	0	0	0	0	1	1	2	0	0
19	30	0	0	0	1	0	1	0	0	0
20	31	0	0	1	0	2	0	1	0	0
21	32	0	0	2	0	0	1	1	0	0
22	33	0	0	1	1	2	2	0	0	0
92	103	0	0	0	0	0	0	0	0	0
93	104	0	0	0	0	0	0	0	0	0
94	105	0	0	0	0	0	0	0	0	0
95	106	0	0	0	0	0	0	0	0	0
96	107	0	0	0	0	0	0	0	0	0
97	108	0	0	0	0	0	0	0	0	0
98	109	0	0	0	0	0	0	0	0	0
99	110	0	0	0	0	0	0	0	0	0
100	TOTAL	0	0	9	26	37	92	75	0	0

Figure 4.28 *Global horizontal solar radiation (GBH) data density analysis spreadsheet of a hot-humid climate, Houston, Texas: number of GBH hours of each range of W and the corresponding Tdb.*

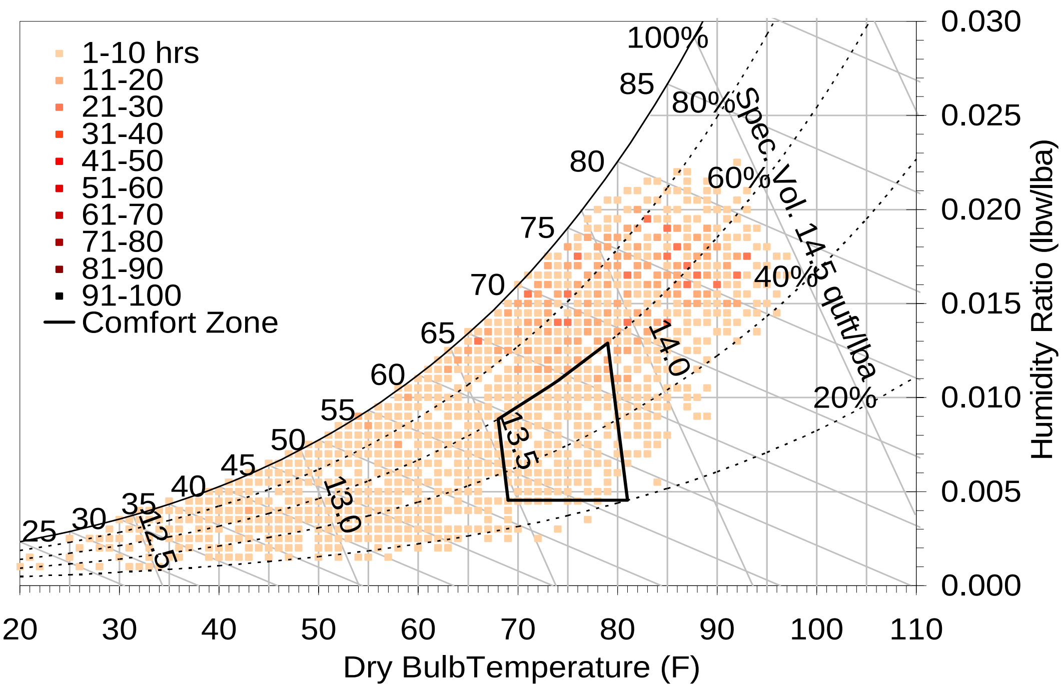


Figure 4.29 *Global horizontal solar radiation (GBH) density plot for the hot-humid climate of Houston, Texas, on the psychrometric chart.*

	A	B	C	D	E	F	G	H	I	J	BN
5	Tdb	20				20	20	20	20	20	20
6			GBH	Outdoor	Outdoor	GBH in each range of W at corresponding Tdb 20F					
7	Date	Time	(hourly)	Tdb	W	0.00025	0.00075	0.00125	0.00175	0.00225	0.03025
8			(BTU/Hr-Sqft)	(F)	(lbw/lbda)	0.0000	0.0005	0.0010	0.0015	0.0020	0.0300
9	1/1/01	0:00	0	51	0.0079						
10	1/1/01	1:00	0	48	0.0066						
11	1/1/01	2:00	0	47	0.0063						
12	1/1/01	3:00	0	46	0.0061						
13	1/1/01	4:00	0	45	0.0063						
14	1/1/01	5:00	0	45	0.0063						
255	1/11/01	6:00	0	15	0.0009						
256	1/11/01	7:00	12	14	0.0009						
257	1/11/01	8:00	58	17	0.0009						
258	1/11/01	9:00	113	20	0.0009			113			
259	1/11/01	10:00	151	22	0.0009						
260	1/11/01	11:00	178	26	0.0009						
261	1/11/01	12:00	192	28	0.0009						
8760	12/31/01	15:00	30	43	0.0058						
8761	12/31/01	16:00	14	42	0.0056						
8762	12/31/01	17:00	3	41	0.0054						
8763	12/31/01	18:00	0	40	0.0052						
8764	12/31/01	19:00	0	39	0.005						
8765	12/31/01	20:00	0	39	0.005						
8766	12/31/01	21:00	0	38	0.0048						
8767	12/31/01	22:00	0	37	0.0046						
8768	12/31/01	23:00	0	36	0.0044						
8769	TEMP	20	513026			0	0	113	0	0	0

Figure 4.30 *Cumulative global horizontal solar radiation (GBH) data analysis spreadsheet for the hot-humid climate of Houston, Texas: amount of the cumulative GBH at a corresponding Tdb (20 °F) and the corresponding range of W.*

	BP	BQ	BR	BS	BT	BU	BV	BW	DX	DY
5										
6	Cumulative GBH of each range of W and corresponding Tdb									
7		W	(lbw/lbda)							
8	Tdb (F)	0.00000	0.00050	0.00100	0.00150	0.00200	0.00250	0.00300	0.02950	0.03000
9	20	0	0	113	0	0	0	0	0	0
10	21	0	0	0	10	0	0	0	0	0
11	22	0	0	151	0	0	0	0	0	0
12	23	0	0	0	0	0	0	0	0	0
13	24	0	0	0	0	0	0	0	0	0
14	25	0	0	0	13	0	16	0	0	0
15	26	0	0	178	0	52	0	0	0	0
16	27	0	0	0	0	0	9	0	0	0
17	28	0	0	192	0	72	121	0	0	0
18	29	0	0	0	0	112	11	70	0	0
19	30	0	0	0	12	0	52	0	0	0
20	31	0	0	125	0	171	0	56	0	0
21	32	0	0	114	0	0	68	12	0	0
22	33	0	0	33	62	236	231	0	0	0
92	103	0	0	0	0	0	0	0	0	0
93	104	0	0	0	0	0	0	0	0	0
94	105	0	0	0	0	0	0	0	0	0
95	106	0	0	0	0	0	0	0	0	0
96	107	0	0	0	0	0	0	0	0	0
97	108	0	0	0	0	0	0	0	0	0
98	109	0	0	0	0	0	0	0	0	0
99	110	0	0	0	0	0	0	0	0	0
100	TOTAL	0	0	9274	0	1941	4383	4401	0	0

Figure 4.31 *Cumulative global horizontal solar radiation (GBH) data analysis spreadsheet for the hot-humid climate of Houston, Texas: amount of the cumulative GBH of each Tdb and the corresponding range of W.*

	EA	EB	EC	ED	EE	EF	EG	EH	EI	EZ	FA
5			COLUMN								
6	Tdb	W	Cumulative	Tdb and the corresponding W in each range of cumulative GBH							
7			GBH	0	1000		2000		3000		12000
8	(F)	(lbw/lbda)	(hour)	T	W	T	W	T	W	T	W
9	20	0.0005	0	-99	-99	-99	-99	-99	-99	-99	-99
10	21	0.0005	0	-99	-99	-99	-99	-99	-99	-99	-99
11	22	0.0005	0	-99	-99	-99	-99	-99	-99	-99	-99
12	23	0.0005	0	-99	-99	-99	-99	-99	-99	-99	-99
13	24	0.0005	0	-99	-99	-99	-99	-99	-99	-99	-99
14	25	0.0005	0	-99	-99	-99	-99	-99	-99	-99	-99
15	26	0.0005	0	-99	-99	-99	-99	-99	-99	-99	-99
96	107	0.0005	0	-99	-99	-99	-99	-99	-99	-99	-99
97	108	0.0005	0	-99	-99	-99	-99	-99	-99	-99	-99
98	109	0.0005	0	-99	-99	-99	-99	-99	-99	-99	-99
99	110	0.0005	0	-99	-99	-99	-99	-99	-99	-99	-99
100	20	0.0010	113	20	0.001	-99	-99	-99	-99	-99	-99
101	21	0.0010	0	-99	-99	-99	-99	-99	-99	-99	-99
102	22	0.0010	151	22	0.001	-99	-99	-99	-99	-99	-99
103	23	0.0010	0	-99	-99	-99	-99	-99	-99	-99	-99
104	24	0.0010	0	-99	-99	-99	-99	-99	-99	-99	-99
105	25	0.0010	0	-99	-99	-99	-99	-99	-99	-99	-99
5463	105	0.0300	0	-99	-99	-99	-99	-99	-99	-99	-99
5464	106	0.0300	0	-99	-99	-99	-99	-99	-99	-99	-99
5465	107	0.0300	0	-99	-99	-99	-99	-99	-99	-99	-99
5466	108	0.0300	0	-99	-99	-99	-99	-99	-99	-99	-99
5467	109	0.0300	0	-99	-99	-99	-99	-99	-99	-99	-99
5468	110	0.0300	0	-99	-99	-99	-99	-99	-99	-99	-99

Figure 4.32 *Spreadsheet of the cumulative global horizontal solar radiation (GBH) data analysis for the hot-humid climate of Houston, Texas: the Tdb and corresponding W of each range of cumulative GBH.*

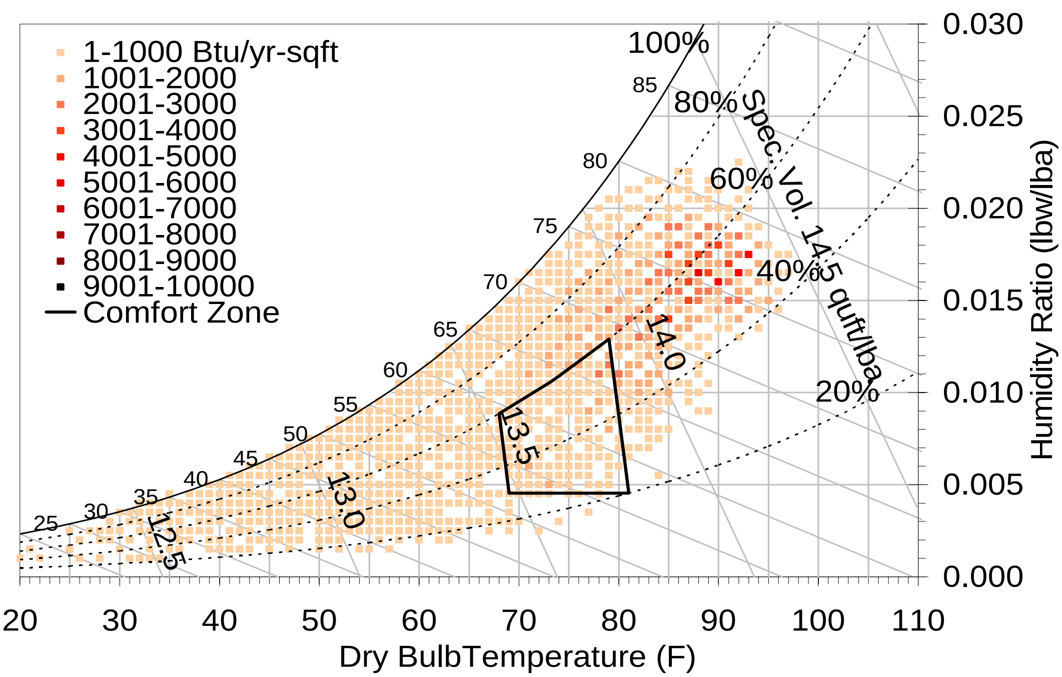


Figure 4.33 *Cumulative global horizontal solar radiation (GBH) plot for the hot-humid climate of Houston, Texas, on the psychrometric chart.*

corresponding range of humidity (W) (Figure 4.30) adding the amount of the whole year GBH for each Tdb at each corresponding range of humidity (W) (Figure 4.30), developing a new spreadsheet and inserting the results of the total GBH data of each Tdb at each corresponding range of W into the appropriate position (Figure 4.31), rearranging the data (Tdb and W) into the appropriate range of cumulative GBH (Figure 4.32), and then plotting the data onto the psychrometric chart (Figure 4.33). The detailed descriptions of the process are follows:

a. Create a spreadsheet for each Tdb reading (20 to 110 °F) similar to Figure 4.30, which columns A through E are date, time, GBH, Tdb, and W; respectively.
b. Copy and paste one year of data (GBH, Tdb, and W), which are extracted from Section 4.3.2.1 and insert the data into the appropriate positions of the spreadsheet (start at cell C6).
c. Create columns (F through BN) for the ranges of W from 0 to 0.03 lbw/lba (Figure 4.30). The increment of the range is 0.0005 lbw/lba (see row 8 in Figure 4.30).
d. Extract GBH (column C) of the Tdb (column D), which corresponds to the working Tdb spreadsheet, and W (column E) and insert into appropriate positions of the range of W (columns F through BN). An example the functions used in the 20 °F Tdb spreadsheet (Figure 4.30) for extracting the 113 (Btu/year-ft^2) GBH at 20 °F Tdb and 0.0009 lbw/lba W from cell C258 and inserting the data into cell H258 in the 0.001 lbw/lba range of W is

   GBH = If 0.00075 < W (0.0009) ≤ 0.00125, and Tdb (20) = 20, then GBH (113), otherwise “blank”;

   which in Excel is

   H258 = IF(AND(AND(E258>$G$7,E258<=$H$7),D258=20,C258,“”).

e. In each Tdb spreadsheet, add the amount of the GBH for the whole year of each corresponding range of W. An example (cell H8769, Figure 4.30) of the function used to find the cumulative GBH of a corresponding 20 °F Tdb and 0.001 lbw/lba of range of W is

   Total GBH = Sum (GBH, the whole year);

   which in Excel is

   H8769 = SUM(H9:H8768).

f. Develop a new spreadsheet to look similar to Figure 4.31, in which column (BP) is for Tdb from 20 to 110 °F and columns (BQ through DY) are for the ranges of W from 0 to 0.03 lbw/lba. The increment of the range is 0.0005 lbw/lba (see row 8 in Figure 4.31).
g. Copy the results of each Tdb spreadsheet, the cumulative GBH of each corresponding range of W, into the appropriate positions of the new spreadsheet developed in the previous step.
h. Rearrange the data copied from the previous step (BP9 through DY99) to the new format by creating columns (EA through EC) for Tdb from 20 to 110 °F for each range of W, ranges of W from 0 to 0.03 lbw/lba, and the cumulative GBH of the corresponding Tdb and W; respectively (Figure 4.32). Then create columns (ED through FA) for the ranges of the cumulative GBH from 0 to 12000 (Btu/year-ft^2) for each corresponding Tdb and W. The increment of the frequency is 1000 Btu/year-ft^2 (see row 7 in Figure 4.32).
i. Insert the Tdb and W (Columns EA and EB) into the appropriate positions in columns (ED through FA), which correspond to the range of the cumulative GBH in column EC. An example (Figure 4.32) of the functions used to extract the 20 °F Tdb with the corresponding 113 Btu/year-ft^2 GBH from cell EA100 and insert the data into cell ED100 in the 1000 Btu/year-ft^2 corresponding range of cumulative GBH is

Tdb = If 0 < GBH (113) ≤, then Tdb (20), otherwise "-99";

which in Excel is

ED100 = IF (AND (EC100>0, EC100<=1000), EA100,-99).

j. Plot the x-y data (Tdb, W) of each range of the cumulative GBH, which are extracted from the previous step (ED9 through FA5468), and insert into the psychrometric chart using different colors varying from light to dark.

Figure 4.33 displays the cumulative plot of the global horizontal solar radiation (GBH) data for the hot-humid climate of Houston, Texas, on the psychrometric chart.

4.3.3.2.3 Average GBH Data

The average global horizontal solar radiation (GBH) data in this study is the amount of the cumulative GBH (Btu/ft^2-year) divided by the number of hours of the occurrence for the whole year of any outdoor condition. On the other hand, it is the data of Figure 4.31 divided by the data of Figure 4.21 or Figure 4.28. The process to develop a tool for data analysis and display of the average GBH data is quite similar to the GBH data density, which is also similar to the daytime thermal data density (Section 4.3.3.1). The only differences are: 1) the range of Figure 4.22 is the range of the average GBH, which ranges from 0 to 400 Btu/ft^2-hour with the increment of 50 Btu/ft^2-hour, and 2) the functions used to find the average GBH (example, GBH BS9 cell in Figure 4.34) is

GBH = if cumulative GBH > 0 and number of hours > 0, then, cumulative GBH / number of hours;

which in Excel is

BS9 = IF(AND(SL-dt(cml)!BS9>0,DT_dt!BS9>0),
SL-dt(cml)!BS9/DT_dt!BS9,"").

File Edit View Insert Format Tools Data Window Help

	BP	BQ	BR	BS	BT	BU	BV	BW	DX	DY
5										
6	Average GBH of each range of W and the corresponding Tdb									
7		W	(lbw/lbda)							
8	Temp (F)	0.0000	0.0005	0.0010	0.0015	0.0020	0.0025	0.0030	0.0295	0.0300
9	20	0	0	113	0	0	0	0	0	0
10	21	0	0	0	10	0	0	0	0	0
11	22	0	0	151	0	0	0	0	0	0
12	23	0	0	0	0	0	0	0	0	0
13	24	0	0	0	0	0	0	0	0	0
14	25	0	0	0	13	0	16	0	0	0
15	26	0	0	178	0	52	0	0	0	0
16	27	0	0	0	0	0	9	0	0	0
17	28	0	0	192	0	36	40	0	0	0
18	29	0	0	0	0	112	11	35	0	0
19	30	0	0	0	12	0	52	0	0	0
20	31	0	0	125	0	86	0	56	0	0
21	32	0	0	57	0	0	68	12	0	0
22	33	0	0	33	62	118	116	0	0	0
92	103	0	0	0	0	0	0	0	0	0
93	104	0	0	0	0	0	0	0	0	0
94	105	0	0	0	0	0	0	0	0	0
95	106	0	0	0	0	0	0	0	0	0
96	107	0	0	0	0	0	0	0	0	0
97	108	0	0	0	0	0	0	0	0	0
98	109	0	0	0	0	0	0	0	0	0
99	110	0	0	0	0	0	0	0	0	0
100	TOTAL	0	0	961	2135.5	2617.167	4197.633	4687.917	0	0

H_dt(NT) / H_dt / C_dt(DT) / C_dt(NT) / C_dt / NHC_dt(DT) / NHC_dt(NT) / NHC_dt / DT_dt / NT_dt / ALL_dt / SL_dt(cml) / **SL_dt(avg)** / 3DT_d

Figure 4.34 *Spreadsheet of the average global horizontal solar radiation (GBH) data analysis for the hot-humid climate of Houston, Texas: amount of the average GBH of each Tdb and the corresponding range of W.*

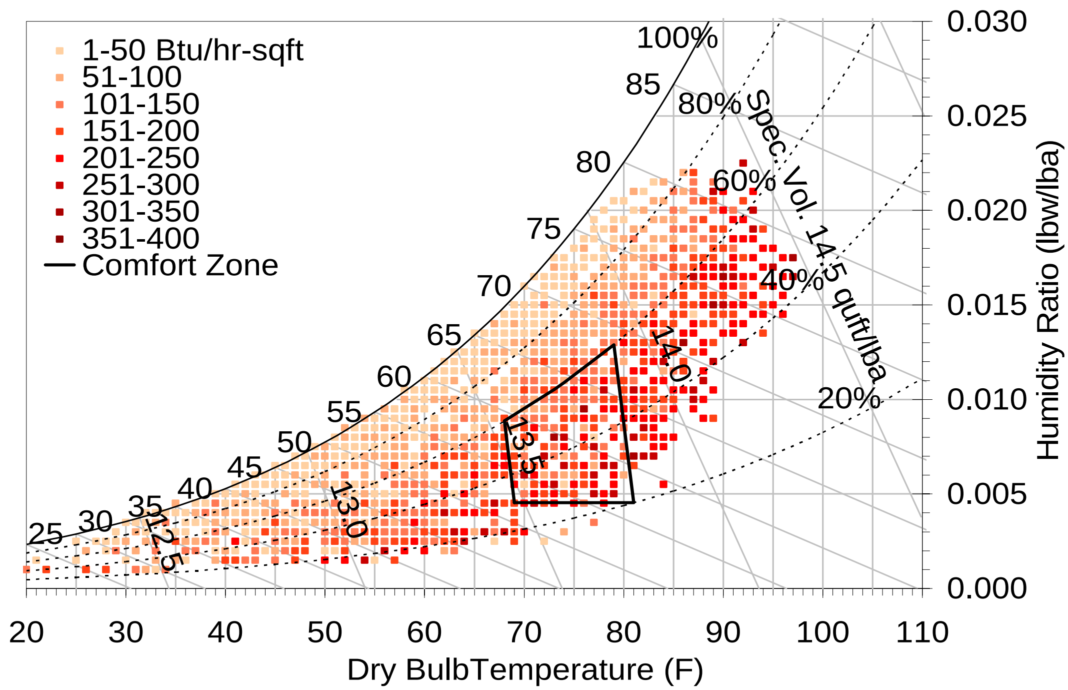


Figure 4.35 *Average global horizontal solar radiation (GBH) data for the hot-humid climate of Houston, Texas, on the psychrometric chart.*

Where "SL-dt(cml)!" is the spreadsheet of the cumulative GBH data and "BS9/DT_dt!" is the spreadsheet of the daytime thermal data density. Figure 4.35 displays the average plot of the GBH data for the hot-humid climate of Houston, Texas, on the psychrometric chart.

4.3.3.2.4 Hourly Average GBH Data

In order to find the relationship of the global horizontal solar radiation (GBH) and the hour of the day, the hourly average GBH data analysis and display tools are developed using similar techniques which are used to develop the average GBH data for the whole year. The only difference is that the GBH data used to develop the tool are not the whole year of data (i.e., all hours from 1 to 24 hours), but are the data for one hour (any hour from 1 to 24) each day of the whole year. For the hours which have both daytime (during sunrise) and nighttime (during sunset) data in one year, the data must be

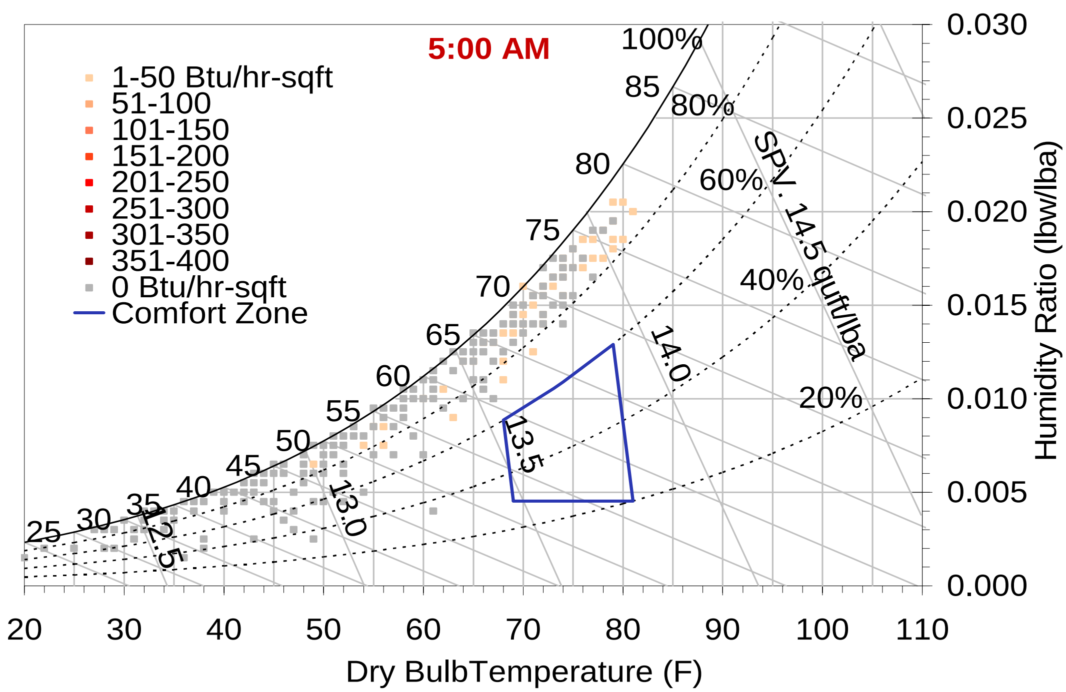


Figure 4.36 *Hourly average global horizontal solar radiation (GBH) plot at 5:00 a.m. for the hot-humid climate of Houston, Texas, on the psychrometric chart.*

presented separately. In this study, a gray color is used to distinguish the nighttime hours from the daytime hours. Figure 4.36 is an example of an hourly average plot of the GBH at 5:00 a.m. for the hot-humid climate of Houston, Texas, on the psychrometric chart.

4.3.3.3 Wind data analysis tools

In this study, wind speed and wind directions were used to indicate the availability of the wind. This study developed the relationship of thermal data and wind speed and then presented the wind speed on the psychrometric chart. The data analysis tools are developed in order to find and present the density, average, and hourly average of the wind speed (see label 3.3C in Figure 4.9). The processes to develop the tools are similar to the processes used to develop the density, average, and hourly average of the global horizontal solar radiation (GBH) data in Section 4.3.3.2.

4.3.3.3.1 Wind Data Density

The wind density plots in this study are the number of hours of the wind which occur in a year at any outdoor conditions. Since, there is wind almost all the time, this type of data is quite similar to the daytime and nighttime thermal density plots in Section 4.3.3.1 (Figure 4.23). Figure 4.37 shows the wind density plot for the hot-humid climate of Houston, Texas, on the psychrometric chart.

4.3.3.3.2 Average Wind Speed Data

The average wind speed in this study is the cumulative wind speed (mph) divided by the number of hours of the occurrence for the whole year of a given outdoor condition. The process to develop the tools for data analysis and display of the average GBH in Section 4.3.3.2 and average wind speed are similar. However, the wind speed extracted from the DOE-2 HOURLY-REPORT is in knots, which had to be converted to mph unit using the equation,

$$\text{mph} = \text{knot} * 1.152. \qquad (4.12)$$

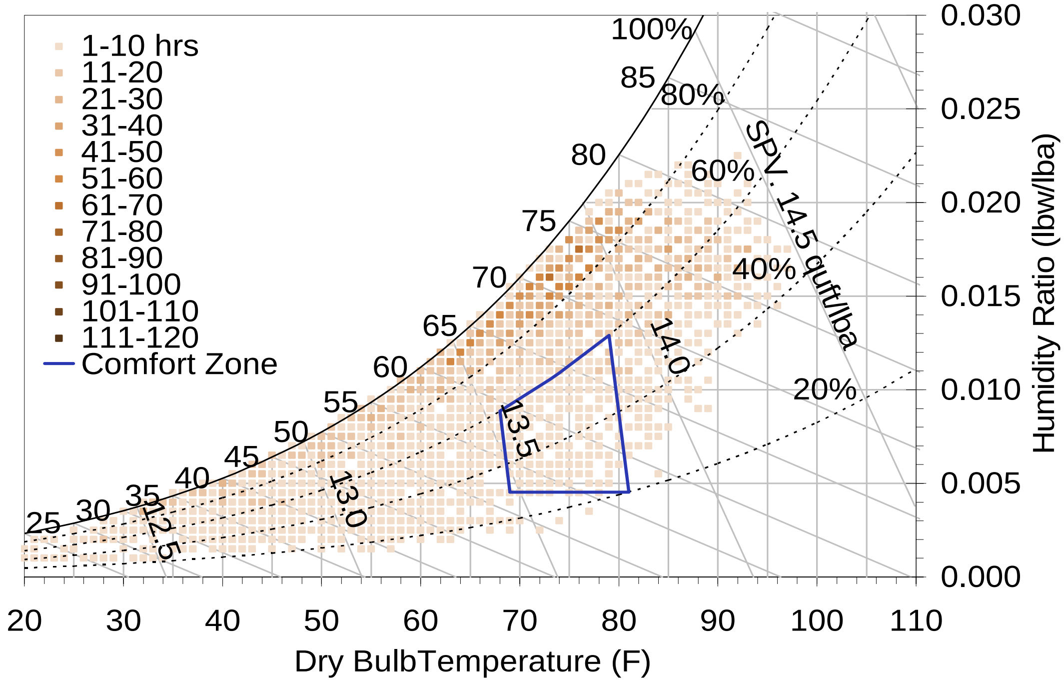


Figure 4.37 *Wind density plot for the hot-humid climate of Houston, Texas, on the psychrometric chart.*

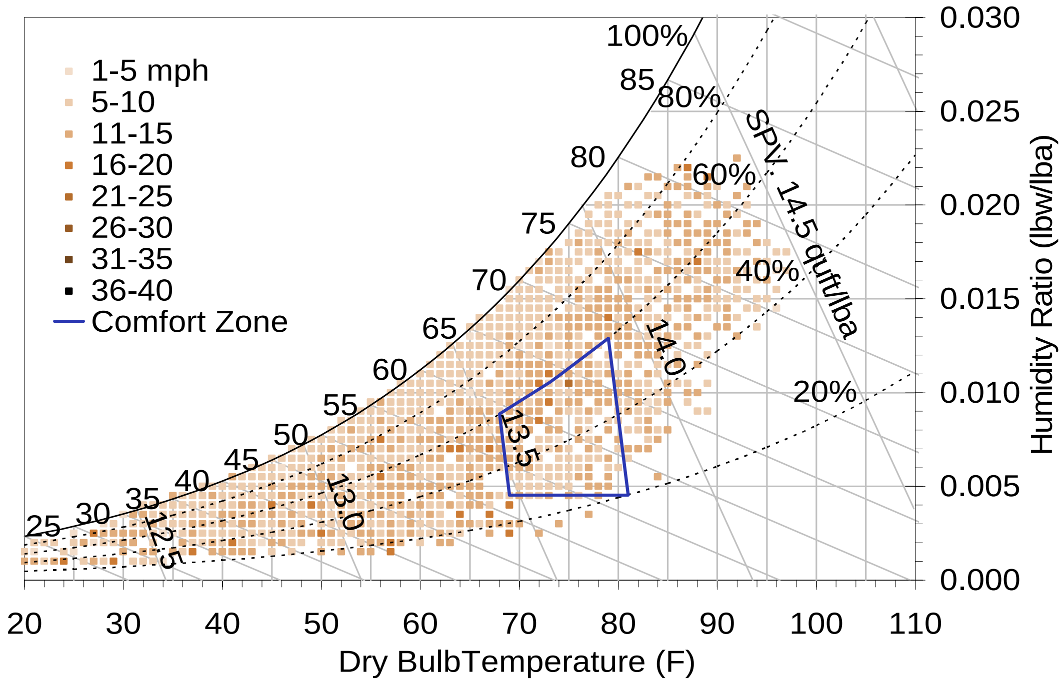


Figure 4.38 *Average wind speed plot for the hot-humid climate of Houston, Texas, on the psychrometric chart.*

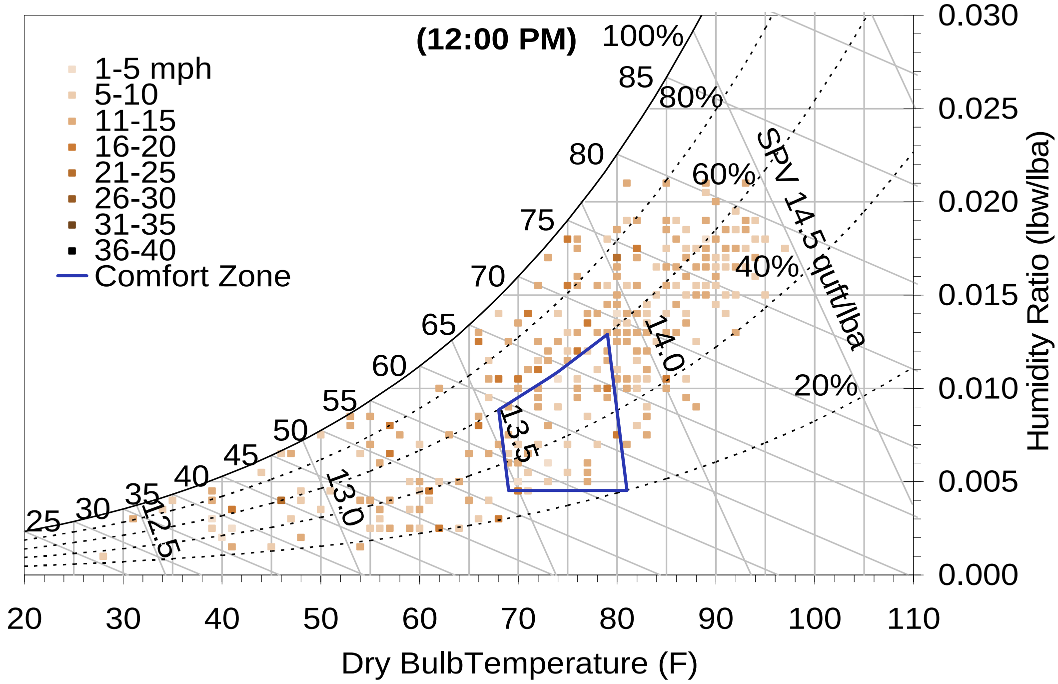


Figure 4.39 *Hourly average wind speed plot at noon for the hot-humid climate of Houston, Texas, on the psychrometric chart.*

Figure 4.38 displays an example of the average wind speed plot for the hot-humid climate of Houston, Texas, on the psychrometric chart.

4.3.3.3.3 Hourly Average Wind Speed Data

In order to find the relationship of the wind speed and the hour of the day, the hourly average wind speed data analysis and display tools were developed using similar techniques used to develop the hourly average GBH data. Figure 4.39 shows an example of an hourly average wind speed plot at noon for the hot-humid climate of Houston, Texas, on the psychrometric chart.

4.4 PROCEDURE FOR ANALYZING AND PROJECTING THE SIMULATION OUTCOMES ONTO THE PSYCHROMETRIC CHART

In order to test the Givoni-Milne bioclimatic chart (1979), simulations of a single-family residence were created with the DOE-2 program and the results were projected onto the G-M Chart. The results of the DOE-2 simulations in Section 4.2.2.2 were analyzed and displayed on the combined plot of the Givoni-Milne design strategies (1979) and the ASHRAE comfort zone (1992). This section describes only the process used for analyzing and displaying one year of data (daytime and nighttime). As similar process was also used to analyze and display the simulation outcomes for daytime and nighttime. Therefore, it is not included in this section.

The process to analyze and display the simulation outcomes includes two main tasks: 1) extracting the simulation results (see label 4.1 in Figure 4.40), and 2) analyzing and projecting the simulation results on the combined chart (see label 4.2 in Figure 4.40). Figure 4.40 shows the steps of the process which were developed using the Excel spreadsheet package (MS Office, 2003). In the figure, the indoor thermal and systems hourly data (label 4.1A and 4.1B, Figure 4.40) and BEPS reports (label 4.1C, Figure 4.40) were extracted from the DOE-2 output. Unlike the BEPS report (Figure 4.41) which is less complicated, the HOURLY-REPORT needs to be extracted and rearranged using the simulation results extraction tool. The extracted simulated data are then used for the analysis. Several simulation analysis tools (label 4.2 A to C, Figure 4.40) were developed to analyze and display the results onto the psychrometric chart and the other graphical displays. This section explains the overall tasks. Detailed descriptions of each step are explained in the following sections.

4.4.1 Extracting the Simulation Results

The DOE-2 simulation results used for the analysis include the HOURLY-REPORT (Figure 4.15) and the Building Energy Performance Summary (BEPS) reports (see label 4.1 in Figure 4.40). The HOURLY-REPORT needed for the analysis include thermal data and systems data. The thermal data used in the study are the indoor dry-bulb temperature (Tdb) and humidity ratio (W). The systems data used for the analysis are the heating and cooling energy usage. The building energy use is important to this study for several reasons. First, the simulated total amounts are compared against those calculated with the G-M bioclimatic chart. Second, the on/off status of the heating and

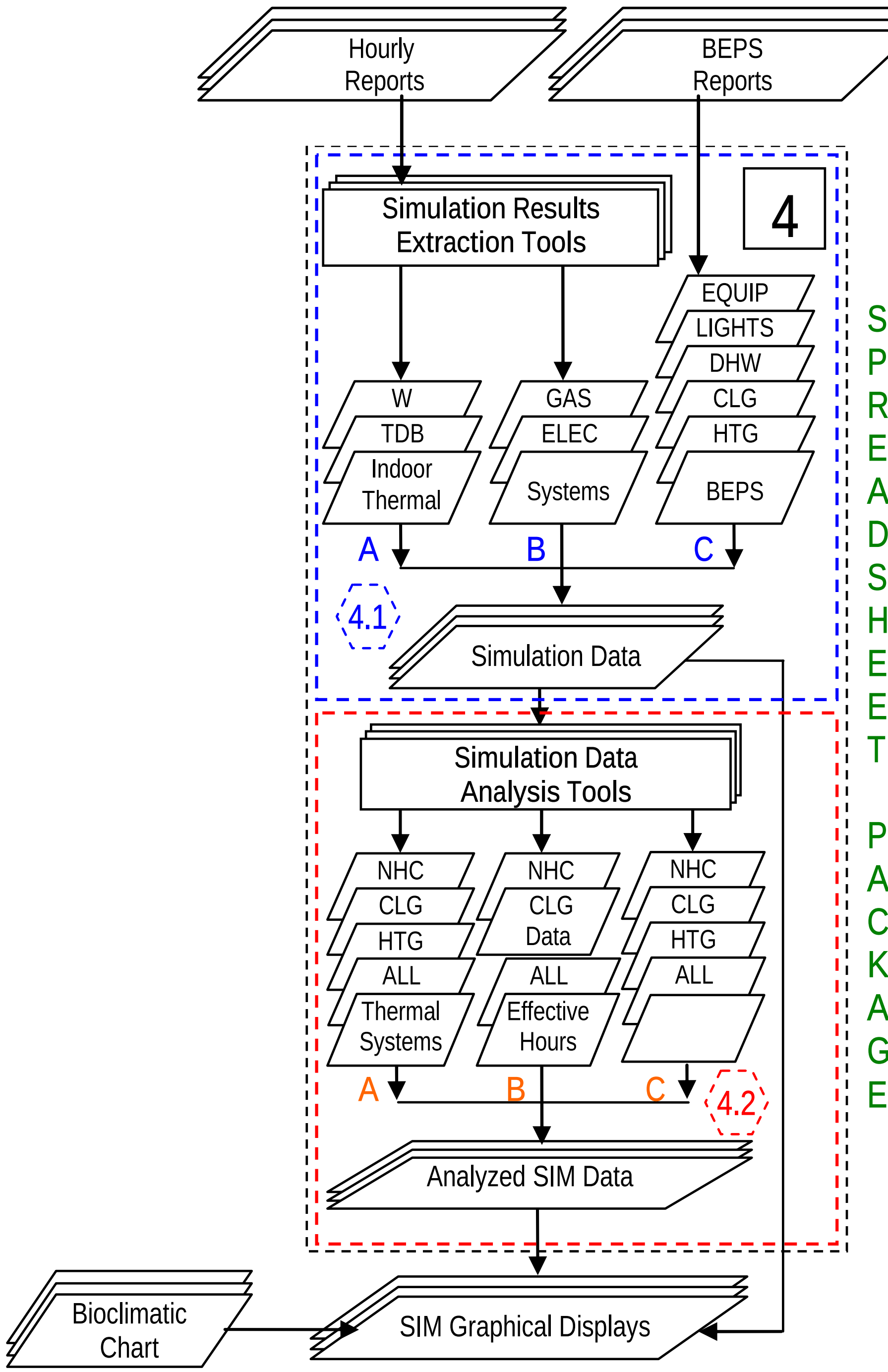


Figure 4.40 *Flowchart of the process for analyzing and projecting the simulation results onto the psychrometric chart.*

cooling systems was used to determine which mode the house was in. The BEPS report indicates the gas and electricity energy usage of the HVAC and lighting systems for the whole year. The reports of each category include: 1) gas consumption of the domestic hot water heater (domestic hot water, DHW); 2) gas consumption of the furnace (space heating); 3) electrical consumption of the cooling equipment (space cooling); 4) electrical consumption of the supply, return, and exhaust fans used to move air into and through the building (ventilation fan); 5) electrical consumption of the pump and

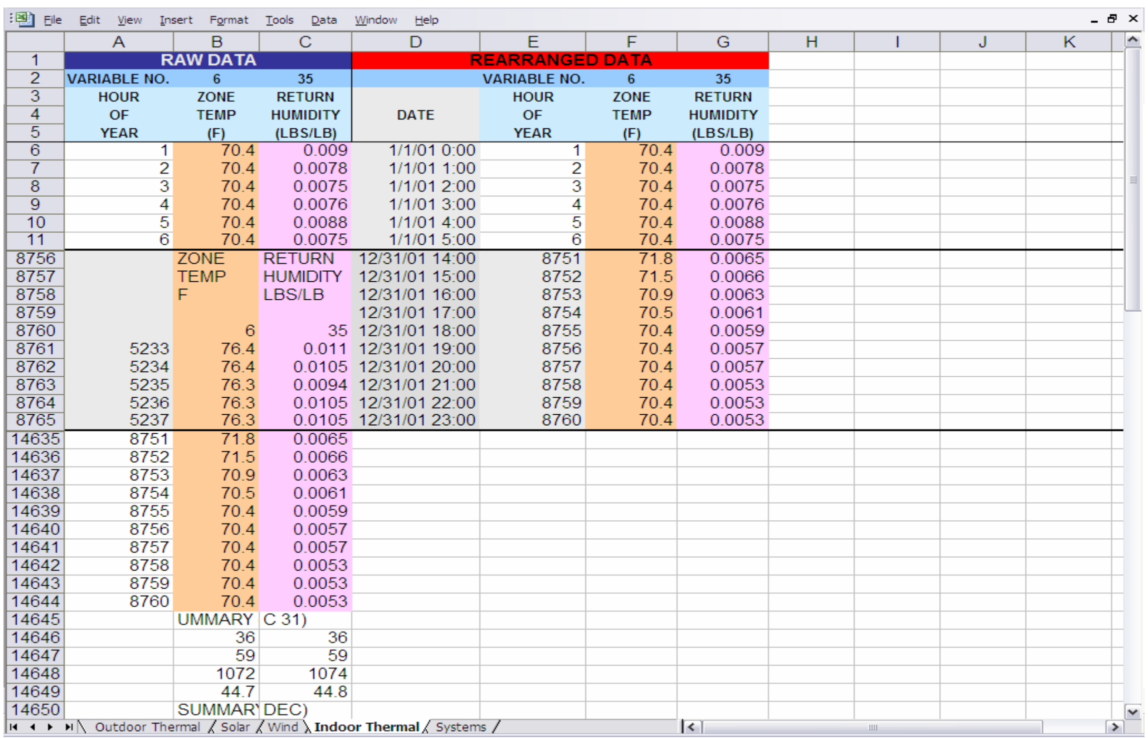
ENERGY TYPE: UNITS: MBTU	ELECTRICITY	NATURAL-GAS
CATEGORY OF USE		
AREA LIGHTS	13.2	0.0
MISC EQUIPMT	13.2	0.0
SPACE HEAT	0.0	14.6
SPACE COOL	25.3	0.0
HEAT REJECT	4.4	0.0
PUMPS & MISC	2.4	0.0
VENT FANS	23.4	0.0
DOMHOT WATER	0.0	11.6
TOTAL	81.8	26.3

Figure 4.41 *Building Energy Performance Summary (BEPS) report of a sample house in the hot-humid climate of Houston, Texas.*

miscellaneous equipment (pump and miscellaneous); 6) electrical consumption of condenser fans (heat rejection); 7) electrical consumption of all household equipment used in the space (miscellaneous equipment); and 8) electrical consumption of all lights except task lighting (area lights). Figure 4.41 is an example of the BEPS report of a sample house in the hot-humid climate of Houston, Texas. The units used in this report are MBtu. The BEPS reports of the prototype houses that are simulated in this study are shown in Appendix B.3.

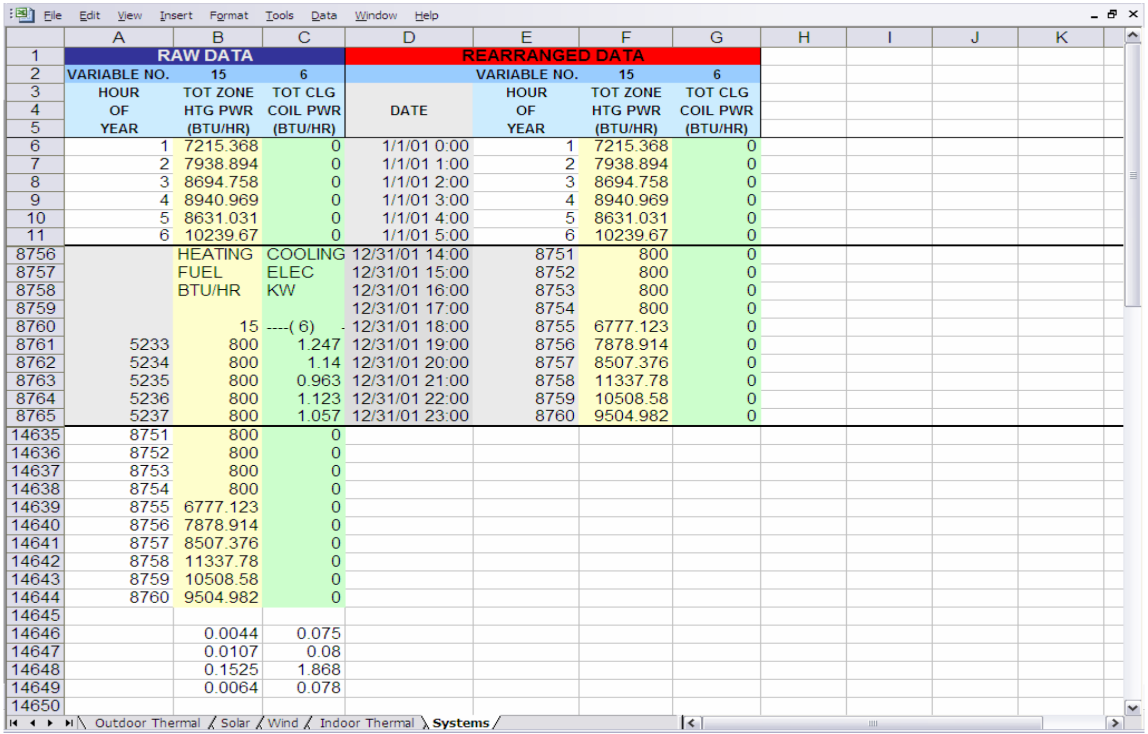
4.4.1.1 Indoor thermal data extraction tool

In order to display and analyze the hourly data from the simulations, the data need to be extracted, and rearranged in the appropriate format. To accomplish this, a simulation data extraction tool was developed to extract and rearrange the data. The



	A	B	C	D	E	F	G
1	RAW DATA			REARRANGED DATA			
2	VARIABLE NO.	6	35		VARIABLE NO.	6	35
3	HOUR	ZONE	RETURN		HOUR	ZONE	RETURN
4	OF	TEMP	HUMIDITY	DATE	OF	TEMP	HUMIDITY
5	YEAR	(F)	(LBS/LB)		YEAR	(F)	(LBS/LB)
6	1	70.4	0.009	1/1/01 0:00	1	70.4	0.009
7	2	70.4	0.0078	1/1/01 1:00	2	70.4	0.0078
8	3	70.4	0.0075	1/1/01 2:00	3	70.4	0.0075
9	4	70.4	0.0076	1/1/01 3:00	4	70.4	0.0076
10	5	70.4	0.0088	1/1/01 4:00	5	70.4	0.0088
11	6	70.4	0.0075	1/1/01 5:00	6	70.4	0.0075
8756		ZONE	RETURN	12/31/01 14:00	8751	71.8	0.0065
8757		TEMP	HUMIDITY	12/31/01 15:00	8752	71.5	0.0066
8758		F	LBS/LB	12/31/01 16:00	8753	70.9	0.0063
8759				12/31/01 17:00	8754	70.5	0.0061
8760		6	35	12/31/01 18:00	8755	70.4	0.0059
8761	5233	76.4	0.011	12/31/01 19:00	8756	70.4	0.0057
8762	5234	76.4	0.0105	12/31/01 20:00	8757	70.4	0.0057
8763	5235	76.3	0.0094	12/31/01 21:00	8758	70.4	0.0053
8764	5236	76.3	0.0105	12/31/01 22:00	8759	70.4	0.0053
8765	5237	76.3	0.0105	12/31/01 23:00	8760	70.4	0.0053
14635	8751	71.8	0.0065				
14636	8752	71.5	0.0066				
14637	8753	70.9	0.0063				
14638	8754	70.5	0.0061				
14639	8755	70.4	0.0059				
14640	8756	70.4	0.0057				
14641	8757	70.4	0.0057				
14642	8758	70.4	0.0053				
14643	8759	70.4	0.0053				
14644	8760	70.4	0.0053				
14645		UMMARY	C 31)				
14646		36	36				
14647		59	59				
14648		1072	1074				
14649		44.7	44.8				
14650		SUMMARY	DEC)				

Figure 4.42 *Annual (daytime and nighttime) hourly indoor thermal data extraction and rearrangement spreadsheet (at the top, the middle, and the end of the data) of a sample house in the hot-humid climate of Houston, Texas.*



	A	B	C	D	E	F	G
1	RAW DATA			REARRANGED DATA			
2	VARIABLE NO.	15	6		VARIABLE NO.	15	6
3	HOUR	TOT ZONE	TOT CLG		HOUR	TOT ZONE	TOT CLG
4	OF	HTG PWR	COIL PWR	DATE	OF	HTG PWR	COIL PWR
5	YEAR	(BTU/HR)	(BTU/HR)		YEAR	(BTU/HR)	(BTU/HR)
6	1	7215.368	0	1/1/01 0:00	1	7215.368	0
7	2	7938.894	0	1/1/01 1:00	2	7938.894	0
8	3	8694.758	0	1/1/01 2:00	3	8694.758	0
9	4	8940.969	0	1/1/01 3:00	4	8940.969	0
10	5	8631.031	0	1/1/01 4:00	5	8631.031	0
11	6	10239.67	0	1/1/01 5:00	6	10239.67	0
8756		HEATING	COOLING	12/31/01 14:00	8751	800	0
8757		FUEL	ELEC	12/31/01 15:00	8752	800	0
8758		BTU/HR	KW	12/31/01 16:00	8753	800	0
8759				12/31/01 17:00	8754	800	0
8760		15	----(6) -	12/31/01 18:00	8755	6777.123	0
8761	5233	800	1.247	12/31/01 19:00	8756	7878.914	0
8762	5234	800	1.14	12/31/01 20:00	8757	8507.376	0
8763	5235	800	0.963	12/31/01 21:00	8758	11337.78	0
8764	5236	800	1.123	12/31/01 22:00	8759	10508.58	0
8765	5237	800	1.057	12/31/01 23:00	8760	9504.982	0
14635	8751	800	0				
14636	8752	800	0				
14637	8753	800	0				
14638	8754	800	0				
14639	8755	6777.123	0				
14640	8756	7878.914	0				
14641	8757	8507.376	0				
14642	8758	11337.78	0				
14643	8759	10508.58	0				
14644	8760	9504.982	0				
14645							
14646		0.0044	0.075				
14647		0.0107	0.08				
14648		0.1525	1.868				
14649		0.0064	0.078				
14650							

Figure 4.43 *Annual (daytime and nighttime) hourly systems data extraction and rearrangement spreadsheet (at the top, the middle, and the end of the data) of a sample house in the hot-humid climate of Houston, Texas..*

process to develop the extraction tool for the simulation data was similar to the weather data (Section 4.3.2.1., Figure 4.16). Figure 4.42 shows an example of one year (daytime and nighttime) of data, hourly indoor thermal data extraction and rearrangement spreadsheet of a sample house in the hot-humid climate of Houston, Texas. Columns B and C are the indoor dry-bulb temperature (Tdb, °F) and indoor humidity ratio (W, lbw/lba) extracted raw data from the DOE-2 HOURLY-REPORT. columns F and G are the rearranged data for the indoor Tdb and W (see label 4.1A in Figure 4.40).

4.4.1.2 DOE-2 systems data extraction tool

The process used for developing the system data extraction tool is similar to the indoor thermal data extraction tool. Figure 4.43 shows an example of a whole year (daytime and nighttime) of hourly systems data of a sample house in the hot-humid climate of Houston, Texas. Columns B and C are the heating and cooling energy use (Btu/hr) extracted raw data from the DOE-2 HOURLY-REPORT. Columns F and G are the rearranged data of the heating and cooling energy use (see label 4.1B in Figure 4.40).

4.4.2 Analyzing and Projecting the Simulation Results onto the Psychrometric Chart

Annual data (daytime and nighttime) from the previous step (Section 4.4.1) are analyzed and displayed in several plots such as time-series plots, x-y plots, three-dimensional plots, bar charts, and psychrometric plots. This research has also developed new techniques to present the simulation data on the psychrometric chart. Several data analysis tools which were developed, using the MS Excel program, to present the annual simulation data on the psychrometric charts are demonstrated in this section. The types of tools are: 1) thermal and systems data analysis tools (see label 4.2A in Figure 4.40), 2) design strategy effective hours counting tools (see label 4.2B in Figure 4.40), and 3) comparison tables of the results from the G-M bioclimatic chart (1979) and the results from the DOE-2 simulations (see label 4.2C in Figure 4.40).

In the analysis, the systems data which indicate the activations of the heating and cooling systems are used in relation with the indoor and outdoor conditions. Using the indoor and outdoor thermal data analysis tools (see Section 4.2.2.1), the density plots of the outdoor conditions and the data of the indoor comfort conditions during the systems activation periods are then analyzed and projected onto the G-M design strategy boundaries (1979) and the ASHRAE comfort zone (1992) combined chart. Next, the design strategy hours are counted (see Section 4.2.2.2) to calculate the effective periods of each design strategy. Comparisons are then presented for the proposed work and the G-M bioclimatic chart.

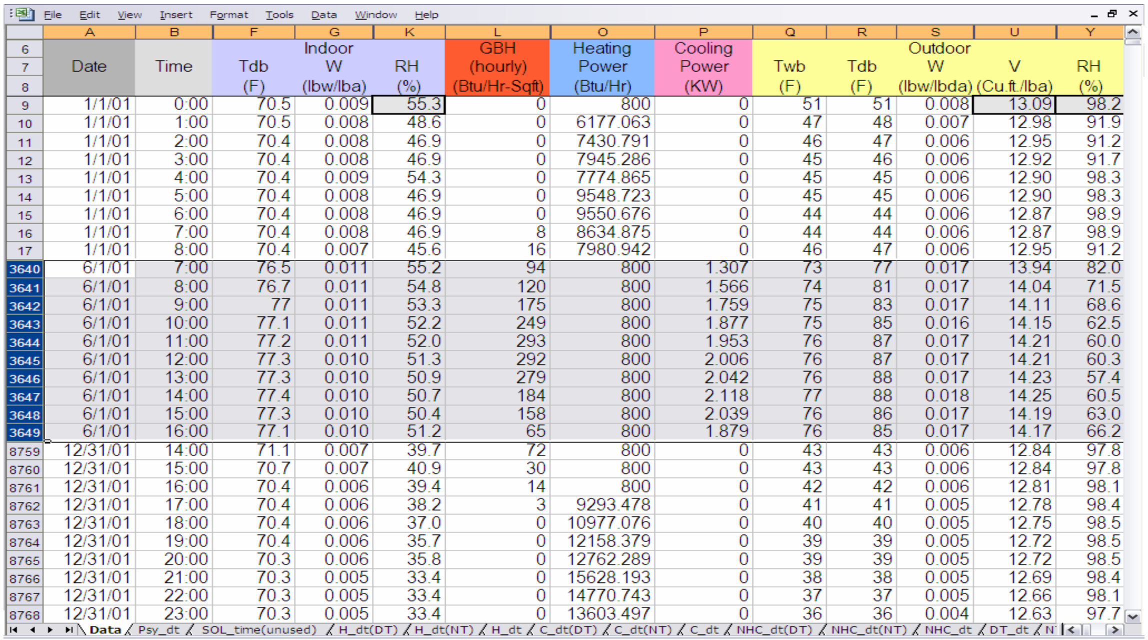
4.4.2.1 Thermal and systems data analysis tools

The extracted simulation data for the indoor thermal and systems (Section 4.4.1.1) are used with the extracted TMY2 weather data (Section 4.3.2). These data are then be used for the analysis in the next step (Section 4.4.2.2). Therefore; the additional data required for the next step are prepared in this step. These data are the indoor (see column K, Figure 4.44) outdoor relative humidity (RH) (see column Y, Figure 4.44) and the specific volume of the outdoor air. The RH is calculated using equations (4.4 through 4.6) and the specific volume of the air (see column U, Figure 4.44) is calculated using the equations (4.3), and (4.8 through 4.11).

The thermal and systems data analysis tools are developed to find the indoor conditions and the data density dots of the outdoor conditions during the heating, cooling, and non-heating-cooling periods, which are the frequency of the occurrence of outdoor conditions when the heating and cooling systems are activated or inactivated. The data density analysis is very useful for the outdoor conditions. However, it is less useful for the indoor conditions in this study, which are thermostatically controlled resulting in a tighter packing at the data. Therefore, standard scatter plots (i.e., without the data density coloring) are used for the indoor conditions in this study. In this way, the thermal and systems data analysis tools ploted the indoor conditions and outdoor conditions on the G-M design chart (1979) and the ASHRAE comfort zone (1992) combined chart. In the next section, the steps for developing the thermal and systems data analysis tools for all periods, heating period, cooling period, and non-heating-cooling period are explained.

4.4.2.1.1 All Periods

The process to develop a tool for the thermal and systems analysis for all periods is quite similar to the process for developing a tool for the whole year weather data (Section 4.3.3.1, Figure 4.20 to Figure 4.22) except that additional data are needed for the analysis are included in the spreadsheet Figure 4.44 shows the first step of the analysis spreadsheet where the indoor and outdoor conditions and the heating and cooling systems data are located. To accomplish this, a “Data” spreadsheet was developed. Columns A, B, F, G, K, L, O, P, Q, R, S, U, and Y include the date, time, indoor dry-bulb temperature (Tdb), indoor humidity ration (W), indoor relative humidity



	A	B	F	G	K	L	O	P	Q	R	S	U	Y
6–8	Date	Time	Indoor Tdb (F)	Indoor W (lbw/lba)	Indoor RH (%)	GBH (hourly) (Btu/Hr-Sqft)	Heating Power (Btu/Hr)	Cooling Power (KW)	Outdoor Twb (F)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)	Outdoor V (Cu.ft./lba)	Outdoor RH (%)
9	1/1/01	0:00	70.5	0.009	55.3	0	800	0	51	51	0.008	13.09	98.2
10	1/1/01	1:00	70.5	0.008	48.6	0	6177.063	0	47	48	0.007	12.98	91.9
11	1/1/01	2:00	70.4	0.008	46.9	0	7430.791	0	46	47	0.006	12.95	91.2
12	1/1/01	3:00	70.4	0.008	46.9	0	7945.286	0	45	46	0.006	12.92	91.7
13	1/1/01	4:00	70.4	0.009	54.3	0	7774.865	0	45	45	0.006	12.90	98.3
14	1/1/01	5:00	70.4	0.008	46.9	0	9548.723	0	45	45	0.006	12.90	98.3
15	1/1/01	6:00	70.4	0.008	46.9	0	9550.676	0	44	44	0.006	12.87	98.9
16	1/1/01	7:00	70.4	0.008	46.9	8	8634.875	0	44	44	0.006	12.87	98.9
17	1/1/01	8:00	70.4	0.007	45.6	16	7980.942	0	46	47	0.006	12.95	91.2
3640	6/1/01	7:00	76.5	0.011	55.2	94	800	1.307	73	77	0.017	13.94	82.0
3641	6/1/01	8:00	76.7	0.011	54.8	120	800	1.566	74	81	0.017	14.04	71.5
3642	6/1/01	9:00	77	0.011	53.3	175	800	1.759	75	83	0.017	14.11	68.6
3643	6/1/01	10:00	77.1	0.011	52.2	249	800	1.877	75	85	0.016	14.15	62.5
3644	6/1/01	11:00	77.2	0.011	52.0	293	800	1.953	76	87	0.017	14.21	60.0
3645	6/1/01	12:00	77.3	0.010	51.3	292	800	2.006	76	87	0.017	14.21	60.3
3646	6/1/01	13:00	77.3	0.010	50.9	279	800	2.042	76	88	0.017	14.23	57.4
3647	6/1/01	14:00	77.4	0.010	50.7	184	800	2.118	77	88	0.018	14.25	60.5
3648	6/1/01	15:00	77.3	0.010	50.4	158	800	2.039	76	86	0.017	14.19	63.0
3649	6/1/01	16:00	77.1	0.010	51.2	65	800	1.879	76	85	0.017	14.17	66.2
8759	12/31/01	14:00	71.1	0.007	39.7	72	800	0	43	43	0.006	12.84	97.8
8760	12/31/01	15:00	70.7	0.007	40.9	30	800	0	43	43	0.006	12.84	97.8
8761	12/31/01	16:00	70.4	0.006	39.4	14	800	0	42	42	0.006	12.81	98.1
8762	12/31/01	17:00	70.4	0.006	38.2	3	9293.478	0	41	41	0.005	12.78	98.4
8763	12/31/01	18:00	70.4	0.006	37.0	0	10977.076	0	40	40	0.005	12.75	98.5
8764	12/31/01	19:00	70.4	0.006	35.7	0	12158.379	0	39	39	0.005	12.72	98.5
8765	12/31/01	20:00	70.3	0.006	35.8	0	12762.289	0	39	39	0.005	12.72	98.5
8766	12/31/01	21:00	70.3	0.005	33.4	0	15628.193	0	38	38	0.005	12.69	98.4
8767	12/31/01	22:00	70.3	0.005	33.4	0	14770.743	0	37	37	0.005	12.66	98.1
8768	12/31/01	23:00	70.3	0.005	33.4	0	13603.497	0	36	36	0.004	12.63	97.7

Figure 4.44 *The "All periods" simulation data analysis spreadsheet of a sample house in the hot-humid climate of Houston, Texas: raw data and calculated data.*

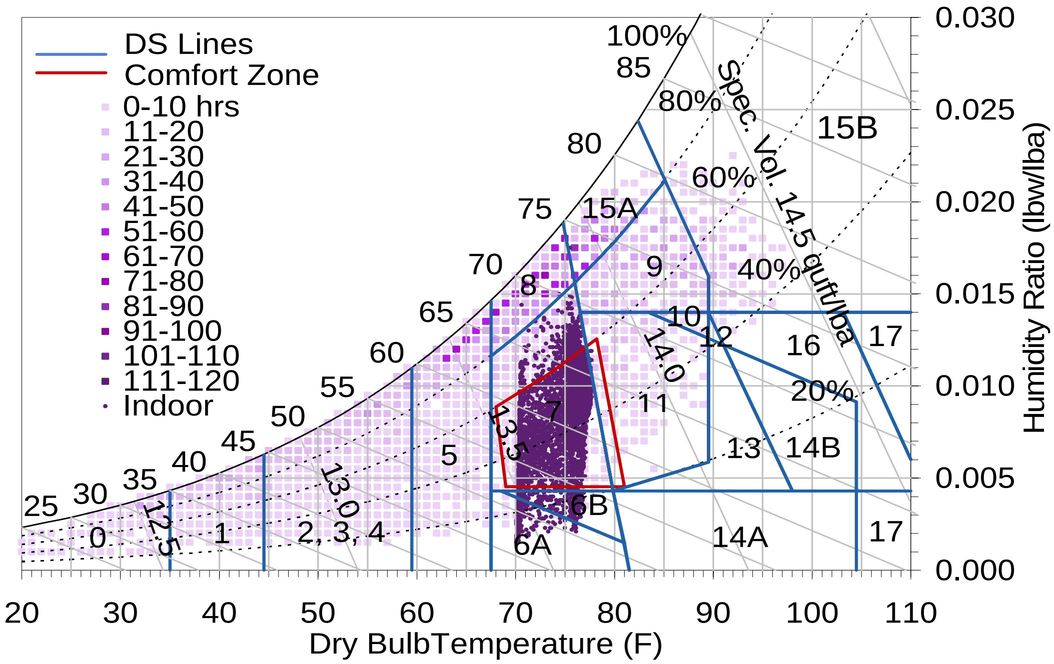


Figure 4.45 *The "All periods" simulation data of a sample house in the hot-humid climate of Houston, Texas, on the psychrometric chart.*

(RH), global horizontal solar radiation (GBH), heating energy use, cooling energy use, outdoor wet-bulb temperature (Twb), outdoor dry-bulb temperature (Tdb), outdoor humidity ratio (W), outdoor specific volume (V), and outdoor relative humidity (RH); respectively. The next steps are to extract and develop the outdoor data density plots by repeating the steps (steps c through i), which were demonstrated in Section 4.3.3.1. Finally, plot the indoor simulated conditions onto the chart using small purple dots. Figure 4.45 displays the "All periods" simulation data of a sample house in the hot-humid climate of Houston, Texas, on the psychrometric chart.

4.4.2.1.2 Heating Period

In order to develop the data for the heating period, the indoor and outdoor dry-bulb temperatures (Tdb) and humidity ratio (W) of the period when the heating system was activated were extracted from the annual data. These data represent those times when the heating energy use was more than 800 (Btu/hr), which is the amount of the energy used for a pilot light of the heating system. In addition to the previous analysis, four more columns are added in the "Data" spreadsheet (Figure 4.46). The new columns from AH through AK are the indoor dry-bulb temperature (Tdb) and humidity ratio (W) and the outdoor dry-bulb temperature (Tdb) and humidity ratio (W), respectively. Examples (see Figure 4.46) of the functions used to extract the data from cells F10 (indoor dry-bulb temperature, Tdb, 70.5 °F) and R10 (outdoor dry-bulb temperature, Tdb, 48 °F) at the corresponding heating energy use (cell O10, 6177 Btu/hr) and then insert the data into cells AH10 and AJ10 are:

> Indoor dry-bulb temperature (Tdb) = If heating energy use (6177) > 800, then indoor dry-bulb temperature (Tdb, 70.5), otherwise "-99" and

> Outdoor dry-bulb temperature (Tdb) = If heating energy use (6177) > 800, then outdoor dry-bulb temperature (Tdb, 48), otherwise "-99";

	A	B	F	G	K	L	O	P	Q	R	S	U	Y	AH	AI	AJ	AK
6			Indoor			GBH	Heating	Cooling			Outdoor			HTG Period		HTG Period	
7	Date	Time	Tdb	W	RH	(hourly)	Power	Power	Twb	Tdb	W	V	RH	Indoor		Outdoor	
8			(F)	(lbw/lba)	(%)	(Btu/Hr-Sqft)	(Btu/Hr)	(KW)	(F)	(F)	(lbw/lbda)	(Cu.ft./lba)	(%)	Tdb	W	Tdb	W
9	1/1/01	0:00	70.5	0.009	55.3	0	800	0	51	51	0.008	13.09	98.2	-99	-99	-99	-99
10	1/1/01	1:00	70.5	0.008	48.6	0	6177	0	47	48	0.007	12.98	91.9	70.5	0.008	48	0.007
11	1/1/01	2:00	70.4	0.008	46.9	0	7431	0	46	47	0.006	12.95	91.2	70.4	0.008	47	0.006
12	1/1/01	3:00	70.4	0.008	46.9	0	7945	0	45	46	0.006	12.92	91.7	70.4	0.008	46	0.006
13	1/1/01	4:00	70.4	0.009	54.3	0	7775	0	45	45	0.006	12.90	98.3	70.4	0.009	45	0.006
14	1/1/01	5:00	70.4	0.008	46.9	0	9549	0	45	45	0.006	12.90	98.3	70.4	0.008	45	0.006
15	1/1/01	6:00	70.4	0.008	46.9	0	9551	0	44	44	0.006	12.87	98.9	70.4	0.008	44	0.006
16	1/1/01	7:00	70.4	0.008	46.9	8	8635	0	44	44	0.006	12.87	98.9	70.4	0.008	44	0.006
17	1/1/01	8:00	70.4	0.007	45.6	16	7981	0	46	47	0.006	12.95	91.2	70.4	0.007	47	0.006
3640	6/1/01	7:00	76.5	0.011	55.2	94	800	1.307	73	77	0.017	13.94	82.0	-99	-99	-99	-99
3641	6/1/01	8:00	76.7	0.011	54.8	120	800	1.566	74	81	0.017	14.04	71.5	-99	-99	-99	-99
3642	6/1/01	9:00	77	0.011	53.3	175	800	1.759	75	83	0.017	14.11	68.6	-99	-99	-99	-99
3643	6/1/01	10:00	77.1	0.011	52.2	249	800	1.877	75	85	0.016	14.15	62.5	-99	-99	-99	-99
3644	6/1/01	11:00	77.2	0.011	52.0	293	800	1.953	76	87	0.017	14.21	60.0	-99	-99	-99	-99
3645	6/1/01	12:00	77.3	0.01	51.3	292	800	2.006	76	87	0.017	14.21	60.3	-99	-99	-99	-99
3646	6/1/01	13:00	77.3	0.01	50.9	279	800	2.042	76	88	0.017	14.23	57.4	-99	-99	-99	-99
3647	6/1/01	14:00	77.4	0.01	50.7	184	800	2.118	77	88	0.018	14.25	60.5	-99	-99	-99	-99
3648	6/1/01	15:00	77.3	0.01	50.4	158	800	2.039	76	86	0.017	14.19	63.0	-99	-99	-99	-99
3649	6/1/01	16:00	77.1	0.01	51.2	65	800	1.879	76	85	0.017	14.17	66.2	-99	-99	-99	-99
8759	12/31/01	14:00	71.1	0.007	39.7	72	800	0	43	43	0.006	12.84	97.8	-99	-99	-99	-99
8760	12/31/01	15:00	70.7	0.007	40.9	30	800	0	43	43	0.006	12.84	97.8	-99	-99	-99	-99
8761	12/31/01	16:00	70.4	0.006	39.4	14	800	0	42	42	0.006	12.81	98.1	-99	-99	-99	-99
8762	12/31/01	17:00	70.4	0.006	38.2	3	9293	0	41	41	0.005	12.78	98.4	70.4	0.006	41	0.005
8763	12/31/01	18:00	70.4	0.006	37.0	0	10977	0	40	40	0.005	12.75	98.5	70.4	0.006	40	0.005
8764	12/31/01	19:00	70.4	0.006	35.7	0	12158	0	39	39	0.005	12.72	98.5	70.4	0.006	39	0.005
8765	12/31/01	20:00	70.3	0.006	35.8	0	12762	0	39	39	0.005	12.72	98.5	70.3	0.006	39	0.005
8766	12/31/01	21:00	70.3	0.005	33.4	0	15628	0	38	38	0.005	12.69	98.4	70.3	0.005	38	0.005
8767	12/31/01	22:00	70.3	0.005	33.4	0	14771	0	37	37	0.005	12.66	98.1	70.3	0.005	37	0.005
8768	12/31/01	23:00	70.3	0.005	33.4	0	13603	0	36	36	0.004	12.63	97.7	70.3	0.005	36	0.004

Data / Psy_dt / SOL_time(unused) / H_dt(DT) / H_dt(NT) / H_dt / C_dt(DT) / C_dt(NT) / C_dt / NHC_dt(DT) / NHC_dt(NT) / NHC_dt / DT_dt

Figure 4.46 *Heating period simulation data analysis spreadsheet of a sample house in the hot-humid climate of Houston, Texas: raw data and calculated.*

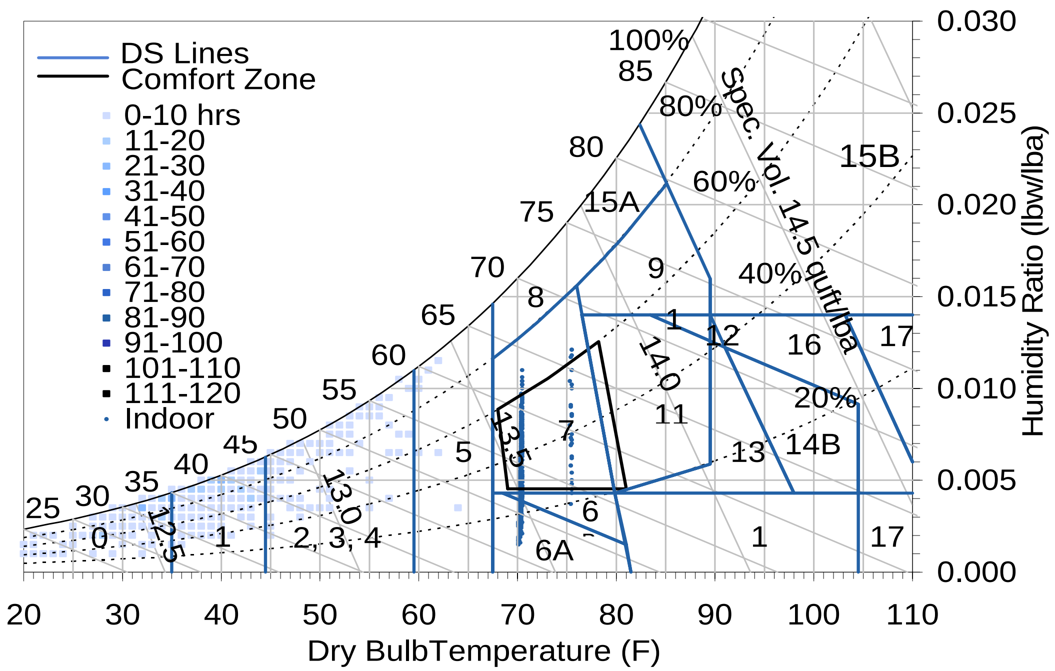


Figure 4.47 *Heating period simulation data of a sample house in the hot-humid climate of Houston, Texas, on the psychrometric chart.*

which in Excel are

AH10 = IF(O10>800,F10,-99) and

AJ10 = IF(O10>800,R10,-99).

The next steps are to develop the outdoor data density plots during the heating period by repeating steps (steps c through i) in Section 4.3.3.1. Finally, plot the heating period indoor simulated conditions onto the chart using small blue dots. Figure 4.47 displays the heating period simulation data of a sample house in the hot-humid climate of Houston, Texas, on the psychrometric chart.

4.4.2.1.3 Cooling Period

In order to develop the data for the cooling period, the indoor and outdoor dry-bulb temperatures (Tdb) and humidity ration (W) of the period, when the cooling system was activated or when the cooling energy use was more than zero (kW), needed to be extracted from one year simulated data. Four more columns were added in the "Data" spreadsheet (Figure 4.48). The new columns from AL through AO are the indoor dry-bulb temperature (Tdb) and humidity ratio (W) and the outdoor dry-bulb temperature (Tdb) and humidity ratio (W), respectively. Examples (see Figure 4.48) of the functions used to extract data from cells F3640 (indoor dry-bulb temperature, Tdb, 76.5 °F) and R3640 (outdoor dry-bulb temperature, Tdb, 77 °F) at the corresponding cooling energy use (cell P3640, 1.307 kW) and then insert the data into cells AL3640 and AN3640 are:

Indoor dry-bulb temperature (Tdb) = If cooling energy use (1.307) > 0, then indoor dry-bulb temperature (Tdb, 76.5), otherwise "-99" and

Outdoor dry-bulb temperature (Tdb) = If cooling energy use (1.307) > 0, then outdoor dry-bulb temperature (Tdb, 77), otherwise "-99";

	A	B	F	G	K	L	O	P	Q	R	S	U	Y	AL	AM	AN	AO
6				Indoor		GBH	Heating	Cooling			Outdoor			CLG Period		CLG Period	
7	Date	Time	Tdb	W	RH	(hourly)	Power	Power	Twb	Tdb	W	V	RH	Indoor		Outdoor	
8			(F)	(lbw/lba)	(%)	(Btu/Hr-Sqft)	(Btu/Hr)	(KW)	(F)	(F)	(lbw/lbda)	(Cu.ft./lba)	(%)	Tdb	W	Tdb	W
9	1/1/01	0:00	70.5	0.009	55.3	0	800	0	51	51	0.008	13.09	98.2	-99	-99	-99	-99
10	1/1/01	1:00	70.5	0.008	48.6	0	6177	0	47	48	0.007	12.98	91.9	-99	-99	-99	-99
11	1/1/01	2:00	70.4	0.008	46.9	0	7431	0	46	47	0.006	12.95	91.2	-99	-99	-99	-99
12	1/1/01	3:00	70.4	0.008	46.9	0	7945	0	45	46	0.006	12.92	91.7	-99	-99	-99	-99
13	1/1/01	4:00	70.4	0.009	54.3	0	7775	0	45	45	0.006	12.90	98.3	-99	-99	-99	-99
14	1/1/01	5:00	70.4	0.008	46.9	0	9549	0	45	45	0.006	12.90	98.3	-99	-99	-99	-99
15	1/1/01	6:00	70.4	0.008	46.9	0	9551	0	44	44	0.006	12.87	98.9	-99	-99	-99	-99
16	1/1/01	7:00	70.4	0.008	46.9	8	8635	0	44	44	0.006	12.87	98.9	-99	-99	-99	-99
17	1/1/01	8:00	70.4	0.007	45.6	16	7981	0	46	47	0.006	12.95	91.2	-99	-99	-99	-99
3640	6/1/01	7:00	76.5	0.011	55.2	94	800	1.307	73	77	0.017	13.94	82.0	76.5	0.011	77	0.017
3641	6/1/01	8:00	76.7	0.011	54.8	120	800	1.566	74	81	0.017	14.04	71.5	76.7	0.011	81	0.017
3642	6/1/01	9:00	77	0.011	53.3	175	800	1.759	75	83	0.017	14.11	68.6	77	0.011	83	0.017
3643	6/1/01	10:00	77.1	0.011	52.2	249	800	1.877	75	85	0.016	14.15	62.5	77.1	0.011	85	0.016
3644	6/1/01	11:00	77.2	0.011	52.0	293	800	1.953	76	87	0.017	14.21	60.0	77.2	0.011	87	0.017
3645	6/1/01	12:00	77.3	0.01	51.3	292	800	2.006	76	87	0.017	14.21	60.3	77.3	0.01	87	0.017
3646	6/1/01	13:00	77.3	0.01	50.9	279	800	2.042	76	88	0.017	14.23	57.4	77.3	0.01	88	0.017
3647	6/1/01	14:00	77.4	0.01	50.7	184	800	2.118	77	88	0.018	14.25	60.5	77.4	0.01	88	0.018
3648	6/1/01	15:00	77.3	0.01	50.4	158	800	2.039	76	86	0.017	14.19	63.0	77.3	0.01	86	0.017
3649	6/1/01	16:00	77.1	0.01	51.2	65	800	1.879	76	85	0.017	14.17	66.2	77.1	0.01	85	0.017
8759	12/31/01	14:00	71.1	0.007	39.7	72	800	0	43	43	0.006	12.84	97.8	-99	-99	-99	-99
8760	12/31/01	15:00	70.7	0.007	40.9	30	800	0	43	43	0.006	12.84	97.8	-99	-99	-99	-99
8761	12/31/01	16:00	70.4	0.006	39.4	14	800	0	42	42	0.006	12.81	98.1	-99	-99	-99	-99
8762	12/31/01	17:00	70.4	0.006	38.2	3	9293	0	41	41	0.005	12.78	98.4	-99	-99	-99	-99
8763	12/31/01	18:00	70.4	0.006	37.0	0	10977	0	40	40	0.005	12.75	98.5	-99	-99	-99	-99
8764	12/31/01	19:00	70.4	0.006	35.7	0	12158	0	39	39	0.005	12.72	98.5	-99	-99	-99	-99
8765	12/31/01	20:00	70.3	0.006	35.8	0	12762	0	39	39	0.005	12.72	98.5	-99	-99	-99	-99
8766	12/31/01	21:00	70.3	0.005	33.4	0	15628	0	38	38	0.005	12.69	98.4	-99	-99	-99	-99
8767	12/31/01	22:00	70.3	0.005	33.4	0	14771	0	37	37	0.005	12.66	98.1	-99	-99	-99	-99
8768	12/31/01	23:00	70.3	0.005	33.4	0	13603	0	36	36	0.004	12.63	97.7	-99	-99	-99	-99

File Edit View Insert Format Tools Data Window Help

Data / Psy_dt / SOL_time(unused) / H_dt(DT) / H_dt(NT) / H_dt / C_dt(DT) / C_dt(NT) / C_dt / NHC_dt(DT) / NHC_dt(NT) / NHC_dt / DT_dt / N

Figure 4.48 *Cooling period simulation data analysis spreadsheet of a sample house in the hot-humid climate of Houston, Texas: raw data and calculated data.*

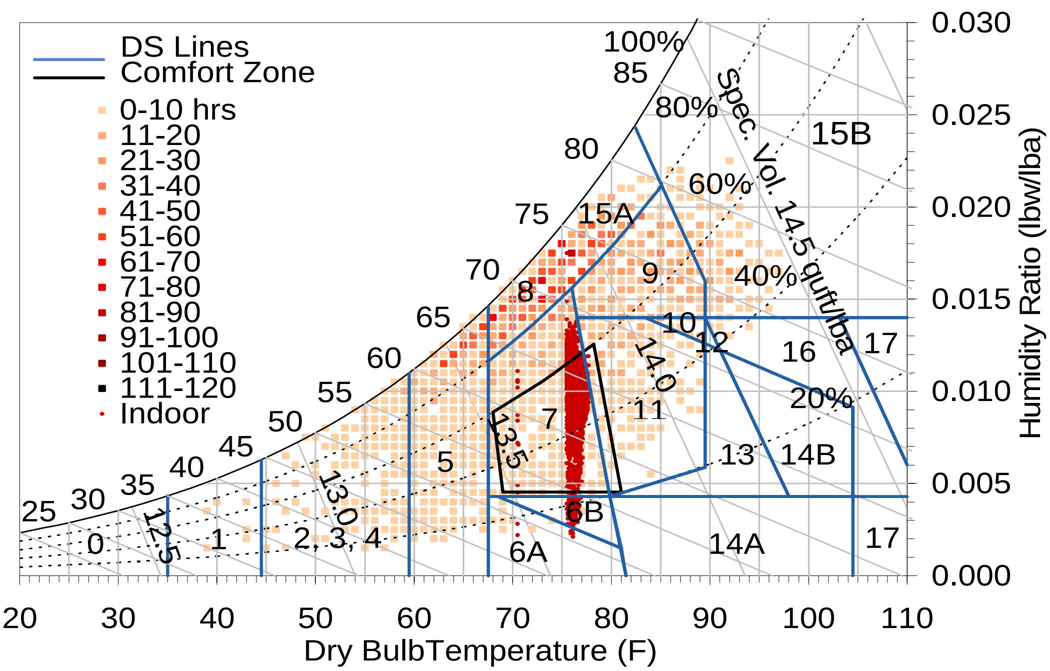


Figure 4.49 *Cooling period simulation data of a sample house in the hot-humid climate of Houston, Texas, on the psychrometric chart.*

which in Excel are

AL3640 = IF($P3640>0,$F3640,-99) and

AN3640 = IF($P3640>800,$R3640,-99).

The next steps are to develop the outdoor data density plots during the cooling period by repeating steps (steps c through i) in Section 4.3.3.1. Finally, plot the heating period indoor simulated conditions onto the chart using small red dots. Figure 4.49 displays the cooling period simulation data of a sample house in the hot-humid climate of Houston, Texas, on the psychrometric chart.

4.4.2.1.4 Non-Heating-Cooling Period

To develop the data for the non-heating-cooling period, the indoor and outdoor dry-bulb temperatures (Tdb) and humidity ratio (W) of the period when neither the heating nor cooling systems was activated need to be extracted from one year simulated data. These data represent periods when the heating energy use was less than or equal to 800 Btu/hr and the cooling energy use was equal to zero (kW). Four more columns were added in the "Data" spreadsheet (Figure 4.50). The new columns from AP through AS are the indoor dry-bulb temperature (Tdb) and humidity ratio (W) and the outdoor dry-bulb temperature (Tdb) and humidity ratio (W), respectively. Examples (see Figure 4.50) of the functions used to extract the data from cells F9 (indoor dry-bulb temperature, Tdb, 70.5 °F) and R9 (outdoor dry-bulb temperature, Tdb, 51 °F) at the corresponding heating energy use (cell O9, 800 Btu/hr) and corresponding cooling energy use (cell P9, 0 kW) and then insert the data into cells AP9 and AR9 are:

Indoor dry-bulb temperature (Tdb) = If heating energy use (800) <= 800 and cooling energy use (0) = 0, then indoor dry-bulb temperature (Tdb, 70.5), otherwise "-99" and

	A	B	F	G	K	L	O	P	Q	R	S	U	Y	AP	AQ	AR	AS
6			Indoor			GBH	Heating	Cooling	Outdoor					Non-HTG-CLG		Non-HTG-CLG	
7	Date	Time	Tdb	W	RH	(hourly)	Power	Power	Twb	Tdb	W	V	RH	Indoor		Outdoor	
8			(F)	(lbw/lba)	(%)	(Btu/Hr-Sqft)	(Btu/Hr)	(KW)	(F)	(F)	(lbw/lbda)	(Cu.ft./lba)	(%)	Tdb	W	Tdb	W
9	1/1/01	0:00	70.5	0.009	55.3	0	800	0	51	51	0.008	13.09	98.2	70.5	0.009	51	0.008
10	1/1/01	1:00	70.5	0.008	48.6	0	6177	0	47	48	0.007	12.98	91.9	-99	-99	-99	-99
11	1/1/01	2:00	70.4	0.008	46.9	0	7431	0	46	47	0.006	12.95	91.2	-99	-99	-99	-99
12	1/1/01	3:00	70.4	0.008	46.9	0	7945	0	45	46	0.006	12.92	91.7	-99	-99	-99	-99
13	1/1/01	4:00	70.4	0.009	54.3	0	7775	0	45	45	0.006	12.90	98.3	-99	-99	-99	-99
14	1/1/01	5:00	70.4	0.008	46.9	0	9549	0	45	45	0.006	12.90	98.3	-99	-99	-99	-99
15	1/1/01	6:00	70.4	0.008	46.9	0	9551	0	44	44	0.006	12.87	98.9	-99	-99	-99	-99
16	1/1/01	7:00	70.4	0.008	46.9	8	8635	0	44	44	0.006	12.87	98.9	-99	-99	-99	-99
17	1/1/01	8:00	70.4	0.007	45.6	16	7981	0	46	47	0.006	12.95	91.2	-99	-99	-99	-99
3640	6/1/01	7:00	76.5	0.011	55.2	94	800	1.307	73	77	0.017	13.94	82.0	-99	-99	-99	-99
3641	6/1/01	8:00	76.7	0.011	54.8	120	800	1.566	74	81	0.017	14.04	71.5	-99	-99	-99	-99
3642	6/1/01	9:00	77	0.011	53.3	175	800	1.759	75	83	0.017	14.11	68.6	-99	-99	-99	-99
3643	6/1/01	10:00	77.1	0.011	52.2	249	800	1.877	75	85	0.016	14.15	62.5	-99	-99	-99	-99
3644	6/1/01	11:00	77.2	0.011	52.0	293	800	1.953	76	87	0.017	14.21	60.0	-99	-99	-99	-99
3645	6/1/01	12:00	77.3	0.01	51.3	292	800	2.006	76	87	0.017	14.21	60.3	-99	-99	-99	-99
3646	6/1/01	13:00	77.3	0.01	50.9	279	800	2.042	76	88	0.017	14.23	57.4	-99	-99	-99	-99
3647	6/1/01	14:00	77.4	0.01	50.7	184	800	2.118	77	88	0.018	14.25	60.5	-99	-99	-99	-99
3648	6/1/01	15:00	77.3	0.01	50.4	158	800	2.039	76	86	0.017	14.19	63.0	-99	-99	-99	-99
3649	6/1/01	16:00	77.1	0.01	51.2	65	800	1.879	76	85	0.017	14.17	66.2	-99	-99	-99	-99
8759	12/31/01	14:00	71.1	0.007	39.7	72	800	0	43	43	0.006	12.84	97.8	71.1	0.007	43	0.006
8760	12/31/01	15:00	70.7	0.007	40.9	30	800	0	43	43	0.006	12.84	97.8	70.7	0.007	43	0.006
8761	12/31/01	16:00	70.4	0.006	39.4	14	800	0	42	42	0.006	12.81	98.1	70.4	0.006	42	0.006
8762	12/31/01	17:00	70.4	0.006	38.2	3	9293	0	41	41	0.005	12.78	98.4	-99	-99	-99	-99
8763	12/31/01	18:00	70.4	0.006	37.0	0	10977	0	40	40	0.005	12.75	98.5	-99	-99	-99	-99
8764	12/31/01	19:00	70.4	0.006	35.7	0	12158	0	39	39	0.005	12.72	98.5	-99	-99	-99	-99
8765	12/31/01	20:00	70.3	0.006	35.8	0	12762	0	39	39	0.005	12.72	98.5	-99	-99	-99	-99
8766	12/31/01	21:00	70.3	0.005	33.4	0	15628	0	38	38	0.005	12.69	98.4	-99	-99	-99	-99
8767	12/31/01	22:00	70.3	0.005	33.4	0	14771	0	37	37	0.005	12.66	98.1	-99	-99	-99	-99
8768	12/31/01	23:00	70.3	0.005	33.4	0	13603	0	36	36	0.004	12.63	97.7	-99	-99	-99	-99

File Edit View Insert Format Tools Data Window Help

Data / Psy_dt / SOL_time(unused) / H_dt(DT) / H_dt(NT) / H_dt / C_dt(DT) / C_dt(NT) / C_dt / NHC_dt(DT) / NHC_dt(NT) / NHC_dt / DT_dt

Figure 4.50 *Non-heating-cooling period simulation data analysis spreadsheet of a sample house in the hot-humid climate of Houston, Texas: raw data and calculated data.*

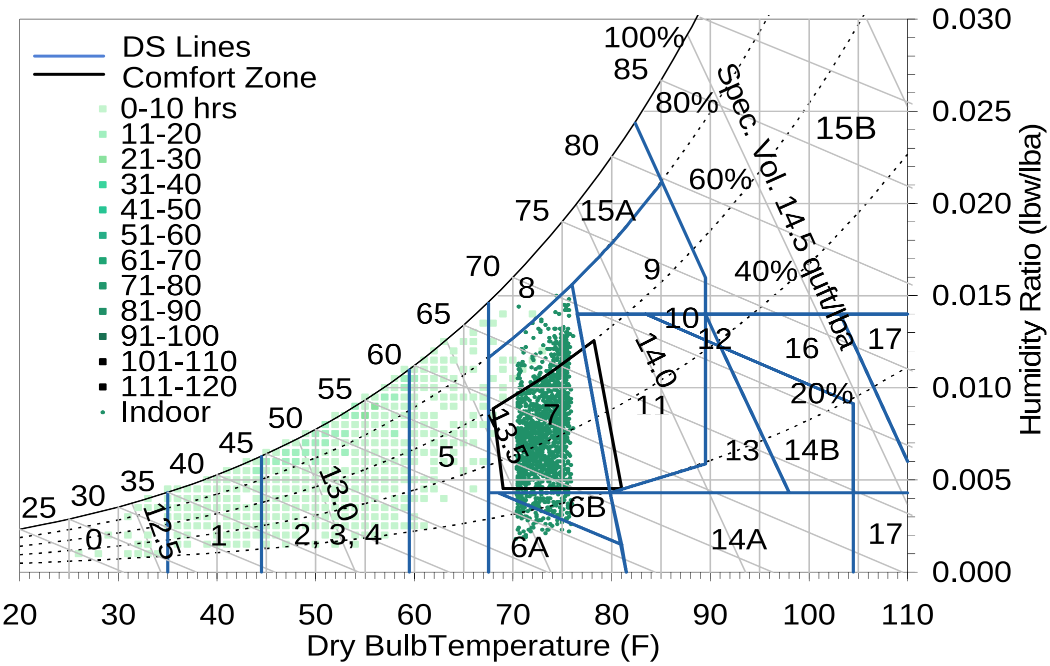


Figure 4.51 *Non-heating-cooling period simulation data of a sample house in the hot-humid climate of Houston, Texas, on the psychrometric chart.*

Outdoor dry-bulb temperature (Tdb) = If heating energy use (800) <= 800 and cooling energy use (0) = 0, then outdoor dry-bulb temperature (Tdb, 51), otherwise “-99”;

which in Excel are

AP9 = IF(AND($O9<=800,$P9=0),$F9,-99) and

AR9 = IF(AND($O9<=800,$P9=0),$R9,-99).

The next steps are to extract and develop the outdoor data density during the non-heating-cooling period by repeating steps (steps c through i) in Section 4.3.3.1. Finally, plot the heating period indoor simulated conditions onto the chart using small green dots. Figure 4.51 displays the non-heating-cooling period simulation data of a sample house in the hot-humid climate of Houston, Texas, on the psychrometric chart.

4.4.2.2 Design strategy effective hours counting tools

The design strategy effective hours counting tools are developed for extracting and counting the number of hours of data (i.e., daytime and nighttime, daytime, and nighttime) for each period (i.e., all, heating, cooling, and non-heating-cooling periods) that fall within each design strategy region (see label 4.2B in Figure 4.40). The results of the design strategy effective hours from the G-M bioclimatic chart and the DOE-2 simulations are compared using comparison tables. This section describes the processes to develop the tools for one year for data (daytime and nighttime). The processes to develop the tools for the daytime and nighttime data, which are not included in this section, are developed using a similar procedure. The steps to develop the tools for each period follow.

4.4.2.2.1 All Periods

In Section 4.4.2.1.1, the outdoor dry-bulb temperature (Tdb) and humidity ratio (W) of all periods data located at columns R and S of the “Data” spreadsheet (see Figure

4.44) are inserted into the new spreadsheet ("A_bin", Figure 4.52). The "A_bin" spreadsheet contains numbers of columns from P through BU (regions 0 through 17). These columns are developed for the extracted outdoor dry-bulb temperature (Tdb) and humidity ratio (W) that correspond to the design strategy regions. The functions are set in each column to extract the data (dry-bulb temperature, Tdb and humidity ratio, W) from the all periods data and insert into the appropriate columns using the design strategy conditions described in Section 4.3.1.3 and in relation to the outdoor conditions data (i.e.; wet-bulb temperature, Twb; dry-bulb temperature, Tdb; humidity ratio, W; specific volume, V; and relative humidity, RH) from the "Data" spreadsheet. Examples (Figure 4.52) of the functions used to transfer the outdoor dry-bulb temperature (Tdb, 44 °F, R15) and humidity ratio (W, 0.006 lba/lbw, S15) of the all periods from the "Data" spreadsheet to cells R15 and S15 in the active solar design strategy (region 1) are:

> Outdoor dry-bulb temperature (Tdb) = If 35 ≤ outdoor dry-bulb temperature (Tdb, 44, "Data" spreadsheet) < 44.5, outdoor dry-bulb temperature (Tdb, 44, "Data" spreadsheet), otherwise "-99" and
>
> Outdoor humidity ratio (W) = If outdoor dry-bulb temperature (Tdb, 44, "A_bin" spreadsheet) = outdoor dry-bulb temperature (Tdb, 44, "Data" spreadsheet) then outdoor humidity ratio (W, 0.006, "Data" spreadsheet), otherwise "-99";
>
> which in Excel are
>
> R15 = IF(AND(Data!R15>=35, Data!R15<44.5),Data!R15,-99,) and
>
> S15 = IF(R15= Data!R15, Data!S15,-99).

The number of hours and the percentage of the hours of each region are counted and calculated at the end of each column region (i.e., from rows 8770 through 8771). The totals of all periods effective hours and the percentages are located at the bottom right (i.e., cells BV8770 through 8771). The results of this period will be compared later with the results from the other periods.

File Edit View Insert Format Tools Data Window Help

	O	P	Q	R	S	AM	AN	AO	AP	AQ	AR	BR	BS	BT	BU	BV
5																
6	REGION	0	0	1	1	8	8	9	9	10	10	17a	17b	17	17	TOTAL
7		Tdb	W	Tdb	W	Tdb	W	Tdb	W	Tdb	W	Tdb	Tdb	Tdb	W	
8		(F)	(lbw/lba)	(F)	(lbw/lba)	(F)	(lbw/lba)	(F)	(lbw/lba)	(F)	(lbw/lba)	(F)	(F)	(F)	(lbw/lba)	
9		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
10		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
11		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
12		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
13		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
14		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
15		-99	-99	44	0.006	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
3062		-99	-99	-99	-99	72	0.015	-99	-99	-99	-99	-99	-99	-99	-99	
3063		-99	-99	-99	-99	72	0.015	-99	-99	-99	-99	-99	-99	-99	-99	
3064		-99	-99	-99	-99	75	0.015	-99	-99	-99	-99	-99	-99	-99	-99	
3065		-99	-99	-99	-99	-99	-99	79	0.015	-99	-99	-99	-99	-99	-99	
3066		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
3067		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
3068		-99	-99	-99	-99	-99	-99	84	0.014	-99	-99	-99	-99	-99	-99	
3069		-99	-99	-99	-99	-99	-99	-99	-99	85	0.014	-99	-99	-99	-99	
3070		-99	-99	-99	-99	-99	-99	-99	-99	86	0.014	-99	-99	-99	-99	
3071		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
8764		-99	-99	39	0.005	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
8765		-99	-99	39	0.005	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
8766		-99	-99	38	0.005	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
8767		-99	-99	37	0.005	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
8768		-99	-99	36	0.004	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
8769	REGION	0		1		8		9		10		17a	17b	17		0-17
8770	HOURS	246		585		1465		1165		52		0		0		8,760
8771	%	2.81%		6.68%		16.72%		13.30%		0.59%		0.00%		0.00%		100%

H_bin(DT) / H_bin(NT) / H_bin / C_bin(DT) / C_bin(NT) / C_bin / NHC_bin(DT) / NHC_bin(NT) / NHC_bin / A_bin(DT) / A_bin(NT) / A_bin / T&Euse

Figure 4.52 *Design strategy effective hours counting spreadsheet of a sample house in the hot-humid climate of Houston, Texas (all periods).*

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	O	P	Q	R	S	AM	AN	AO	AP	AQ	AR	BR	BS	BT	BU	BV
5																
6	REGION	0	0	1	1	8	8	9	9	10	10	17a	17b	17	17	TOTAL
7		Tdb	W	Tdb	W	Tdb	W	Tdb	W	Tdb	W	Tdb	Tdb	Tdb	W	
8		(F)	(lbw/lba)	(F)	(lbw/lba)	(F)	(lbw/lba)	(F)	(lbw/lba)	(F)	(lbw/lba)	(F)	(F)	(F)	(lbw/lba)	
9		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
10		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
11		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
12		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
13		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
14		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
15		-99	-99	44	0.006	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
3062		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
3063		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
3064		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
3065		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
3066		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
3067		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
3068		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
3069		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
3070		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
3071		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
8764		-99	-99	39	0.005	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
8765		-99	-99	39	0.005	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
8766		-99	-99	38	0.005	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
8767		-99	-99	37	0.005	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
8768		-99	-99	36	0.004	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
8769	REGION	0		1		8		9		10		17a	17b	17		0-17
8770	HOURS	224		366		0		0		0		0		0		738
8771	%	2.56%		4.18%		0.00%		0.00%		0.00%		0.00%		0.00%		8.42%

H_bin(DT) / H_bin(NT) / H_bin / C_bin(DT) / C_bin(NT) / C_bin / NHC_bin(DT) / NHC_bin(NT) / NHC_bin / A_bin(DT) / A_bin(NT) / A_bin / T&Euse

Figure 4.53 *Design strategy effective hours counting spreadsheet of a sample house in the hot-humid climate of Houston, Texas (heating period).*

4.4.2.2.2 Heating Period

The process to develop the design strategy counting tools for heating period is similar to the strategy for “all periods”. The dry-bulb temperature (Tdb) and humidity ratio (W) of the heating period data in Section 4.4.2.1.2, which is located at columns AJ and AK of the “Data” spreadsheet (see Figure 4.46), are transferred to the new spreadsheet (called “H_bin”, Figure 4.53). Similar to the “A_bin” spreadsheet, the “H_bin” spreadsheet contains numbers of columns with the extracted functions for regions 0 through 17. Examples (Figure 4.53) of the functions used to transfer the outdoor dry-bulb temperature (Tdb, 38 °F, AJ8766) and humidity ratio (W, 0.005 lba/lbw, AK8766) of the heating period from the “Data” spreadsheet to cells R8766 and S8766 in the active solar design strategy (region 1) are:

Outdoor dry-bulb temperature (Tdb) = If 35 ≤ outdoor dry-bulb temperature (Tdb, 38, “Data” spreadsheet) < 44.5, outdoor dry-bulb temperature (Tdb, 38, “Data” spreadsheet), otherwise “-99” and

Outdoor humidity ratio (W) = If outdoor dry-bulb temperature (Tdb, 38, “H_bin” spreadsheet) = outdoor dry-bulb temperature (Tdb, 38, “Data” spreadsheet) then outdoor humidity ratio (W, 0.005, “Data” spreadsheet), otherwise “-99”;

Which in Excel are

R8766 = IF(AND(Data!AJ8766>=35, Data!AJ8766<44.5),Data!AJ8766,-99,)

and

S8766 = IF(R8766= Data!AJ8766, Data!AK8766,-99).

The number of hours and the percentage of hours of each region are counted and calculated at the end of each column region (i.e., rows 8770 through 8771). The totals of the heating period effective hours and the percentages are located at the right bottom (i.e., cells BV8770 through 8771). The results of this period will later be compared with the results from the other periods.

4.4.2.2.3 Cooling Period

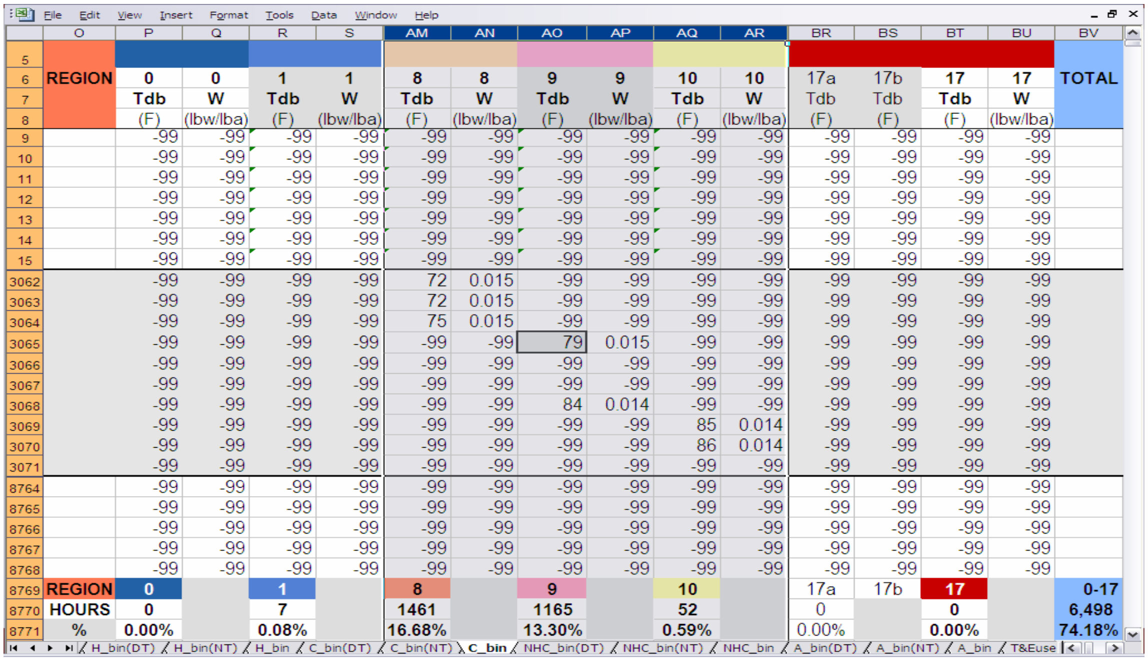
The process to develop the design strategy counting tools for cooling period is similar to the strategy for "all periods". The dry-bulb temperature (Tdb) and humidity ratio (W) of the cooling period data in Section 4.4.2.1.3, which is located at column AN and AO of the "Data" spreadsheet (Figure 4.48), are transferred to the new spreadsheet (called "C_bin", Figure 4.54). Similar to the "A_bin" spreadsheet, the "C_bin" spreadsheet contains numbers of columns with the extracted functions for regions 0 through 17. . Examples (Figure 4.54) of more complicated functions used to transfer the outdoor temperature (Tdb, 79 °F, AN3065) and humidity ratio (W, 0.015 lba/lbw, AO3065) with the corresponding outdoor relative humidity (RH, 70.9%, Data!Y3065) and specific volume (V, 13.97 ft^3/lba, Data!U3065) of the cooling period from the "Data" spreadsheet to cells AO3065 and AP3065 in a portion of ventilation design strategy (regions 9) are:

Outdoor dry-bulb temperature (Tdb) = If 72.5 < outdoor dry-bulb temperature (Tdb, 79, "Data" spreadsheet) ≤ 89.5 and outdoor humidity ratio (W, 0.015, "Data" spreadsheet) > 0.014 and outdoor relative humidity (RH, 70.9, "Data" spreadsheet) ≤ 80 and outdoor specific volume (V, 13.97, "Data" spreadsheet) ≤ 14.2, then outdoor dry-bulb temperature (Tdb, 79, "Data" spreadsheet), otherwise "-99" and

Outdoor humidity ratio (W) = If outdoor dry-bulb temperature (Tdb, 79, "C_bin" spreadsheet) = outdoor dry-bulb temperature (Tdb, 79, "Data" spreadsheet) then outdoor humidity ratio (W, 0.015, "Data" spreadsheet), otherwise "-99";

which in Excel are

AO3065 = IF(AND(AND(AND(AND(Data!AN3065>72.5,
Data!AN3065<=89.5), Data!AO3065>0.014), Data!Y3065<= 80),
Data!U3065<=14.2), Data!AN3065,-99,) and



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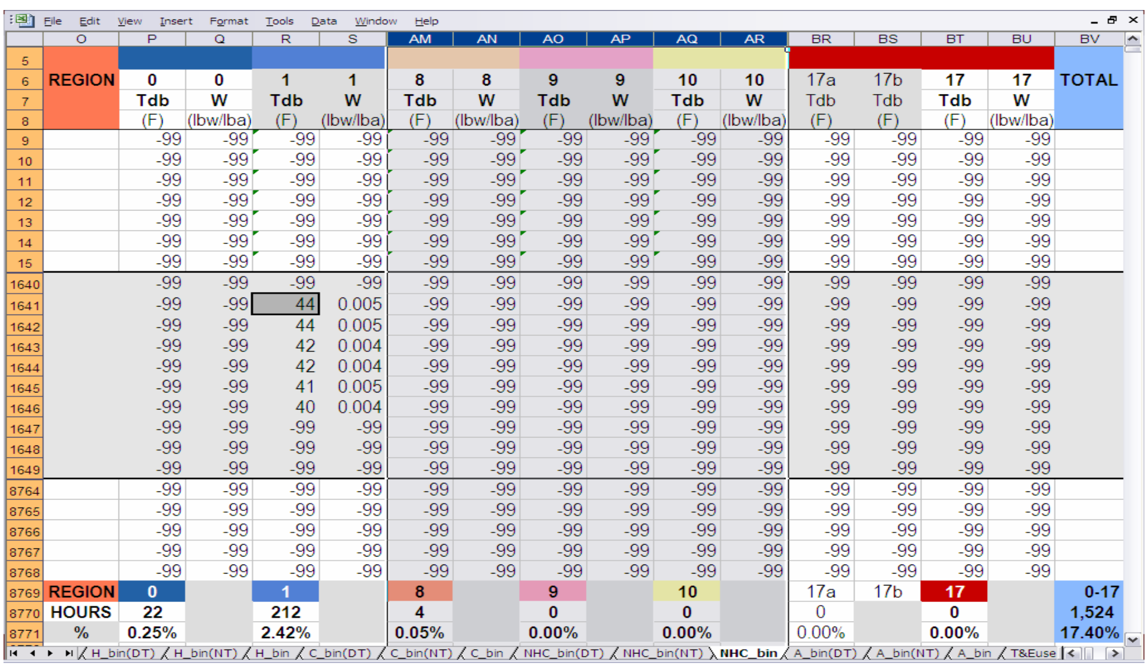
	O	P	Q	R	S	AM	AN	AO	AP	AQ	AR	BR	BS	BT	BU	BV
5																
6	REGION	0	0	1	1	8	8	9	9	10	10	17a	17b	17	17	TOTAL
7		Tdb	W	Tdb	W	Tdb	W	Tdb	W	Tdb	W	Tdb	Tdb	Tdb	W	
8		(F)	(lbw/lba)	(F)	(lbw/lba)	(F)	(lbw/lba)	(F)	(lbw/lba)	(F)	(lbw/lba)	(F)	(F)	(F)	(lbw/lba)	
9		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
10		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
11		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
12		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
13		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
14		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
15		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
3062		-99	-99	-99	-99	72	0.015	-99	-99	-99	-99	-99	-99	-99	-99	
3063		-99	-99	-99	-99	72	0.015	-99	-99	-99	-99	-99	-99	-99	-99	
3064		-99	-99	-99	-99	75	0.015	-99	-99	-99	-99	-99	-99	-99	-99	
3065		-99	-99	-99	-99	-99	-99	79	0.015	-99	-99	-99	-99	-99	-99	
3066		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
3067		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
3068		-99	-99	-99	-99	-99	-99	84	0.014	-99	-99	-99	-99	-99	-99	
3069		-99	-99	-99	-99	-99	-99	-99	-99	85	0.014	-99	-99	-99	-99	
3070		-99	-99	-99	-99	-99	-99	-99	-99	86	0.014	-99	-99	-99	-99	
3071		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
8764		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
8765		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
8766		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
8767		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
8768		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
8769	REGION	0		1		8		9		10		17a	17b	17		0-17
8770	HOURS	0		7		1461		1165		52		0		0		6,498
8771	%	0.00%		0.08%		16.68%		13.30%		0.59%		0.00%		0.00%		74.18%

H_bin(DT) / H_bin(NT) / H_bin / C_bin(DT) / C_bin(NT) / C_bin / NHC_bin(DT) / NHC_bin(NT) / NHC_bin / A_bin(DT) / A_bin(NT) / A_bin / T&Euse

Figure 4.54 *Design strategy effective hours counting spreadsheet of a sample house in the hot-humid climate of Houston, Texas (cooling period).*



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	O	P	Q	R	S	AM	AN	AO	AP	AQ	AR	BR	BS	BT	BU	BV
5																
6	REGION	0	0	1	1	8	8	9	9	10	10	17a	17b	17	17	TOTAL
7		Tdb	W	Tdb	W	Tdb	W	Tdb	W	Tdb	W	Tdb	Tdb	Tdb	W	
8		(F)	(lbw/lba)	(F)	(lbw/lba)	(F)	(lbw/lba)	(F)	(lbw/lba)	(F)	(lbw/lba)	(F)	(F)	(F)	(lbw/lba)	
9		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
10		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
11		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
12		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
13		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
14		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
15		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
1640		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
1641		-99	-99	44	0.005	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
1642		-99	-99	44	0.005	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
1643		-99	-99	42	0.004	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
1644		-99	-99	42	0.004	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
1645		-99	-99	41	0.005	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
1646		-99	-99	40	0.004	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
1647		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
1648		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
1649		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
8764		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
8765		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
8766		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
8767		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
8768		-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	
8769	REGION	0		1		8		9		10		17a	17b	17		0-17
8770	HOURS	22		212		4		0		0		0		0		1,524
8771	%	0.25%		2.42%		0.05%		0.00%		0.00%		0.00%		0.00%		17.40%

H_bin(DT) / H_bin(NT) / H_bin / C_bin(DT) / C_bin(NT) / C_bin / NHC_bin(DT) / NHC_bin(NT) / NHC_bin / A_bin(DT) / A_bin(NT) / A_bin / T&Euse

Figure 4.55 *Design strategy effective hours counting spreadsheet of a sample house in the hot-humid climate of Houston, Texas (non-heating-cooling period).*

AP3065 = IF(AO3065= Data!AN3065, Data!AO3065,-99).

In this region, the 78 °F EF* limit line is estimated to the 72.5 °F for the upper part of the 78 °F EF*. The number of hours and the percentage of hours of each region are counted and calculated at the end of each column region (i.e., rows 8770 through 8771). The total of the cooling period effective hours and the percentages are located at the right bottom (cells BV8770 through 8771). The results of this period will later be compared with the results from the other periods.

4.4.2.2.4 Non-Heating-Cooling Period

The process to develop the design strategy counting tools for the heating period is similar to the strategy for "all periods". The dry-bulb temperature (Tdb) and humidity ratio (W) of the non-heating-cooling period data in Section 4.4.2.1.4, which is located at columns AR and AS of the "Data" spreadsheet (Figure 4.50), are transferred to the new spreadsheet (called "NHC_bin", Figure 4.55). Similar to the "A_bin" spreadsheet, the "NHC_bin" spreadsheet contains numbers of columns with the extracted functions for regions 0 through 17.

Examples (Figure 4.55) of the functions used to transfer the outdoor Tdb (44 °F, AR1641) and W (0.005 lba/lbw, AS1641) of the non-heating-cooling period from the "Data" spreadsheet to cells R1641 and S1641 in the active solar design strategy (region 1) are:

Outdoor dry-bulb temperature (Tdb) = If 35 ≤ outdoor dry-bulb temperature (Tdb, 44, "Data" spreadsheet) < 44.5, outdoor dry-bulb temperature (Tdb, 44, "Data" spreadsheet), otherwise "-99" and Outdoor humidity ratio (W) = If outdoor dry-bulb temperature (Tdb, 44, "NHC_bin" spreadsheet) = outdoor dry-bulb temperature (Tdb, 44, "Data" spreadsheet) then outdoor humidity ratio (W, 0.005, "Data" spreadsheet), otherwise "-99";

which in Excel are

R1641 = IF(AND(Data!AR1641>=35, Data!AR1641<44.5),Data!AR1641,-99,)

and

S1641 = IF(R1641= Data!AR1641, Data!AS1641,-99).

The number of hours and the percentage of the hours of each region are counted and calculated at the end of each column region (i.e., rows 8770 through 8771). The totals of the non-heating-cooling period effective hours and the percentages are located at the right bottom (cells BV8770 through 8771). The results of this period will later be compared with the results from the other periods.

4.4.2.3 Comparison tables

Comparison tables (see an example in Figure 4.56) are developed to comply and compare the results of the effective design strategies of each period (see label 4.2C in Figure 4.40). The list of the design strategies in the G-M bioclimatic chart (1979) and the effective regions are located in the first and second sets of the columns. The third set of the columns is the results of the G-M bioclimatic chart (all periods). The last third sets of columns are the results from the DOE-2 simulation for heating, cooling, and non-heating-cooling periods; respectively. The total of the effective hours and the percentages are at the end of the last design strategy region (i.e., rows 17 and 18).

To compare the results of the G-M chart and the DOE-2 simulations, a G-M and DOE-2 design strategy comparison table was created as shown in Figure 4.56. Figure 4.56 shows the data; which are the number and percentage of hours in each region; from the G-M chart for all periods (Figure 4.52) as well as the data from the DOE-2

Design Strategies	Regions	G-M Bio-Chart (%)	DOE-2 Simulation HTG (%)	CLG (%)	N-H-C (%)
Conventional Heating	0	2.81	2.56	0.00	0.25
Active Solar	1	6.68	4.18	0.08	2.42
Passive Solar	2,3,4	16.07	1.60	2.60	11.87
Internal Gains	5	13.89	0.09	11.22	2.58
Humidification	6A, 6B	0.17	0.00	0.17	0.00
Comfort Zone	7	9.94	0.00	9.71	0.23
Dehumidification	8	16.72	0.00	16.68	0.05
Ventilation	9,10,11	19.76	0.00	19.76	0.00
Evaporative Cooling	6B,11,13,14A,14B	5.92	0.00	5.92	0.00
High Thermal Mass	10,11,12,13	6.48	0.00	6.48	0.00
High Thermal Mass with Night Ventilation	16, 14B	0.15	0.00	0.15	0.00
Air-Conditioning	17	0.00	0.00	0.00	0.00
Air-Conditioning & Dehumidification	15A,15B	13.78	0.00	13.78	0.00
Number of Hours/Year		8760	738	6498	1524
Percentage of Hours/Year		100.00	8.42	74.18	17.40

Region	0	1	2	3	4	5	6A	6B	7	8	9	10	11	12	13	14A	14B	15A	15B	16	17	Total
Hours	246	585	368	478	562	1217	10	5	871	1465	1165	52	514	2	0	0	0	781	426	13	0	8760
G-M (%)	2.8	6.7	4.2	5.5	6.4	13.9	0.1	0.1	9.9	16.7	13.3	0.6	5.9	0.0	0.0	0.0	0.0	8.9	4.9	0.1	0.0	100.00
Total (%)		9.49								40.08											50.43	100.00

Figure 4.56 *The design strategy effective hours comparison table (Givoni-Milne Chart vs. DOE-2 simulation) of a sample house in the hot-humid climate of Houston, Texas.*

simulation for heating (Figure 4.53), cooling (Figure 4.54), and non-heating-cooling periods (Figure 4.55). In this table, color-coding is used to assist with the comparison. In the upper left of the table, a description of the design strategies is presented, followed by the G-M region numbers to the immediate left. In the next section, columns M to P, the percentage of hours from a traditional G-M analysis (G-M Bio-Chart %) are shown. Further to the left are the percentage of hours from the DOE-2 simulation for heating (HTG %), cooling (CLG %), and non-heating-cooling (N-H-C %) periods. Totals for the G-M and DOE-2 analysis are given in rows 17 and 18. Rows 20 and 21 present the G-M analysis results, which are the number and percentage of hours for each region number (row 19). According to the G-M chart results, row 22 shows the totals of percentage of hours of the effective regions for heating (blue columns), cooling (pink columns), and non-heating-cooling (green column) design strategies for a specific sample house. This

G-M chart results in row 22 are then used to compare to the DOE-2 simulation results in row 18 (columns G through X).

4.5 SUMMARY OF METHODOLOGY

This chapter has discussed the methodology used in this study including selecting and preparing representative TMY2 weather data to use with the DOE-2 simulations, simulating the selected design strategies, analyzing and mapping the TMY2 weather data outcomes onto the psychrometric chart, and analyzing and projecting the simulation results onto the psychrometric chart.

Seven TMY2 representative weather data of the U.S and Thailand are selected using four criteria. The "Weather Converter Program" of the EnergyPlus program (Crawley et al., 2000) was used to convert weather data in IWEC format to TMY2 format. To prepare the TMY2 files for use with the DOE-2 simulation, the TMY2 file (ASCII) was converted into the binary file using the DOE-2 weather processor.

Several DOE-2 input files for the prototype houses were developed for specific design strategies and simulated using the prepared weather files of the representative cities. Several techniques were used to analyze and present the data, with an emphasis on the bioclimatic analysis. Therefore, this Chapter focused on the techniques used to analyze and present the data on the psychrometric chart. The MS Excel spreadsheet package (MS Office, 2003) was used to extract, analyze and display the data.

To begin the analysis, the bioclimatic analysis display models were developed in psychrometric chart format. First, the ASHRAE comfort chart (1992) and the Givoni-Milne design strategy boundaries were overlaid onto the psychrometic chart. Using number of tools developed for the specific tasks, the weather data (thermal, solar, and wind) were extracted from the DOE-2 HOURLY-REPORT and rearranged in appropriate format. The rearranged data for the whole year (daytime and nighttime), daytime, and nighttime, were analyzed and displayed onto the psychrometric chart. The types of the data displays include; density, cumulative, average, and hourly average data plots.

The DOE-2 simulation outcomes from the DOE-2 HOURLY-REPORT and BEPS report were also extracted and rearranged in appropriate format. The thermal and systems data analysis tools and the one year of data for all periods, heating period, cooling period, and non-heating-cooling period, were transferred to the appropriate effective design strategy regions. The number and percentage of hours for each period that fall upon each design strategy region are counted and calculated. These results were displayed and compared on the specially designed, color-coded comparison tables. This comparison plots and tables are then used to compare the traditional Givoni-Milne bioclimatic chart (1979) against the DOE-2 simulations of a code-compliant single-family residence.

CHAPTER V

DATA ANALYSIS AND RESULTS

This chapter contains graphical displays and discussions of the analysis and the results. The outdoor conditions from the TMY2 weather data, the simulated indoor comfort conditions, the energy usage from the DOE-2 HOURLY-REPORT s, and the Building Energy Performance Summary (BEPS) data were used to analyze and develop graphical display results. Data displays are presented using several existing and new discovery techniques that were found to be useful for the analysis. The types of graphical display include: time series plots, x-y plots, three dimensional plots, psychrometric plots, bar charts, and tables (see Figure 5.1).

The results consist of two main parts, which are: 1) weather analysis for the hot-humid climate of Houston, Texas, and 2) results from the DOE-2 simulation. The first part presents as full version of the weather data results. This part contains weather data characteristics as well as detailed discussions of thermal, solar, and wind data, which influence building performance and indoor comfort conditions.

The second part shows simulation results of prototype houses in the selected climates (Houston, Texas; Phoenix, Arizona; and San Francisco, California). The indoor and out door hourly conditions against heating and cooling energy usage as well as annual energy use of each category are presented. The indoor and outdoor hourly conditions from the DOE-2 simulations for one year of data and periods of heating, cooling, and non-heating-cooling, are displayed on the G-M Chart. Comparison tables of the G-M chart analysis and the DOE-2 simulation results are also included. Results of all other simulations in the other selected climates are presented in Appendix D.

Finally, summary of the results includes discussions, findings, and suggestions about possibilities to improve the usefulness of the bioclimatic chart as well as ways the bioclimatic chart can be modified for a thermostatic-controlled house.

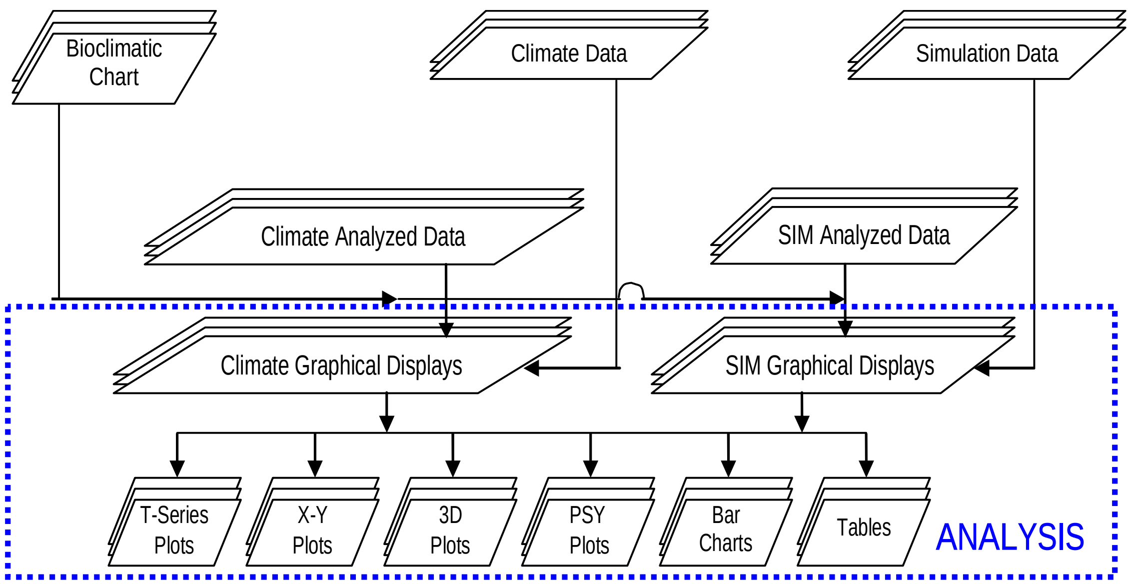


Figure 5.1 *Flowchart of types of climate and simulation graphical display results.*

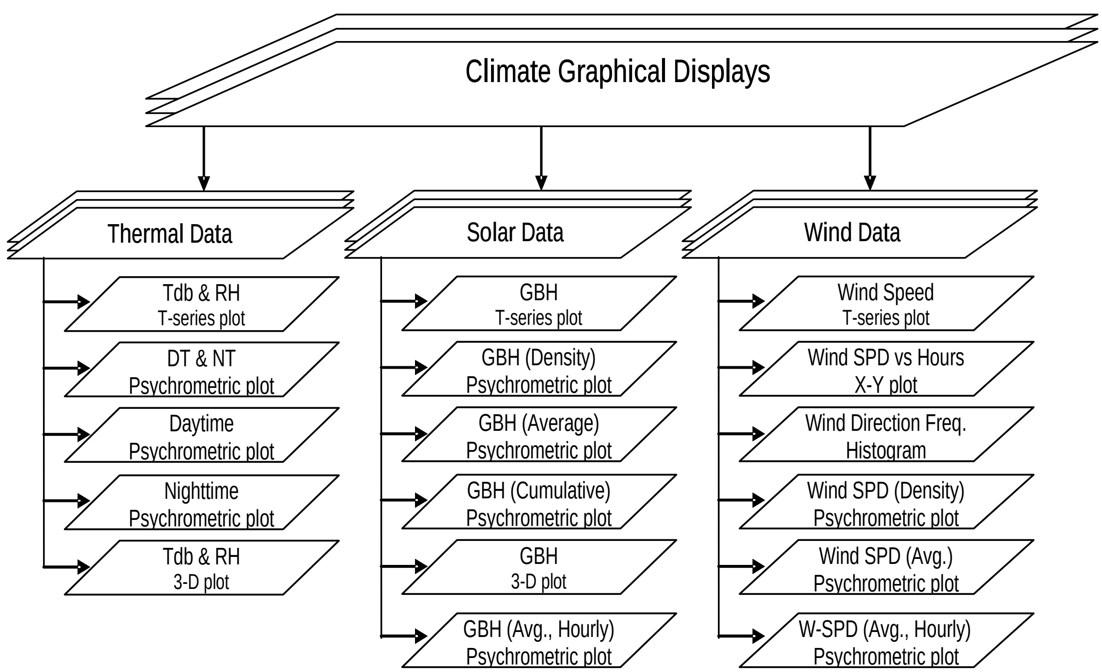


Figure 5.2 *Flowchart diagram of climate graphical display results.*

5.1 WEATHER ANALYSIS FOR THE HOT-HUMID CLIMATE OF HOUSTON, TEXAS

Results from the TMY2 weather data for the hot-humid location of Houston, Texas, were extracted from the DOE-2 HOURLY-REPORT. The data analysis and calculations tools used to prepare data for the graphical displays were generated using special Microsoft Excel spreadsheets (Microsoft Office, 2003). The data include: dry-bulb temperature (Tdb), humidity ratio (W), relative humidity (RH), global horizontal (GBH) solar radiation, wind speed, and wind directions. Figure 5.2 is a flowchart of the graphical analysis presented in several figures in Sections 5.1.1 through 5.1.3. The full analysis includes thermal data (see Section 5.1.1), solar data (see Section 5.1.2), and wind data (see Section 5.1.3). Summary and discussion of the weather analysis for the hot-humid climate of Houston, Texas, are in Section 5.1.4.

5.1.1 Thermal Data

The thermal data analyses of the representative hot-humid climate of Houston, Texas, are presented in this section. Figure 5.3 consists of four plots (Figures 5.3a through 5.3d). Figure 5.3a shows a time series plot of the annual hourly ambient dry-bulb temperature and relative humidity (RH). Figures 5.3b through 5.3d display the annual hourly ambient conditions on the psychrometric chart for daytime and nighttime (Figure 5.3b), daytime (Figure 5.3c), and nighttime (Figure 5.3d).

In Figure 5.3a, a time series plot of the annual hourly ambient dry-bulb temperature is shown in upper figure, along-with the corresponding relative humidity (lower figure). The left y-axis represents dry-bulb temperature (°F) and the right y-axis represents relative humidity (%). The ambient temperature is displayed is the upper pink line and the relative humidity is the lower purple line.

Figure 5.3a shows a wide range of the ambient dry-bulb temperature. The difference between the minimum temperature (14 °F) and maximum temperature (97 °F) is 83 °F. The range of the outdoor temperature in the summer, in the range of 60 to 95 °F, is narrower than in the winter, which is in the range of 20 to 85 °F. The

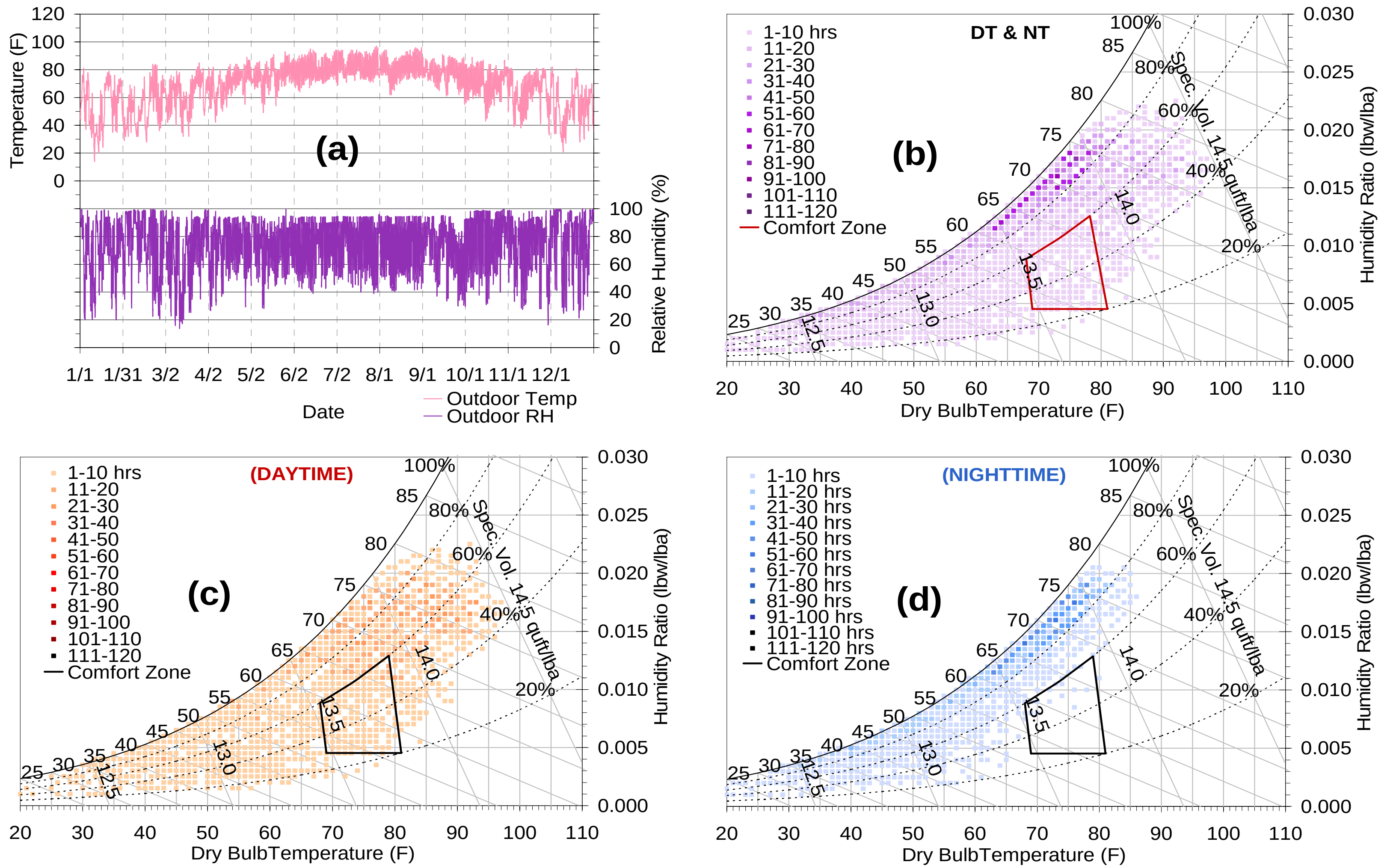


Figure 5.3 *Hourly outdoor conditions in the hot-humid climate, Houston, Texas. (a) Dry-bulb temperature (top figure) and relative humidity (bottom figure), (b) Daytime and nighttime outdoor conditions, (c) Daytime outdoor conditions, (d) Nighttime outdoor conditions.*

winter minimum average daily temperature is 25 °F and the summer maximum average daily temperature is 86 °F.

The lower figure also shows a significant wide range of the ambient relative humidity. The difference between the minimum relative humidity (14%) and maximum relative humidity (100%) is 86%. Similar to the range of the ambient dry-bulb temperature the range of the ambient relative humidity is narrower in the summer, in the range of 40 to 95 °F, than in the winter, which is in the range of 15 to 100%. The relative humidity rarely dips below 40% in summer, but in winter there are many hours that the relative humidity dips below 40%. During most of the year, the relative humidity reaches 80 to 90% a significant portion of the time.

Figure 5.3b shows a psychrometric plot of the daytime and nighttime annual hourly ambient conditions. The x-axis represents dry-bulb temperature (°F). The y-axis represents humidity ratio (lbw/lba). The curved lines represent relative humidity (%). Dewpoint temperatures (°F) are located along the 100 % relative humidity line. The diagonal lines represent the specific volume of the air (ft^3/lba). The ambient conditions are displayed in squares where the frequency of the range of occurrence is shown as varying colors from very light to very dark purple as indicated on the legend of the plot. The ASHRAE comfort zone, which is in the middle of the chart, is shown with a red line.

Figure 5.3b shows that the ambient conditions for the whole year are widely spread-out above the 20% relative humidity line, also covering the comfort zone. Above the comfort zone, the frequency of occurrence is very high at the ambient conditions between 60 to 85 °F with the corresponding relative humidity above 80%. The figure shows that the relative humidity does not exceed 80% at a temperature above 85 °F.

Figure 5.3c shows a psychrometric plot of the daytime annual hourly ambient conditions. This chart is similar to Figure 5.3b except that the ambient conditions are displayed in red tone colors and the ASHRAE comfort zone is represented by a black line. In difference to Figure 5.3b, the frequency of the range of occurrence above the comfort zone shifts to the right as expected with the increased solar energy.

Figure 5.3d shows a psychrometric plot of the nighttime annual hourly ambient conditions. This chart is similar to Figure 5.3b except that the ambient conditions are displayed in blue tones. In this figure, the frequency of the data point below 60% relative humidity and above 70 °F almost disappears entirely leaving very few data points in the comfort zone.

In Figure 5.4, three dimensional plots of the annual hourly ambient dry-bulb temperatures (upper figure) and relative humidity (lower figure) are presented. The x-axis represents the day in the year. The y-axis represents hour of the day. The z-axis in the upper figure represents the dry-bulb temperature (°F). The z-axis of the lower figure represents the relative humidity (%).

The figures show results similar to Figure 5.3a. In addition, the time of occurrence is also shown in the figures. The upper figure shows that the highest temperature each day usually occurs around midday when the solar radiation is high. The lower figure shows that the relative humidity is usually low during the midday and significantly high at nighttime. Periods of more than 90% relative humidity occur frequently in the early morning hours during most of the year.

5.1.2 Solar Data

The global horizontal (GBH) solar radiation data of the representative hot-humid climate of Houston, Texas, are presented in this section.

In Figure 5.5, four plots are presented (Figures 5.5a through 5.5d). Figure 5.5a shows a time series plot of the annual hourly global horizontal (GBH) solar radiation. Figures 5.3b through 5.3d display the frequency of occurrence (Figure 5.3b), the average solar radiation of data points represented by each square (Figure 5.3c), and total hourly global horizontal (GBH) solar radiation of the data points represented by each square (Figure 5.3d).

In Figure 5.5a, a time series plot of the annual hourly global horizontal (GBH) solar radiation is presented. This figure shows that the global horizontal solar radiation changes from day to day and from season to season. The average global horizontal solar

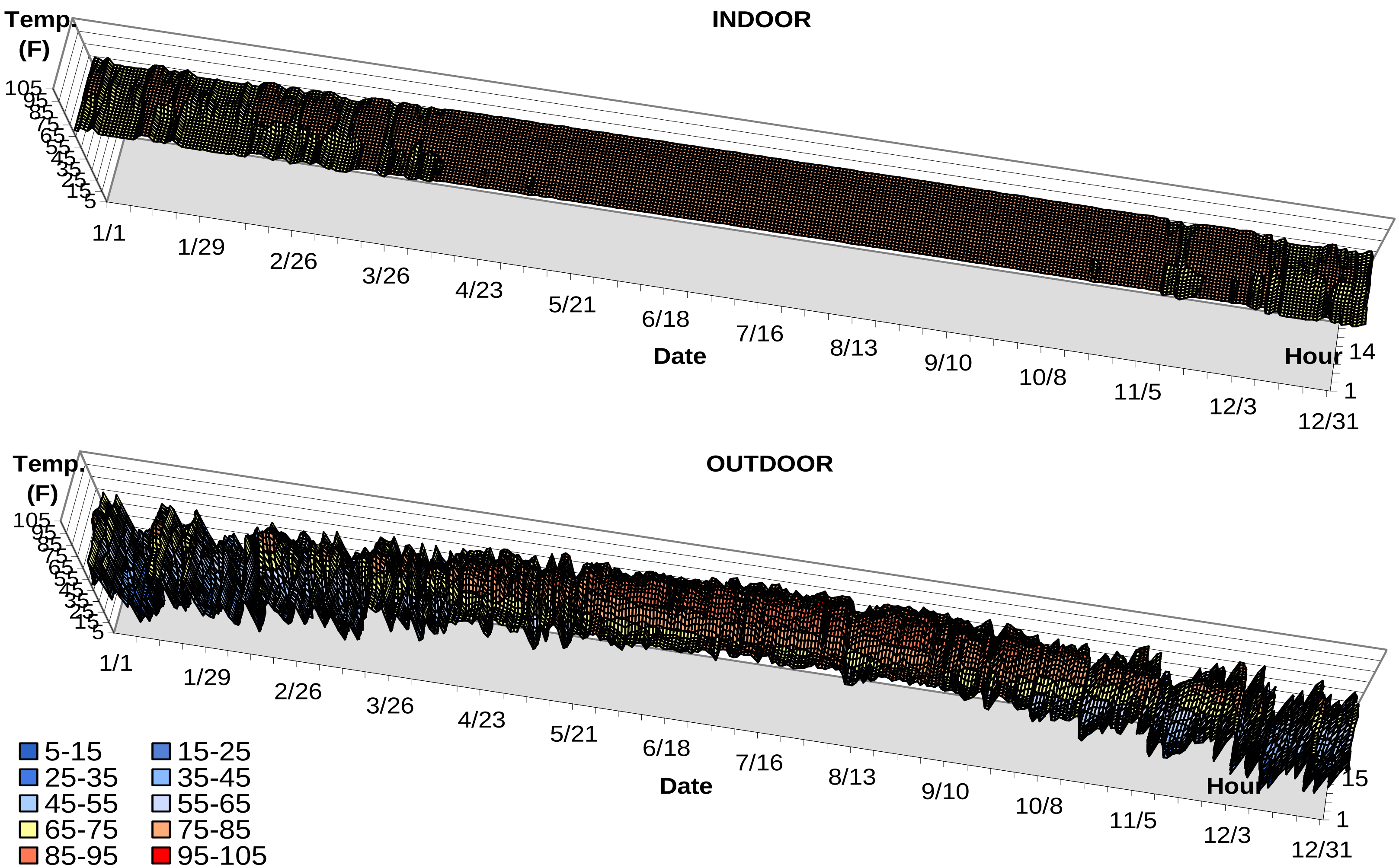


Figure 5.4 *Three dimensional surface plots of hourly indoor and outdoor temperatures of the lightweight house (base case) in the hot-humid climate, Houston, Texas.*

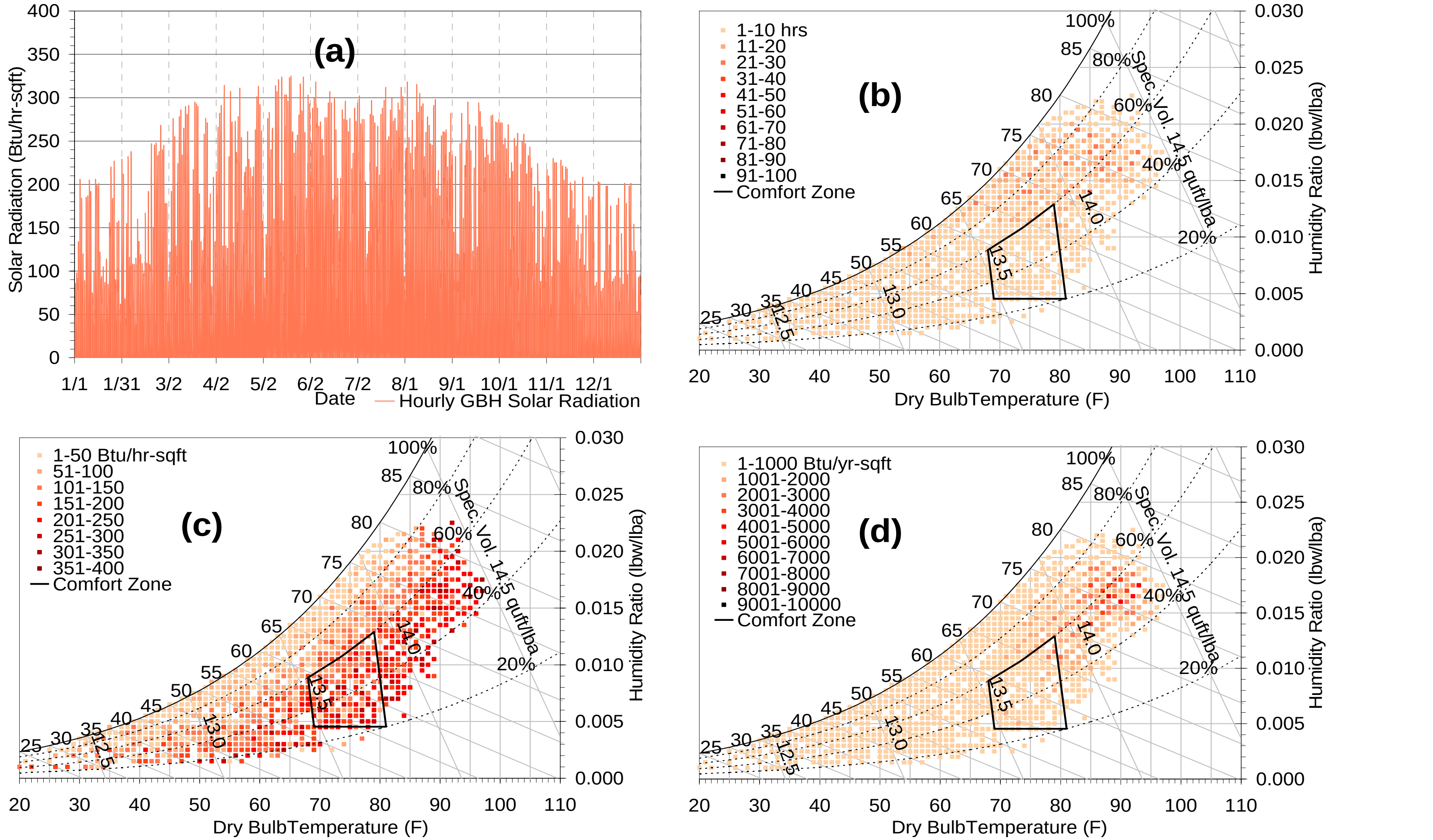


Figure 5.5 *Hourly global horizontal (GBH) solar radiation in the hot-humid climate, Houston, Texas. (a) Global horizontal solar radiation, (b) Global horizontal solar radiation density, (c) Average global horizontal solar radiation, (d) Cumulative global horizontal solar radiation.*

radiation is higher in the summer than in the winter. The highest hour in the summer is about 325 Btu/hr-ft^2 and the highest hour in the winter is about 205 Btu/hr-ft^2. The figure also shows that, at nighttime, the global horizontal solar radiation drops to 0 Btu/hr-ft^2, as expected.

In Figure 5.5b, a psychrometric plot of the frequency of occurrence of the annual hourly global horizontal (GBH) solar radiation is presented. This chart is identified to Figure 5.3c which shows daytime annual hourly ambient conditions. The figure shows that the frequency of occurrence of solar radiation is high at the temperature range between 65 to 95 °F and above 60 °F dewpoint temperature.

In Figure 5.5c, a psychrometric plot of the average hourly global horizontal (GBH) solar radiation is presented. This chart is similar to Figure 5.5b except that the varying colors are the average amount of the global horizontal solar radiation. The figure shows the relationship between the average global horizontal solar radiation, the ambient temperature, and the relative humidity. The figure shows that the average global horizontal solar radiation varies along the relative humidity line. The global horizontal solar radiation is very high at higher temperature and lower relative humidity, where these conditions usually occur during the midday. At the temperature below 30 °F, there is seldom an occurrence of high global horizontal solar radiation, indicating days of little solar radiation.

In Figure 5.5d, a psychrometric plot of the cumulative hourly global horizontal (GBH) solar radiation is presented. This chart is similar to Figure 5.5c with the exception that each point shows the total solar radiation. The figure shows the availability of solar radiation at specific ambient conditions. The figure shows that the cumulative global horizontal solar radiation is very high at temperatures above 80 °F and at relative humidity between 40 to 60%. Cumulative global horizontal solar radiation in other area is usually less than 1,000 Btu/ft^2. The total annual global horizontal solar radiation is 513,026 Btu/ft^2-year (see the DOE-2 HOURLY-REPORT, Appendix B).

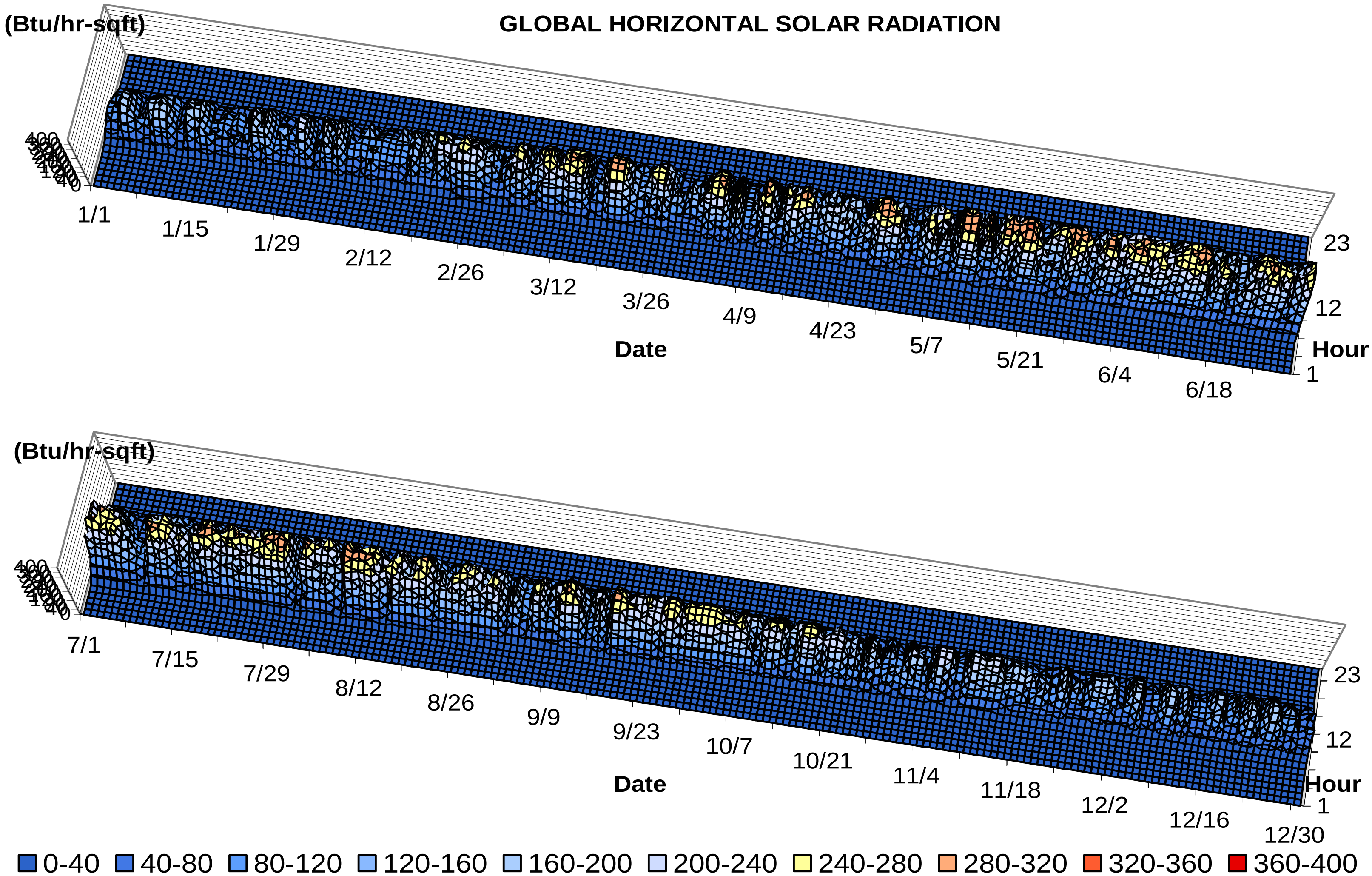


Figure 5.6 *Three dimensional surface plots of hourly global horizontal (GBH) solar radiation in the hot-humid climate, Houston, Texas.*

In Figure 5.6, the three dimensional plots of the hourly global horizontal (GBH) solar radiation are presented. The upper figure displays the period from January to June and the lower figure displays the period from July to December. This figure is similar to Figure 5.4 except that the z-axis represents the amount of solar radiation (Btu/hr-ft^2). The figures show similar results as Figures 5.5a. In addition, the hours of the occurrence is also shown in the figures. The figures show that the highest global horizontal solar radiation usually occurs around midday when solar radiation is high. global horizontal solar radiation is available longer in the summer than in the winter indicating that the daytime period is longer in the summer than in the winter. Therefore, the availability of solar radiation is significantly lower in winter.

Figures 5.7 through 5.9 are similar to Figure 5.5c. In each figure, the data for one hour across the year is shown beginning with the upper left figure in Figure 5.7 (12:00 midnight) and ending with the lower right figure in Figure 5.9 (11:00 p.m.).

These figures clearly show the hours with and without solar radiation at the corresponding ambient conditions. The ambient conditions move back and forth from left to right on the chart. At night, when there is no solar radiation, the ambient conditions stay close to the left side of the chart. The maximum temperature at night does not exceed 86 °F. The relative humidity at night stays around 60% to 100%. The figure shows that the relative humidity of the hours before sunrise is very high, around 80% to 100%. The coldest hour (14 °F) occurs in the winter at 7:00 a.m. before sunrise. In the daytime, the hottest hours (97 °F) occur at 12:00 noon and 1:00 p.m. The average global horizontal solar radiation is low in early morning and late afternoon and very high during the midday. The maximum average global horizontal solar radiation occurs at solar noon (12:00 noon). However, the temperatures continue spreading to the right of the chart for a few hours before moving back to the left. These figures show that the highest temperature of the day usually occurs around 2:00 p.m. The figures show that some hours are mixed with daytime and nighttime hours because daytime is longer in the summer than in the winter. These hours are shown in Figure 5.7 (at 5:00 and 6:00 a.m.) and Figure 5.8 (at 6:00 to 7:00 p.m.).

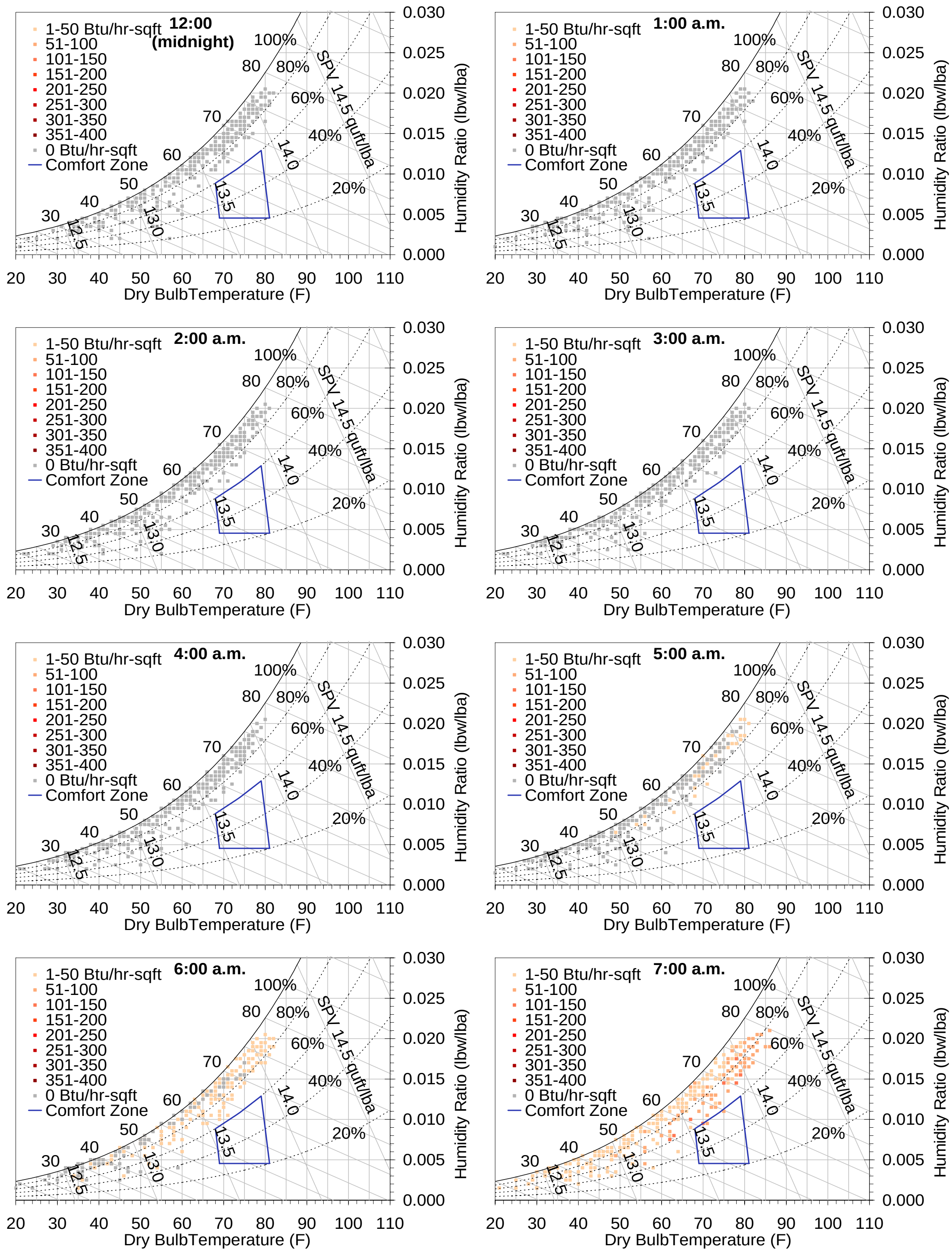


Figure 5.7 *Hourly average global horizontal (GBH) solar radiation from 12:00 (midnight) through 7:00 a.m. in the hot-humid climate, Houston, Texas.*

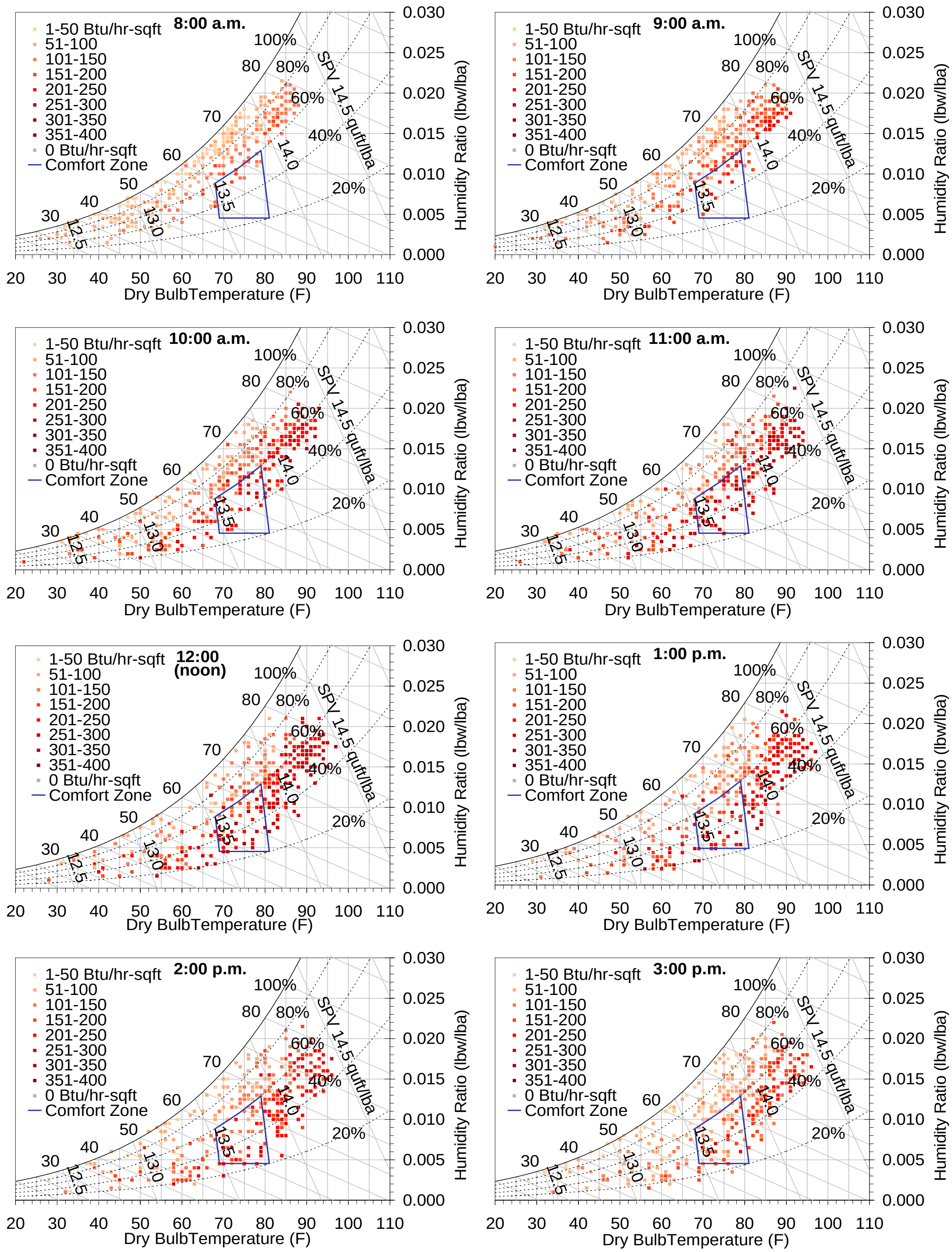


Figure 5.8 *Hourly average global horizontal (GBH) solar radiation from 8:00 a.m. through 3:00 p.m. in the hot-humid climate, Houston, Texas.*

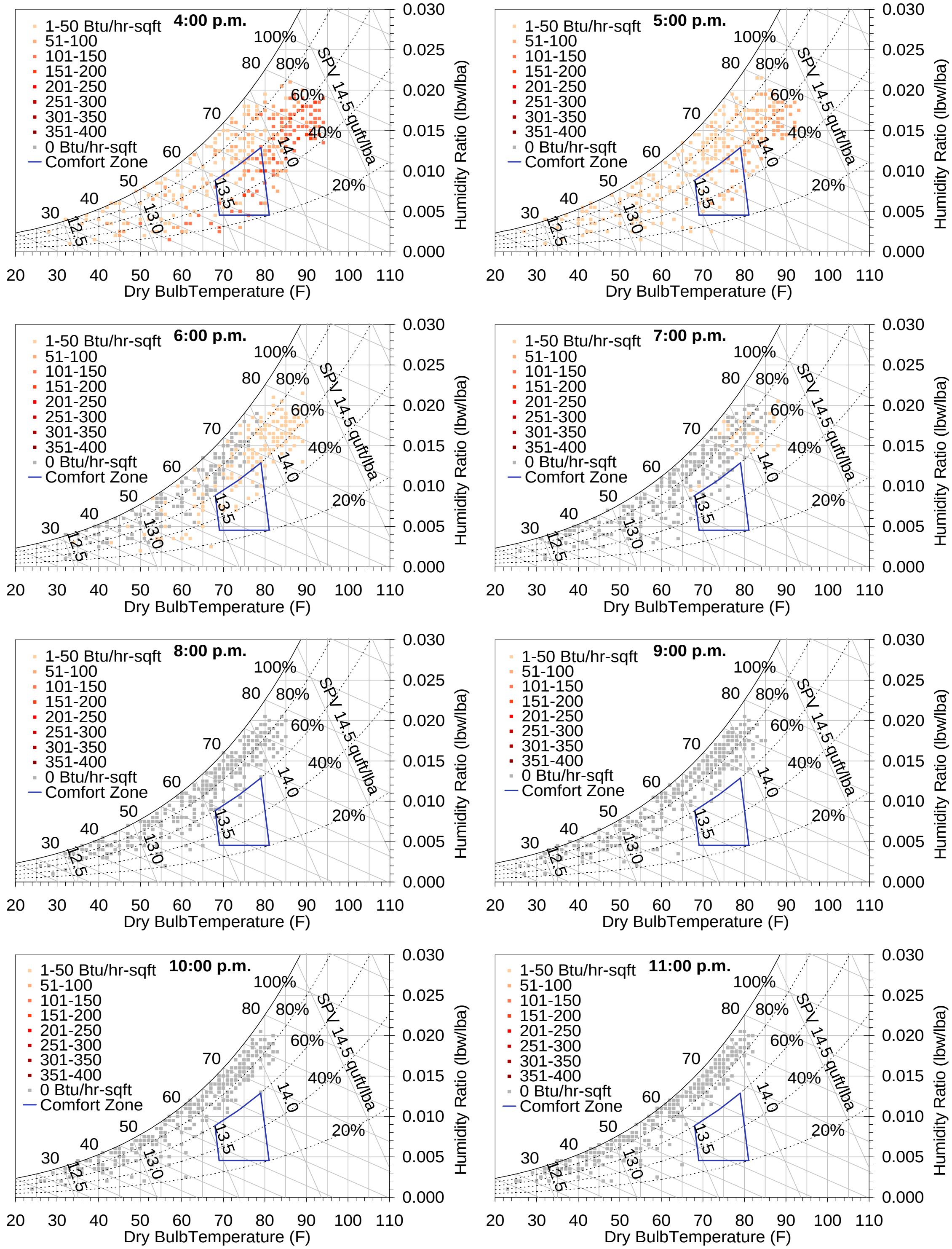


Figure 5.9 *Hourly average global horizontal (GBH) solar radiation from 4:00 p.m. through 11:00 p.m. in the hot-humid climate, Houston, Texas.*

5.1.3 Wind Data

The wind data of the representative hot-humid climate of Houston, Texas, are presented in this section.

Figure 5.10 consists of four figures (Figures 5.10a through 5.10d). Figure 5.10a shows a time series plot of the hourly wind speed. Figure 5.10b shows a 24-hour profile average hourly wind speed (upper figure) and a histogram of the wind directions (lower figure). Figures 5.10c and 5.10d display the density and the average hourly wind speed on the psychrometric chart.

In Figure 5.10a, a time series plot of the hourly wind speed is presented. The y-axis represents wind speed (mph). The figure shows that the average hourly wind speed rarely goes above 35 mph and is usually less than 20 mph. There is seldom any time when there is no wind or wind speed exceeds 20 mph.

In Figure 5.10b, the upper figure shows that the average wind speed is higher in the daytime (8 to 12 mph) than at night when the nighttime average wind speed is around 5 to 7 mph. The lowest average wind speed (5.8 to 5.9 mph) occurs during a few hours before sunrise. The highest average wind speed (11.2 mph) occurs during a few hours after solar noon. The lower figure in Figure 5.10b shows a high number of hours when the wind blows from the south (1,017 hours) and the southeast (1,027 hours). The third highest frequency is the north (805 hours). In several, with the exception of the northerly winds, the wind tends to blow from the south to east quadrant.

In Figure 5.10c, a psychrometric plot of the density of wind speed is shown that corresponds to the ambient conditions presented in Figure 5.10a. This chart is similar to Figures 5.3b and 5.5b.

In Figure 5.10d, a psychrometric plot of the average hourly wind speed is shown. The figure shows that the average wind speed is higher at higher ambient temperature

In Figure 5.10c, a psychrometric plot of the density of wind speed is shown that corresponds to the ambient conditions presented in Figure 5.10a. This chart is similar to Figures 5.3b and 5.5b.

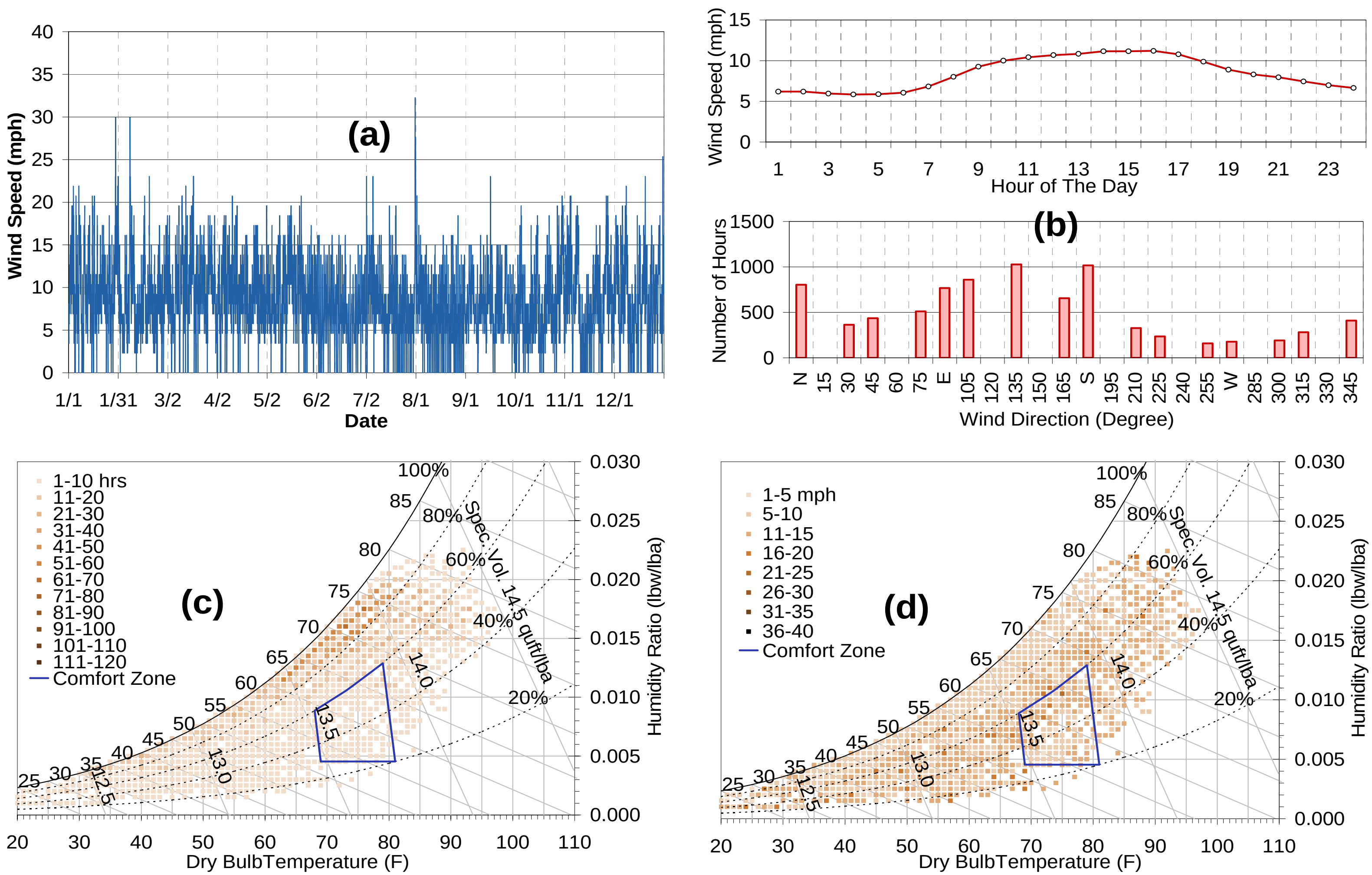


Figure 5.10 *Hourly wind speed and direction in the hot-humid climate, Houston, Texas. (a) Wind speed (top figure) and Wind direction (bottom figure), (b) Hour of the day average wind speed (top figure) and Wind direction histogram (bottom figure), (c) Wind density, and (d) Average wind speed.*

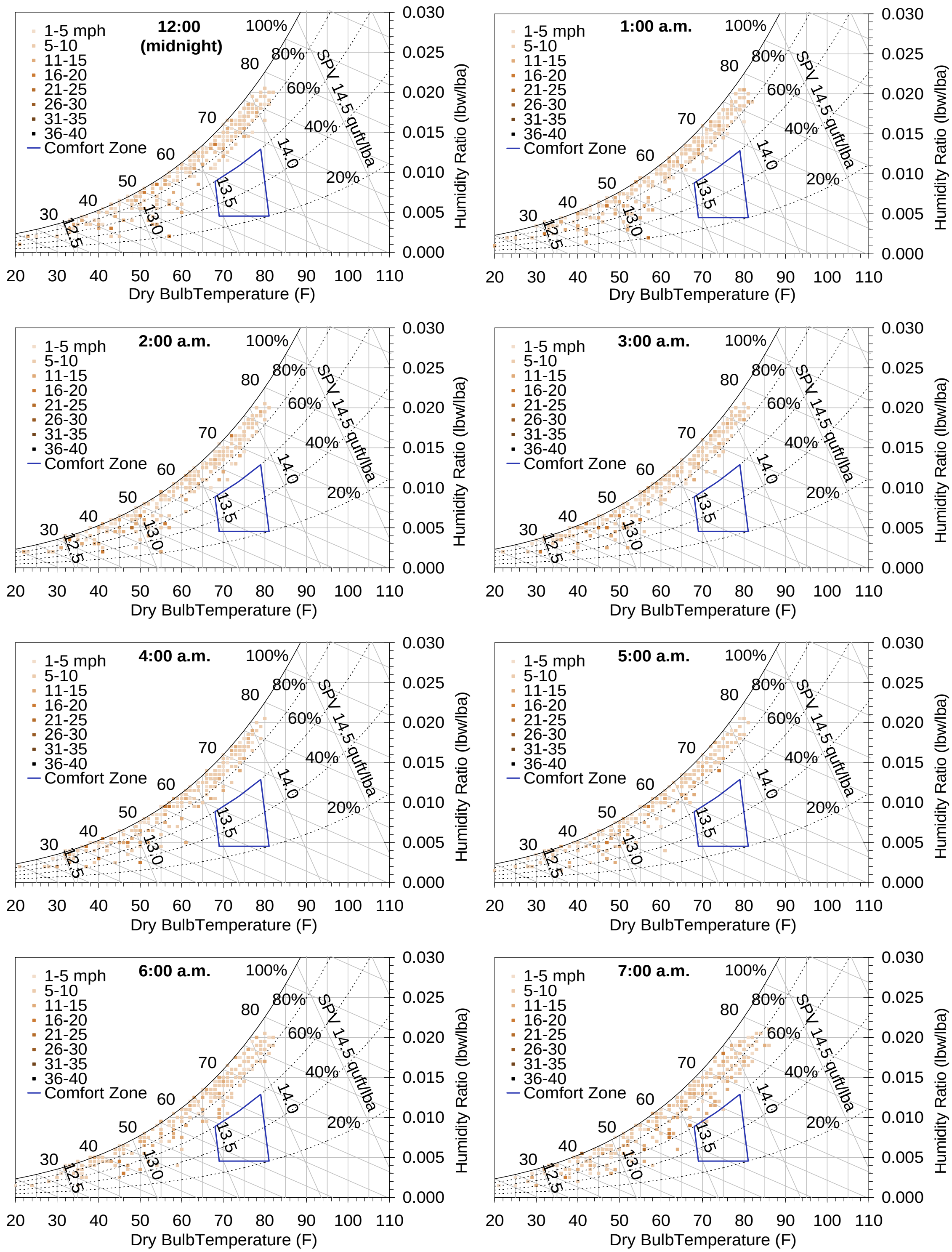


Figure 5.11 *Hourly average wind speed from 12:00 (midnight) through 7:00 a.m. in the hot-humid climate, Houston, Texas.*

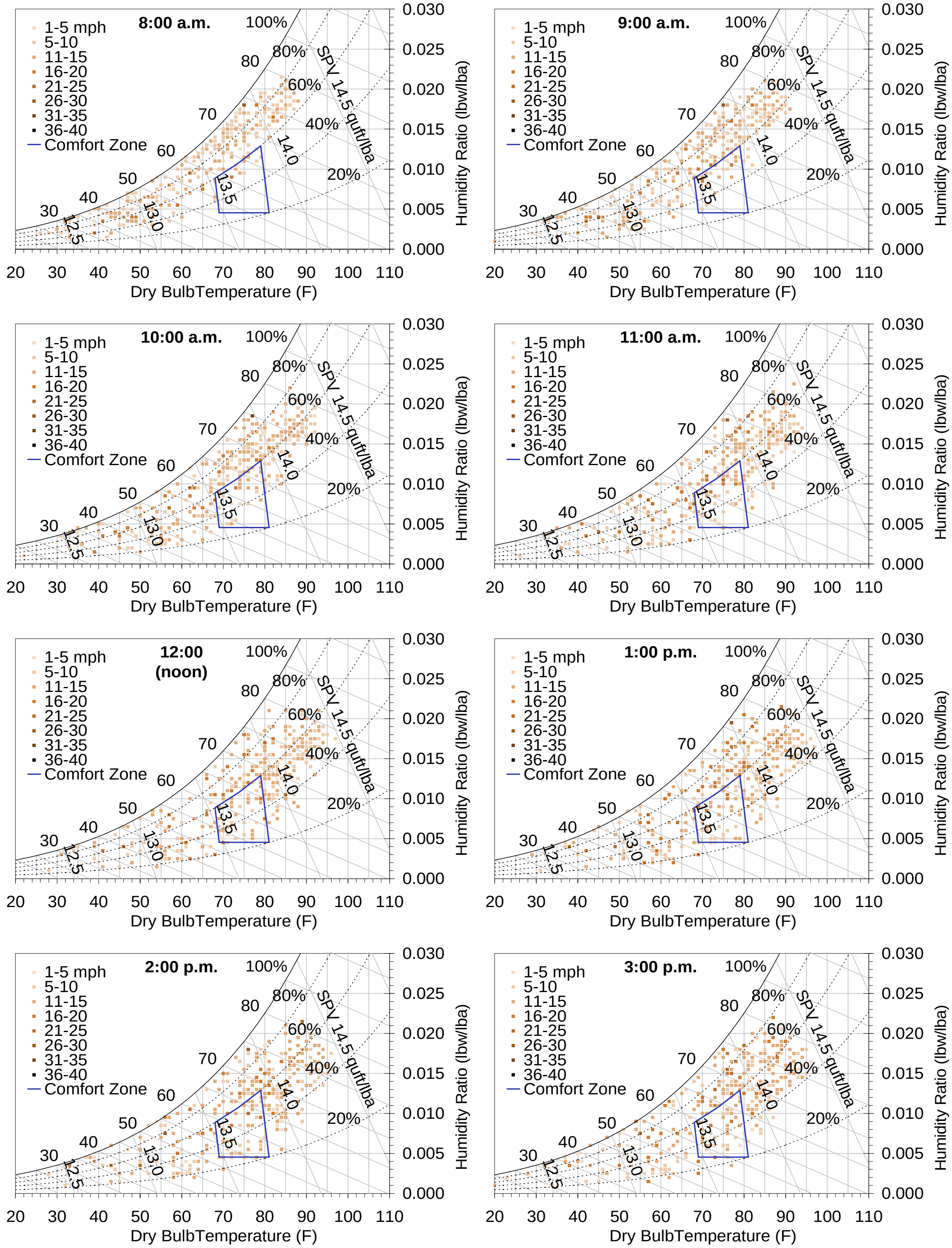


Figure 5.12 *Hourly average wind speed from 8:00 a.m. through 3:00 p.m. in the hot-humid climate, Houston, Texas.*

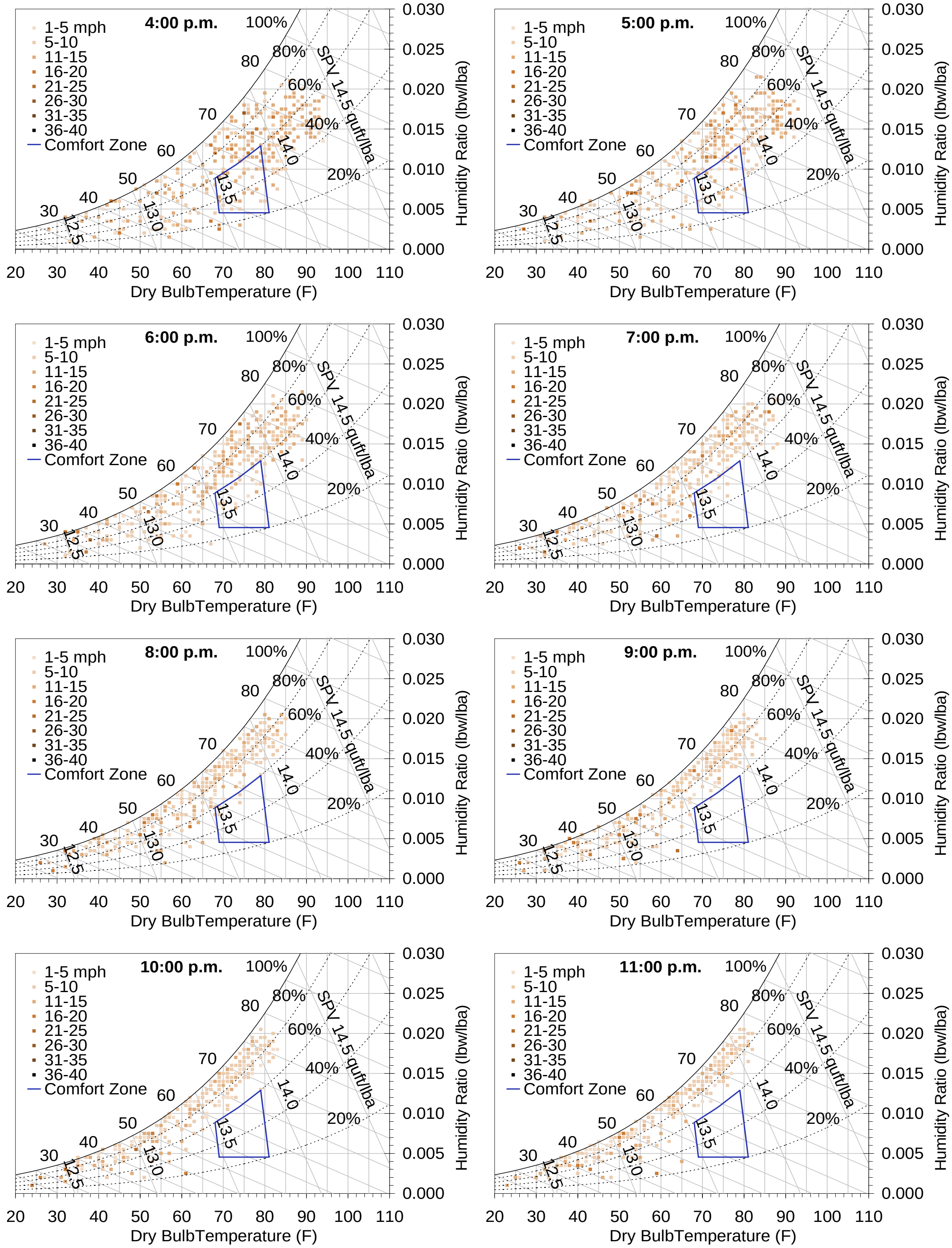


Figure 5.13 *Hourly average wind speed from 4:00 p.m. through 11:00 p.m. in the hot-humid climate, Houston, Texas.*

In Figure 5.10d, a psychrometric plot of the average hourly wind speed is shown. The figure shows that the average wind speed is higher at higher ambient temperature and lower relative humidity, which occur during the day.

Figures 5.11 through 5.13 are similar to Figure 5.10d and contain 24 figures which represent the average annual wind speed for each hour of the day that corresponds to the ambient conditions.

As stated before in Figures 5.7 through 5.9 for the solar data the wind conditions also move back and forth from the left to the right across the psychrometric chart. The results of Figures 5.11 through 5.13 correspond to the results of Figure 5.10d. Figures 5.11 through 5.13 show that the average heavy wind speed stays low at night, and increases in the day. The lowest average wind speed usually occurs during the coldest hours of the day or a few hours before sunrise. In contrast, the highest average wind speed usually occurs during the hottest hours of the day or a few hours after solar noon, which corresponds to the trend indicated in Figure 5.10b.

5.1.4 Summary and Discussion of the Weather Analysis

The results of an analysis of the representative hot-humid climate of Houston, Texas, were presented in Figures 5.3 through 5.13. These results included an analysis of thermal, solar, and wind data. The thermal data showed a wide range of the ambient dry-bulb temperature and relative humidity conditions. The ambient conditions for the whole year covered the comfort zone and were widely spread-out above the 20% relative humidity line to the left and the right of the chart. The range of the temperature and relative humidity was narrower in the summer than in the winter. In the winter, the minimum hourly temperature was 14 °F and the minimum average daily temperature was 25 °F. In the summer, the maximum hourly temperature is 97 °F and the maximum average daily temperature was 86 °F. The minimum relative humidity was 14% and maximum relative humidity was 100%. During most of the year, the relative humidity was above 80% relative humidity, which usually occurred at night.

The solar data showed that the average global horizontal (GBH) solar radiation was higher in summer than in the winter. The highest hourly average value in the summer was 325 Btu/ft²-hour and the highest hourly average value in the winter was 205 Btu/ft²-hour, and as expected the average hourly global horizontal solar radiation was highest during midday, and the daytime was longer in the summer than in the winter. Therefore, the availability of solar radiation was highest in the summer and lowest in the winter, especially at temperatures below 30 °F. The cumulative global horizontal solar radiation was very high at temperatures above 70 °F at the relative humidity between 40 to 60%. The total annual global horizontal solar radiation of Houston was 513,026 Btu/ft²-year (see the DOE-2 HOURLY-REPORT, Appendix B). On the psychometric chart, the ambient conditions moved back and forth from the left (nighttime) to the right (daytime). The coldest hour of the year (14 °F) occurred in the winter at 7:00 a.m. The hottest hours (97 °F) of the year occurred at 12:00 to 1:00 p.m. The maximum average hourly global horizontal solar radiation occurred at solar noon. The hottest hour of the day was usually around 2:00 p.m.

The wind data showed that wind speed stayed below 35 mph, and was usually less than 20 mph. Furthermore, there was seldom any time when there was no wind or the wind speed exceeded 20 mph. The average wind speed was higher in the daytime (8 to 12 mph) than at night (5 to 7 mph). The lowest average wind speed occurred a few hours before sunrise and the highest average wind speed occurred during a few hours after solar noon. The wind direction usually occurred from the south through the east. The frequency of the occurrence of the wind from the northwest to the southwest directions was low.

5.2 RESULTS OF THE DOE-2 SIMULATION AND THE G-M CHART ANALYSIS

Figure 5.14 shows a diagram of the graphical output extracted from the DOE-2 simulations. The DOE-2 simulations of four prototype houses include: 1) lightweight (base case), 2) lightweight without internal loads, 3) high thermal mass, and

4) lightweight with an economizer. These prototype houses were simulated using TMY2 weather data from the six U.S. climates and IWEC weather data from Thailand climate. This chapter presents results of the lightweight houses (base case) (Section 5.2.1) in Houston, Phoenix, and San Francisco; the lightweight house without internal loads (Section 5.2.2) in Houston; the high thermal mass house (Section 5.2.3) in Houston and Phoenix; and the lightweight house with an economizer (Section 5.2.4) in Houston and San Francisco. Additional results of the base-case houses in Bangkok, Chicago, Boston, and Boise are presented in Appendix D.

Figure 5.15 is a diagram of the results which consist of the full version (i.e., shown for Houston only) and the typical version (used for other sites). The graphical display results include several displays of the whole year of data and the results from selected periods of the year. Only the results of the lightweight house (base case) in Houston, Texas, are presented in full version (see Section 5.2.1). Results of all other simulations are presented using the typical graphs.

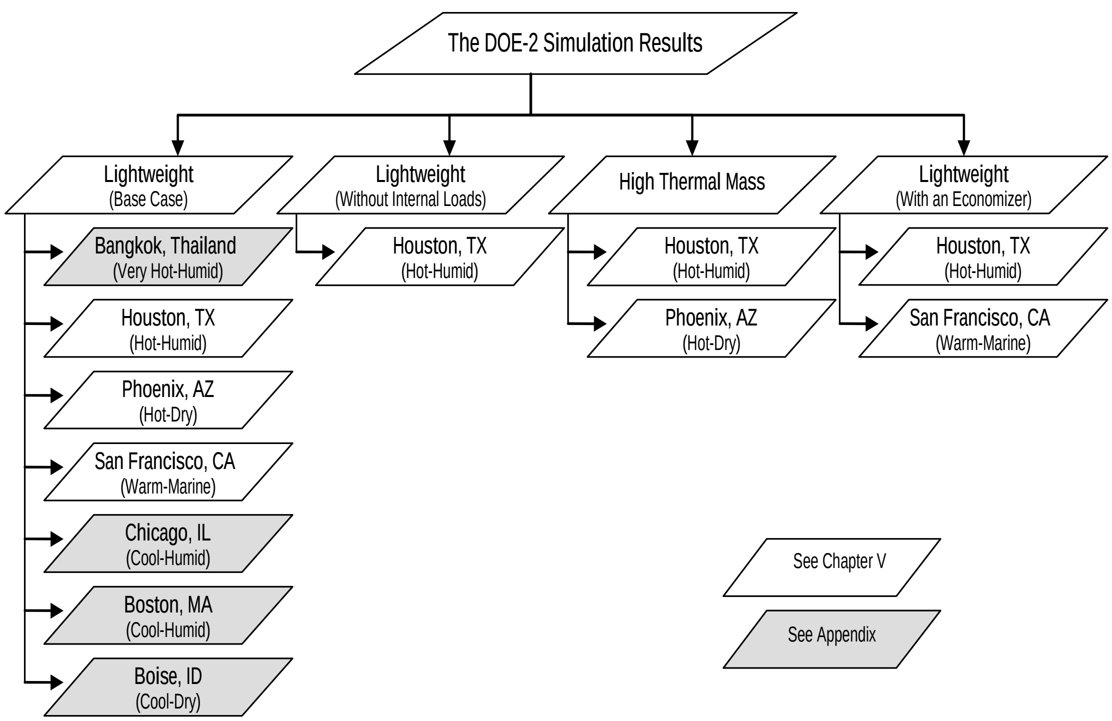


Figure 5.14 *Diagram of the DOE-2 simulation results of the prototype houses in the selected climates.*

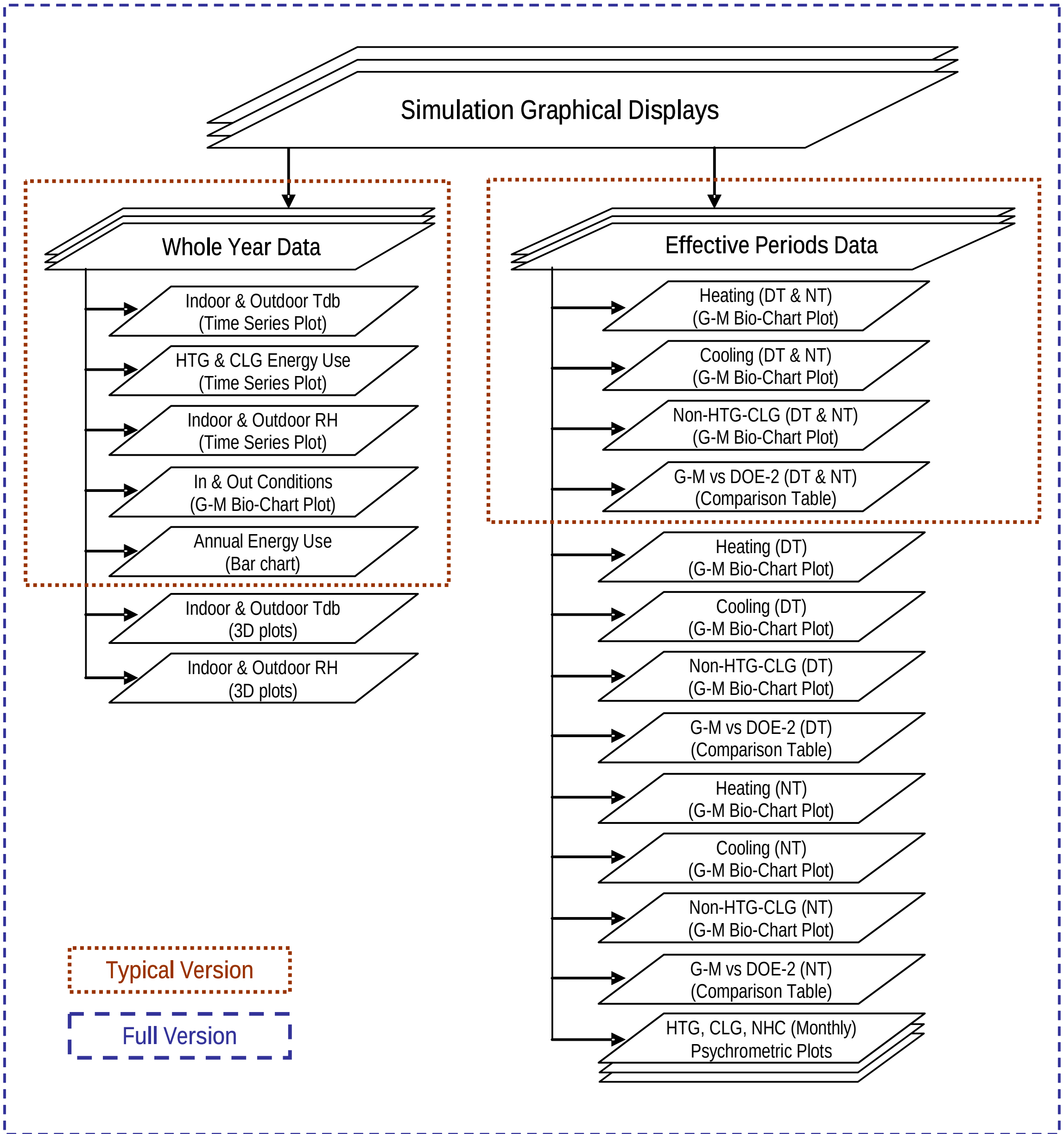


Figure 5.15 *Diagram of the graphical displays of the DOE-2 simulation results.*

Results of the DOE-2 simulation are extracted from the DOE-2 HOURLY-REPORT and the Building Energy Performance Summary (BEPS) reports. Data analysis and calculations tools are used to prepare data for the graphical displays, which are generated using Microsoft Excel. The hourly data include: dry-bulb temperature, wet-bulb temperature, humidity ratio, relative humidity (RH), specific volume, global horizontal (GBH) solar radiation, and the energy usage for heating and cooling. The BEPS report was used for the annual energy of each category, which includes domestic hot water (DHW), space heating, space cooling, ventilation fans, pump and miscellaneous, heat rejection, miscellaneous equipment, and lights.

5.2.1 Lightweight House (Base Case)

This section presents the simulated results and discussion of the lightweight house (base case) in three different climates, which are: 1) the hot-humid climate of Houston, Texas; 2) the hot-dry climate of Phoenix, Arizona; and 3) the warm-marine climate of San Francisco, California.

5.2.1.1 Lightweight house (base case) in the hot-humid climate of Houston, Texas

The full version results of the base-case house in the representative hot-humid climate of Houston, Texas, are presented in this section. Figure 5.16 consists of three plots and a bar chart (Figures 5.16a through 5.16d). Figure 5.16a shows a time series plot of the annual hourly indoor and outdoor dry-bulb temperature (Tdb) and the hourly energy use of the heating and cooling systems. Figure 5.16b presents a time series plot of the annual hourly indoor and outdoor relative humidity (RH). Figure 5.16c displays the annual hourly indoor and outdoor conditions on the G-M bioclimatic chart. Figure 5.16d presents a bar chart of annual energy use in each category.

Figure 5.16a is a time series plot of the annual hourly indoor and outdoor dry-bulb temperature (Tdb) and the hourly energy use of heating and cooling systems. The x-axis represents the day of the year. The left-hand y-axis represents dry-bulb temperature (°F) and the right-hand y-axis represents heating and cooling energy use (kW). The pink line represents the outdoor temperature and the blue line represents the indoor temperature. The heating energy uses are displayed as red triangles and cooling energy uses are displayed as blue circles.

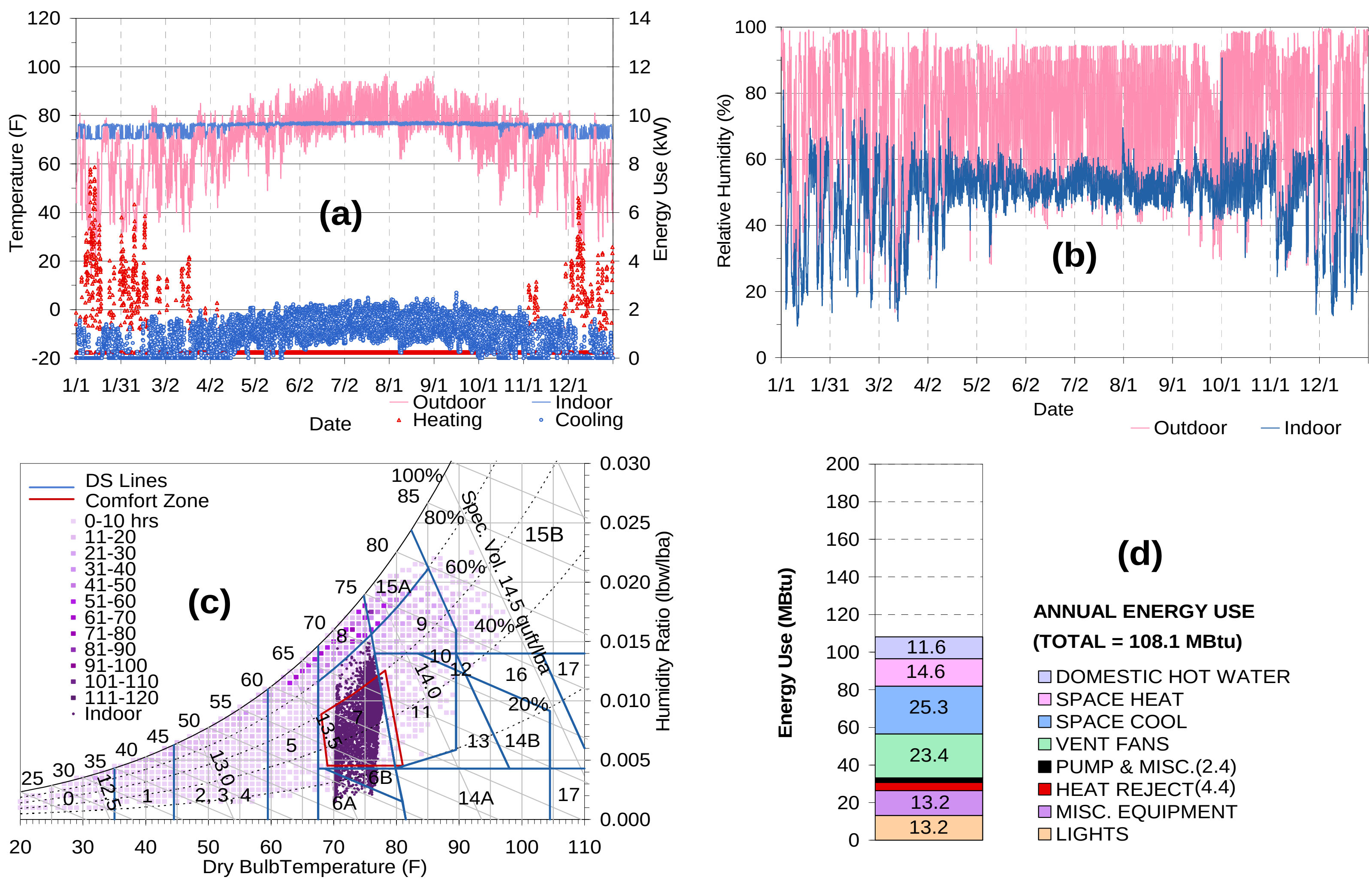


Figure 5.16 *Hourly indoor and outdoor conditions and energy use of the lightweight house (base case) in the hot-humid climate, Houston, Texas. (a) Indoor and outdoor dry-bulb temperature and energy use of gas and electricity, (b) Indoor and outdoor relative humidity, (c) Indoor and outdoor conditions on the G-M Chart, and (d) Energy use of each category.*

The figure shows a wide range of outdoor temperature for the whole year, which is in the 20 to 95 °F range. The range of the outdoor temperature in the summer, in the range of 60 to 95 °F; is narrower than the range in the winter, which is in the range of 20 to 85 °F. The indoor temperature in the cooling periods (April through October) is very well maintained, especially from mid-April to mid-October when the cooling system is activated all the time. The indoor temperature during the cooling period stays close to the cooling temperature setpoint of 78 °F. During all other periods, the indoor temperature fluctuates between heating and cooling setpoints (68 to 78 °F), which correspond to the activation of the cooling or heating systems. As expected, the cooling energy use in Houston occurs throughout the year, while the heating energy use occurs only from November to March. Throughout the year, the small, constant heating load represents the energy used by a pilot light.

Figure 5.16b is a time series plot of the hourly indoor and outdoor relative humidity (RH) is presented in this figure. The x-axis represents the day of the year. The y-axis represents relative humidity (%). The pink line represents the outdoor relative humidity and the blue line represents the indoor relative humidity.

The figure shows significant variation in the outdoor relative humidity for the whole year, which is in the 20 to 100% range. The range of the outdoor relative humidity in the summer, in the range of 40 to 95%; is narrower than the range in the winter, which is in the range of 20 to 100%. The indoor relative humidity in the summer is well maintained between 40 to 65%. However, in the other periods of the year is not very well maintained. During these other periods, the indoor relative humidity is sometimes too high or too low from 10 to 80% relative humidity. During a few times in the year, the indoor relative humidity reaches 80 to 90 % relative humidity.

Figure 5.16c is a psychrometric plot of the annual hourly indoor and outdoor conditions on the G-M Chart. The indoor conditions are displayed in small dark purple dots, which occur mostly in the 68 to 78 °F temperature range. The dots for the indoor conditions do not show the frequency of occurrence. The outdoor conditions are displayed in squares, with ranges of the frequency of occurrence shown in varying colors from very light to very dark purple as indicated in the legend. The G-M Chart design strategy boundaries are presented as blue lines and the ASHRAE comfort zone shown as a red line. The design strategy code numbers from 0 to 17 specify the areas of each design strategy region (for an explanation see Figure 5.17d).

Figure 5.16c shows that the outdoor conditions for the whole year are widely spread-out above the 20% relative humidity line, and cover areas to the left (i.e., colder) and to the right (i.e., warmer) of the comfort zone. The frequency of occurrence is highest in the areas of 60 to 85 °F when the relative humidity is above 80%, which are the G-M areas of internal gains, dehumidification, and A/C with dehumidification design strategies (regions 5, 8, and 15A). The indoor temperature falls within the comfort zone, where the temperatures stay between the heating and cooling temperature setpoints (68 to 78 ºF). However, there are many hours of the year when the indoor conditions fall above or below the humidity constraints of the comfort zone (i.e., above 60% relative humidity and below 36 °F dewpoint).

Figure 5.16d shows a stacked bar chart of annual energy use in each category. The x-axis represents the total annual energy use and the energy use in each category, which are presented in different colors as shown in the legend. The y-axis represents the energy use in MBtu/year. The energy use categories include the energy use of gas which is the energy used for domestic hot water (DHW) and space heating; and the energy use of electricity for space cooling, ventilation fans, pumps and miscellaneous, heat rejection, miscellaneous equipment, and lights.

Figure 5.16d shows that the total annual energy use is 108.1 MBtu. The energy use includes: domestic hot water (11.6 MBtu), space heating (14.6 MBtu), space cooling (25.3 MBtu), ventilation fans (23.4 MBtu), pump and miscellaneous (2.4 MBtu), heat rejection (4.4 MBtu), miscellaneous equipment (13.2 MBtu), and lights (13.2 MBtu). From the results, the energy use for cooling is the highest, with almost twice that of energy used for heating.

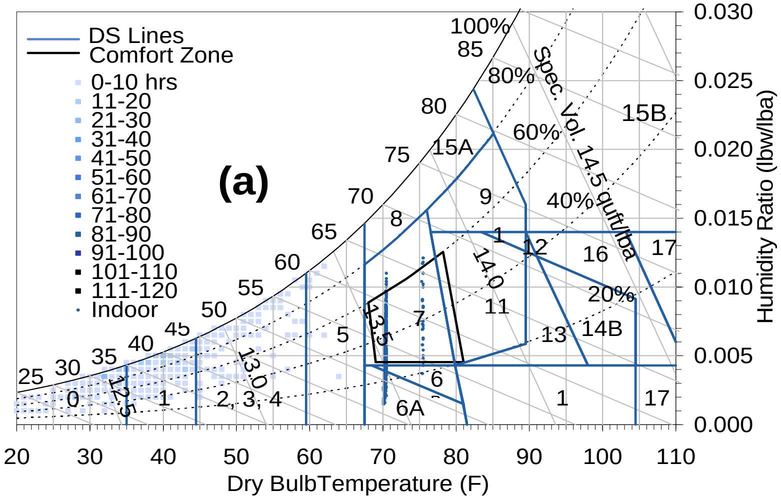
Figure 5.17 consists of Figures 5.17a through 5.17d, which shows the daytime and nighttime annual hourly indoor and outdoor conditions on the G-M Chart during the heating period (Figure 5.17a), cooling period (Figure 5.17b), non-heating period (Figure 5.17c), and a comparison table of the results from the G-M Chart and the DOE-2 simulations (Figure 5.17d).

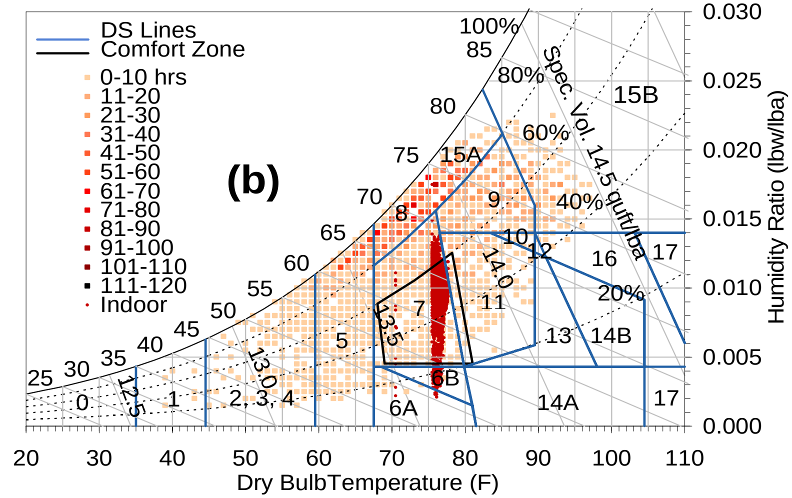
Figure 5.17a is a psychrometric plot of the annual hourly daytime and nighttime indoor and outdoor conditions on the G-M Chart during the heating period as determined by the DOE-2 program. Figure 5.17a is similar to Figure 5.16c except that the ASHRAE comfort zone is displayed as a black line and the indoor and outdoor conditions are displayed in shades of blue.

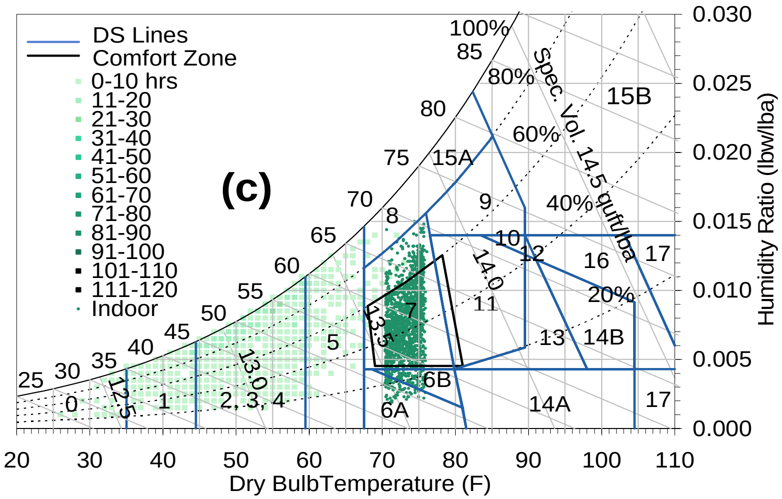
The figure shows that most of the outdoor conditions during the heating period cover an area to the left of the comfort zone. The majority of the hours involve the G-M definitions of conventional heating, active solar, and passive solar design strategies (regions 0 to 4). Only a few hours fall upon internal gains design strategy (region 5). Most of indoor temperatures stay close to the heating temperature setpoint of 68 °F. However, there is very small portion of the hours that stay close to the cooling temperature setpoint of 78 °F. Most of these hours occur individually right after the hours that the cooling system was continuously activated (see the DOE-2 HOURLY-REPORT, Appendix B). These are most likely due to the indoor temperature fluctuations that are usually found in a lightweight house. In Figure 5.17a, there are many hours in this period that the indoor conditions fall above or below the humidity constraints of the ASHRAE comfort zone.

Figure 5.17b displays a psychrometric plot of the annual hourly daytime and nighttime indoor and outdoor conditions on the G-M Chart during the cooling period as determined by the DOE-2 program. Figure 5.17b is similar to Figure 5.17a except that the indoor and outdoor conditions from January- through December are shown in shades of red.

The figure shows that the outdoor conditions during the cooling period fall into the comfort zone and are spread-out to the right, left, and above the comfort zone. The cooling data covers regions of heating design strategy, which are passive solar and internal gains (regions 2 to 5); the G-M comfort zone (region 7); and the cooling design







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Design Strategies	Regions	G-M Bio-Chart (%)	DOE-2 Simulation		
			HTG (%)	CLG (%)	N-H-C (%)
Conventional Heating	0	2.81	2.56	0.00	0.25
Active Solar	1	6.68	4.18	0.08	2.42
Passive Solar	2,3,4	16.07	1.60	2.60	11.87
Internal Gains	5	13.89	0.09	11.22	2.58
Humidification	6A, 6B	0.17	0.00	0.17	0.00
Comfort Zone	7	9.94	0.00	9.71	0.23
Dehumidification	8	16.72	0.00	16.68	0.05
Ventilation	9,10,11	19.76	0.00	19.76	0.00
Evaporative Cooling	6B,11,13,14A,14B	5.92	0.00	5.92	0.00
High Thermal Mass	10,11,12,13	6.48	0.00	6.48	0.00
High Thermal Mass with Night Ventilation	16, 14B	0.15	0.00	0.15	0.00
Air-Conditioning	17	0.00	0.00	0.00	0.00
Air-Conditioning & Dehumidification	15A,15B	13.78	0.00	13.78	0.00
Number of Hours/Year		8760	738	6498	1524
Percentage of Hours/Year		100.00	8.42	74.18	17.40

Region	0	1	2	3	4	5	6A	6B	7	8	9	10	11	12	13	14A	14B	15A	15B	16	17	Total
Hours	246	585	368	478	562	1217	10	5	871	1465	1165	52	514	2	0	0	0	781	426	13	0	8760
G-M (%)	2.8	6.7	4.2	5.5	6.4	13.9	0.1	0.1	9.9	16.7	13.3	0.6	5.9	0.0	0.0	0.0	0.0	8.9	4.9	0.1	0.0	100.00
Total (%)		9.49								40.08											50.43	100.00

Figure 5.17 *Daytime and nighttime hourly indoor and outdoor conditions of the lightweight house (base case) in the hot-humid, Houston, Texas, on the G-M Chart. (a) Heating period, (b) Cooling period, (c) Non-heating-cooling period, and (d) Comparison of the results from the G-M Chart vs. the DOE-2 simulation.*

strategy regions, which include dehumidification, ventilation, evaporative cooling, high thermal mass, and A/C with dehumidification (regions 8, 9 to 11, 10 to 12, and 15). A small portion of the cooling data falls within the areas of active solar, humidification, and high thermal mass with night ventilation design strategies (regions 1, 6, and 16). The frequency of occurrence is very high in the areas of internal gains, dehumidification, and air-conditioning (A/C) with dehumidification design strategies (regions 5, 8, and 15A). Most indoor temperatures stay close to the cooling temperature setpoint of 78 °F. However, a very few hours stay close to the heating temperature setpoint of 68 °F. Most of these hours occur individually right after the hours that the heating system was continuously activated (see the DOE-2 HOURLY-REPORT, Appendix B). These are most likely due to the indoor temperature fluctuations of a lightweight house. There are many hours in this period that the indoor conditions fall above or below the humidity constraints of the comfort zone.

Figure 5.17c shows a psychrometric plot of the annual hourly daytime and nighttime indoor and outdoor conditions on the G-M Chart during the non-heating-cooling period. Figure 5.17c is similar to Figure 5.17a except that the indoor and out door conditions are displayed in shades of green.

The figure shows that majority of the outdoor conditions during the non-heating-cooling period fall to the left of the comfort zone, which include areas of active solar, passive solar, and internal gains design strategies (regions 1 to 5). Only a small portion falls within the area of conventional heating, the G-M comfort zone, and dehumidification (regions 0, 7, and 8). The frequency of occurrence is high in the area of passive solar design strategies (regions 2 to 4). The indoor temperatures mostly float between the heating and cooling temperature setpoints (68 to 78 °F). There are many hours in this period that the indoor conditions fall above or below the humidity constraints of the comfort zone.

Figure 5.17d shows the design strategies of the G-M Chart that correspond to the G-M region code numbers in the second column. The third column shows results from the G-M Chart as the percentage of hours that fall in each design strategy region. The last three columns show results from the DOE-2 simulation as the percentage of hours that fall within each design strategy region during heating, cooling, and non-heating-cooling periods; respectively. The number of hours and percentages-per-year are shown at the bottom of the columns. The forth row from the bottom displays the G-M design strategy regions from 0 to 17. The percentage and number of hours that fall within these regions are displayed in the second and third rows from the bottom. The last row presented the hours in the specific regions are grouped into the heating period (blue), cooling period (pink), and non-heating-cooling period (green) that correspond to the DOE-2 simulation conditions.

The results from the DOE-2 simulation show that there are 738 hours (8.42%) of the year that the heating system is activated. The cooling system is activated for 6,498 hours (74.18%) and there are 1,524 hours (17.40%) when neither the heating nor cooling systems is activated. The results from the G-M Chart analysis show that there are 831 hours (9.49%) in the heating period. There are 3,511 hours (50.43%) in the cooling period, and 4,418 hours (40.08%) in the non-heating-cooling period.

In this simulation, there are some influences from solar radiation on the house and the house has internal loads. Therefore, passive solar and internal gains design strategies (regions 2 to 4 and 5) are excluded from the heating period design strategies and were added instead to the non-heating-cooling period. The effective design strategy regions for heating period in the G-M Chart analysis include conventional heating and active solar design strategies (regions 0 and 1; see as last row, blue region). The effective design strategy regions for cooling period in the G-M Chart analysis cover the regions from 8 to 17, which are: dehumidification, ventilation, evaporative cooling, high thermal mass (with and without night ventilation), and air-conditioning (with and without dehumidification) (see last row, pink region). The effective design strategy regions for non-heating-cooling period in the G-M Chart analysis cover the regions from 2 to 7, which are: passive solar, internal gains, humidification, and the G-M comfort zone (see the last row, green region).

Figure 5.17d allows the results from the DOE-2 simulation to be compared to the G-M bioclimatic chart. As mentioned in the previous paragraphs, the DOE-2 simulation showed 8.42% of the time in heating period, which is similar but slightly less than the G-M Chart results (9.49%). In this period, DOE-2 shows that 2.56% of the time falls into conventional heating design strategy (region 0). This is also very close to the results from the G-M Chart, which show 2.81%. However, in active solar design strategy (region 1), the percentage of the time from the DOE-2 simulation results (4.18%) is less than the results from the G-M Chart (6.68%). In addition, DOE-2 shows that there is a portion of heating period in passive solar (regions 2 to 4, 1.60%) and internal gains (region 5, 0.09%) design strategies.

In the cooling period, DOE-2 calculated 74.18% of the hours-per-year versus the G-M Chart showing only 50.43%. In regions 8 to 17, which are the cooling design strategy regions, the results from the DOE-2 simulation correspond to the results from the G-M Chart analysis. The differences are in regions 1 to 7. In Figure 5.17d, DOE-2 shows that a significant portion falls into region 5 (internal gains, 11.22%) and region 7 (the G-M comfort zone, 9.71%). Unfortunately, in a G-M Chart analysis, regions 5 and 7 are not usually considered cooling periods.

In the non-heating-cooling period (Figure 5.17d), the results from the DOE-2 simulation are far from the same results from the G-M Chart. The DOE-2 simulation shows 17.40% of the hours in the year in this period while the G-M Chart shows as much as 40.08% of the time. The DOE-2 simulation shows a small portion occurs in regions 0 and 1 (conventional heating and active solar), where for this period are not included in the G-M Chart analysis. In region 2 to 4 (passive solar), the results from the DOE-2 simulation (11.87%) are less than the results from the G-M Chart analysis (16.07%). Surprisingly, there are significant differences in regions 5 and 7 (internal gains and G-M comfort zone). DOE-2 shows only 2.58% in region 5 and 0.23% in region 7 versus the G-M Chart which shows 13.89% in region 5 and 9.94% in region 7.

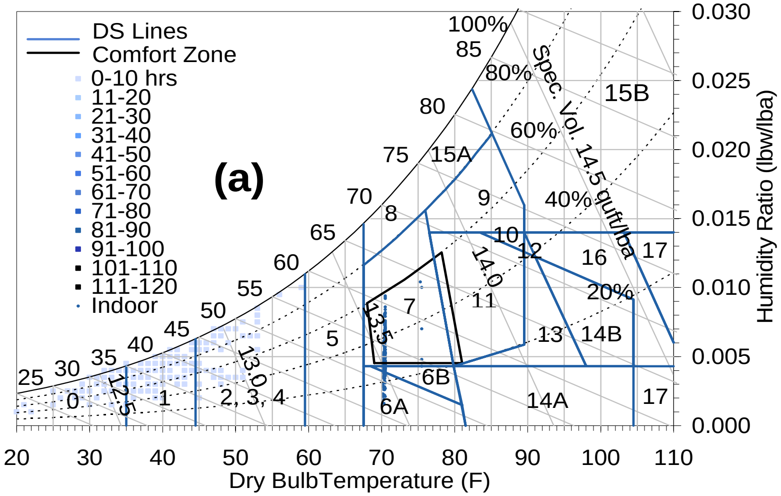
Figure 5.18 is similar to Figure 5.17. The figure consists of Figures 5.18a through 5.18d, which include the daytime annual hourly indoor and outdoor conditions on the

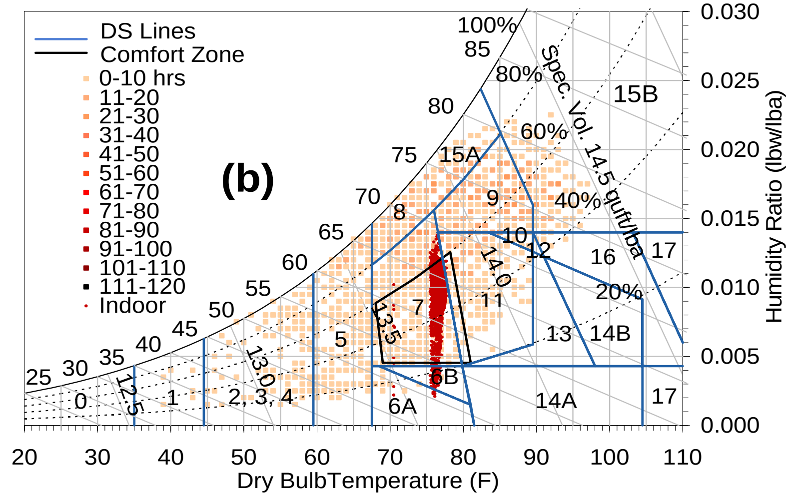
G-M Chart during heating period (Figure 5.18a is similar to Figure 5.17a), cooling period (Figure 5.18b is similar to Figure 5.17b), non-heating-cooling period (Figure 5.18c is similar to Figure 5.17c), and a comparison table of the results from the G-M Chart and the DOE-2 simulation (Figure 5.18d is similar to Figure 5.17d).

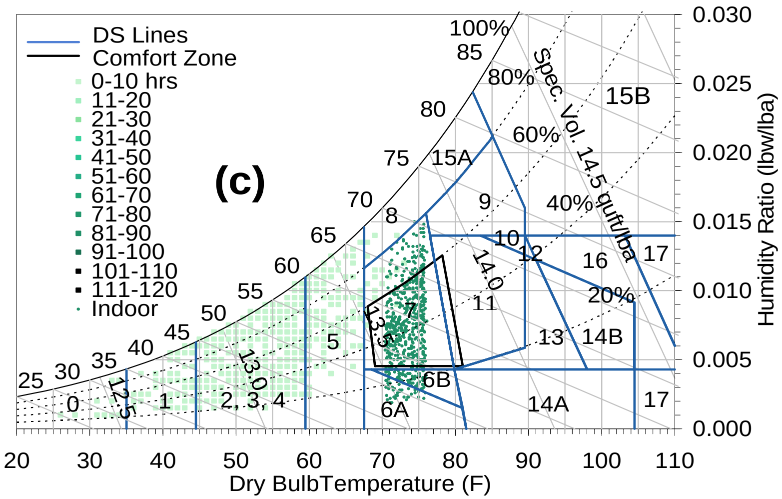
Figure 5.19 is also similar to Figure 5.17. The figure also consists of: Figures 5.19a through 5.19d, which include the nighttime annual hourly indoor and outdoor conditions on the G-M Chart during heating period (Figure 5.19a is similar to Figure 5.17a), cooling period (Figure 5.19b is similar to Figure 5.17b), non-heating-cooling period (Figure 5.19c is similar to Figure 5.17c), and a comparison table of the results from the G-M Chart and the DOE-2 simulation (Figure 5.19d is similar to Figure 5.17d). Figures 5.18 and 5.19 are daytime and nighttime results of heating, cooling, and non-heating-cooling periods. The daytime and nighttime outdoor conditions of all periods are presented in Figures 5.3c through 5.3d.

Figures 5.18a and 5.19a show that the outdoor conditions of the heating period are spread-out to cover a wide range at nighttime than in daytime. The majority of daytime and nighttime heating period fall upon the G-M conventional heating, active solar, and passive solar design strategies (regions 0 to 4). Only a small portion of heating period during the nighttime falls into the internal gains design strategy (region 5). As expected, since the temperature during the nighttime is lower than during the daytime, the need for heating occurs at a lower temperature than in the daytime. In the conventional heating design strategy (region 0), where the availability of solar radiation is very low (see Figures 5.5b and 5.5c), the heating system is activated all day long from daytime to nighttime (see the DOE-2 HOURLY-REPORT, Appendix B).

In the active solar design strategies region (region 1), the need for heating is usually found consecutively from 9 to 10 a.m. or 9 to 10 p.m., which is about 3 to 4 hours after sunrise and sunset (see the DOE-2 HOURLY-REPORT, Appendix B). The delay for heating after sunrise and sunset could be the effect of thermal time lag, which is the time needed to store or release the solar radiation into or out of the mass of the building’s interior.







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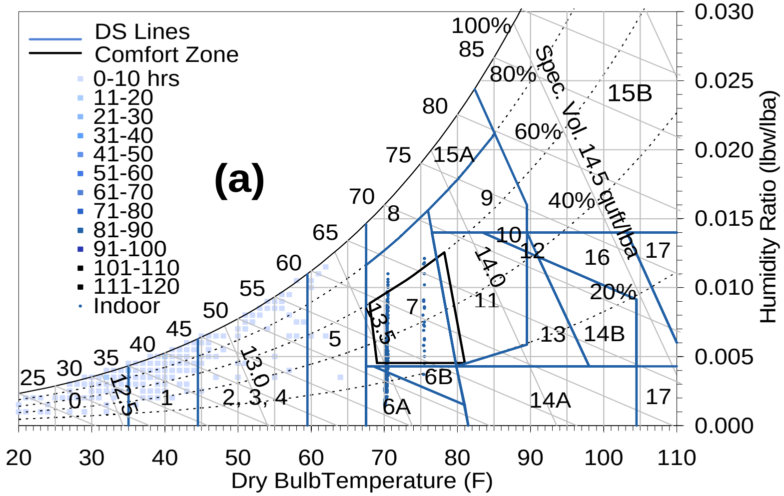
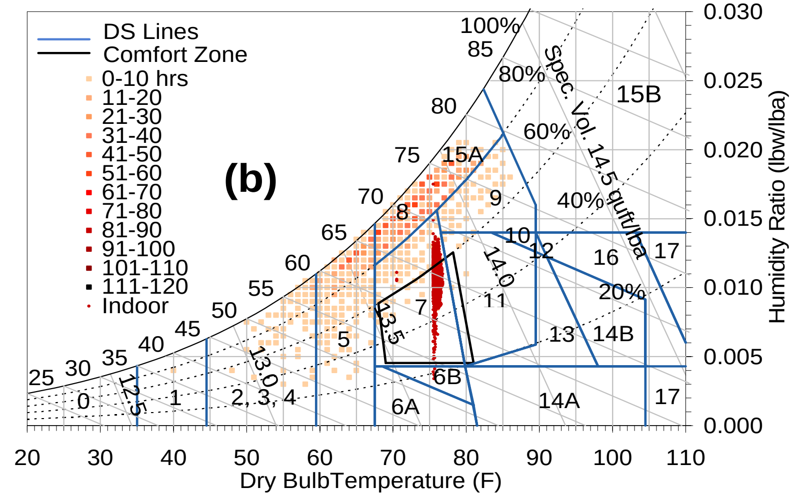
(d)

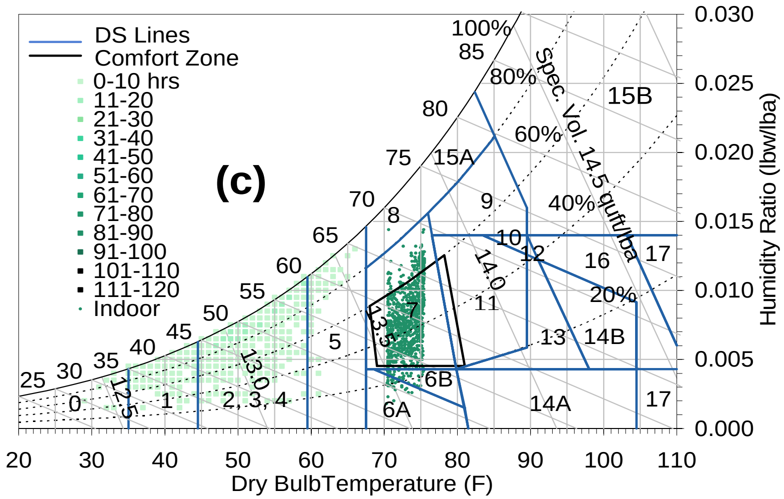
Design Strategies	Regions	G-M Bio-Chart (%)	DOE-2 Simulation HTG (%)	DOE-2 Simulation CLG (%)	DOE-2 Simulation N-H-C (%)
Conventional Heating	0	0.78	0.64	0.00	0.14
Active Solar	1	2.20	1.44	0.07	0.70
Passive Solar	2,3,4	6.62	0.61	1.48	4.53
Internal Gains	5	5.38	0.00	3.73	1.64
Humidification	6A, 6B	0.17	0.00	0.17	0.00
Comfort Zone	7	7.88	0.00	7.65	0.23
Dehumidification	8	4.77	0.00	4.73	0.05
Ventilation	9,10,11	17.82	0.00	17.82	0.00
Evaporative Cooling	6B,11,13,14A,14B	5.80	0.00	5.80	0.00
High Thermal Mass	10,11,12,13	6.36	0.00	6.36	0.00
High Thermal Mass with Night Ventilation	16, 14B	0.15	0.00	0.15	0.00
Air-Conditioning	17	0.00	0.00	0.00	0.00
Air-Conditioning & Dehumidification	15A,15B	7.80	0.00	7.80	0.00
Number of Hours/Year		4694	235	3821	638
Percentage of Hours/Year		53.58	2.68	43.62	7.28

Region	0	1	2	3	4	5	6A	6B	7	8	9	10	11	12	13	14A	14B	15A	15B	16	17	Total
Hours	68	193	132	194	254	471	10	5	690	418	1006	52	503	2	0	0	0	257	426	13	0	4694
G-M (%)	0.8	2.2	1.5	2.2	2.9	5.4	0.1	0.1	7.9	4.8	11.5	0.6	5.7	0.0	0.0	0.0	0.0	2.9	4.9	0.1	0.0	53.58
Total (%)		2.98							20.05												30.56	53.58

Figure 5.18 *Daytime hourly indoor and outdoor conditions of the lightweight house (base case) in the hot-humid, Houston, Texas, on the G-M Chart. (a) Heating period, (b) Cooling period, (c) Non-heating-cooling period, and (d) Comparison of the results from the G-M Chart vs. the DOE-2 simulation.*







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(d)

Design Strategies	Regions	G-M Bio-Chart (%)	DOE-2 Simulation HTG (%)	DOE-2 Simulation CLG (%)	DOE-2 Simulation N-H-C (%)
Conventional Heating	0	2.03	1.92	0.00	0.11
Active Solar	1	4.47	2.74	0.01	1.72
Passive Solar	2,3,4	9.45	0.99	1.12	7.34
Internal Gains	5	8.52	0.09	7.49	0.94
Humidification	6A, 6B	0.00	0.00	0.00	0.00
Comfort Zone	7	2.07	0.00	2.07	0.00
Dehumidification	8	11.95	0.00	11.95	0.00
Ventilation	9,10,11	1.94	0.00	1.94	0.00
Evaporative Cooling	6B,11,13,14A,14B	0.13	0.00	0.13	0.00
High Thermal Mass	10,11,12,13	0.13	0.00	0.13	0.00
High Thermal Mass with Night Ventilation	16, 14B	0.00	0.00	0.00	0.00
Air-Conditioning	17	0.00	0.00	0.00	0.00
Air-Conditioning & Dehumidification	15A,15B	5.98	0.00	5.98	0.00
Number of Hours/Year		4066	503	2677	886
Percentage of Hours/Year		46.42	5.74	30.56	10.11

Region	0	1	2	3	4	5	6A	6B	7	8	9	10	11	12	13	14A	14B	15A	15B	16	17	Total
Hours	178	392	236	284	308	746	0	0	181	1047	159	0	11	0	0	0	0	524	0	0	0	4066
G-M (%)	2.0	4.5	2.7	3.2	3.5	8.5	0.0	0.0	2.1	12.0	1.8	0.0	0.1	0.0	0.0	0.0	0.0	6.0	0.0	0.0	0.0	46.42
Total (%)		6.51								20.03											19.87	46.42

Figure 5.19 *Nighttime hourly indoor and outdoor conditions of the lightweight house (base case) in the hot-humid, Houston, Texas, on the G-M Chart. (a) Heating period, (b) Cooling period, (c) Non-heating-cooling period, and (d) Comparison of the results from the G-M Chart vs. the DOE-2 simulation.*

In the area of passive solar and internal gains design strategies (regions 2 to 4 and 5), the figures show that the range of outdoor temperatures is higher during the daytime than at night. The need for heating at higher temperatures at night is not fully understood.

Usually, the daytime and nighttime indoor temperatures stay close to the heating temperature setpoint (68 °F). The hours when the indoor temperatures stay close to the cooling temperature setpoint (78 °F), appear more often at night than in the day. These hours are found individually right after the hours when the cooling system was continuously activated, usually in the late evening in the wintertime when the stored from solar radiation is high and there is a need for cooling (see the DOE-2 HOURLY-REPORT, Appendix B). Figure 5.19a shows a significant portion of the indoor humidity falls below the lower level of the comfort zone. Figure 5.19a shows that the indoor conditions during the daytime do not exceed the upper level of the comfort zone.

In Figures 5.18b and 5.19b, the cooling period shows that the outdoor conditions are spread-out and cover a wide range during the day than at night. The daytime outdoor conditions during the cooling period fall into the comfort zone and are spread-out to the right, the left, and above the comfort zone. A significant portion of the outdoor conditions during the cooling period at night falls above the 60% relative humidity line with a very high frequency of 80 to 100% relative humidity.

The need for cooling was found at higher temperatures during the day because the outdoor temperature was higher in the daytime than at night. On the other hand, the need for cooling was found at a lower temperature during the day than at night. This could be the results of the contribution of heat from the sun that are added to the air. In the winter, the need for cooling usually occurs on a warm or a mild day when the available solar radiation and intensity are high. These hours of occurrence are around midday to late evening up to four hours after sunset when the thermal time lag takes effect (see the DOE-2 HOURLY-REPORT, Appendix B). Many of these hours fall into the passive solar and internal gains design strategy (regions 2 to 4) and some fall into the G-M comfort zone (region 7).

During the cooling period, the daytime and nighttime indoor temperatures stay close to the cooling temperature setpoint (78 °F). However, the fluctuation of indoor temperature during the daytime is larger than at night. This could be the effect of the solar radiation during the daytime that changes from hour to hour. The hours when the indoor temperatures remain close to the heating temperature setpoint (68 °F) are usually found during the day rather than at night. These hours are found individually right after the hours when the heating system was activated, usually early in the morning of a normal cold day when the heating was needed at night (see the DOE-2 HOURLY-REPORT, Appendix B). The figures show that there are many hours, both day and night, when the indoor humidity levels are too high or too low. Humidity above the upper level of the comfort zone is more severe at night than in the day and humidity below the lower level is more severe during the day than at night.

In Figures 5.18c and 5.19c, in a similar fashion as the heating period, the non-heating-cooling period shows that the outdoor conditions fall mostly to the left of the comfort zone and spread-out over a wider range during the day than during the night.

In the conventional heating design strategy (region 0), there should be no need for heating when the availability of solar radiation is significantly high (see Figures 5.5b and 5.5c). These hours rarely occur, but if they do, they are usually found in late morning to late afternoon of a very cold day (see the DOE-2 HOURLY-REPORT, Appendix B). The nighttime hours of the non-heating-cooling period in region 0 are usually found around 9 to11 p.m. on a normal cold day when temperatures are continuing to drop after sunset from region 2 to region 0 or until they are about to reach the hours that the heating system is activated (see the DOE-2 HOURLY-REPORT, Appendix B).

In the active solar design strategies region (region 1), there should be no need for heating when the solar radiation is high. The portion of the non-heating-cooling period in region 1 is usually found in a normal cold day from 9 or 10 a.m. to 9 or 10 p.m., which is about 3 to 4 hours after sunrise and sunset. This is due to the heat from the solar radiation, which is stored in the mass of the house, which helps to balance indoor and outdoor conditions and delay the need for heating at night.

In region 2 to 4 and 5, the hours of the occurrence of the non-heating-cooling period varies through out the seasons. The non-heating-cooling period in these regions is usually found during a cold day, when the sun is available, during the hours when the daytime overlaps into the night or found during a warm day during the hours when the nighttime overlaps into daytime (see the DOE-2 HOURLY-REPORT, Appendix B). These could also be the results from the solar radiation and thermal time lag.

In Figures 5.18c and 5.19c, the daytime and nighttime indoor temperatures stay between the heating and cooling temperature setpoint temperatures (68 to 78 °F). The figures also show that the indoor humidity levels during the day and night are sometimes above or below the comfort zone. A closer inspects of the figure reveals there are more hours below the comfort zone during the daytime than at night.

In Figures 5.18d and 5.19d, the total daytime hours (4,694 hours, 53.58%) are more than the total nighttime hours (4,066 hours, 46.42%)[1]. The DOE-2 simulation shows that the percentage of daytime hours for heating, cooling, and non-heating-cooling periods are 2.68%, 43.62%, and 7.28%; respectively. The DOE-2 simulation results of nighttime hours for heating, cooling, and non-heating-cooling periods are 5.74%, 30.56%, and 10.11%; respectively. As expected, the percentages of heating and non-heating-cooling periods at night are higher than in daytime and the percentage of cooling periods in the daytime are higher than at night.

The G-M Chart shows that the percentage of hours in the heating period is higher at night (6.51%) than during the day (2.98%) and the percentage of cooling period in the daytime (30.56%) are higher than in the nighttime (19.87%). These results correspond to the results from the DOE-2 simulation. However, in the non-heating-cooling period, the

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[1] In fact, the daytime hours are equal to the nighttime hours for the hours of the year. However, in this study the hourly reports from the DOE-2 simulations were used to count the number of hours that have daylight, which some of those hours could have daylight only a portion of hour. This results the number of daytime hours in the year to be more than 50% of the time.

G-M Chart shows that the percentage of daytime hours (20.05%) is almost equal to the percentage of nighttime hours (20.03%). The results of the G-M Chart for this period do not correspond to the results from the DOE-2 simulation.

Figures 5.20 through 5.22 contain 12 monthly figures, which present monthly data of the hourly indoor and outdoor conditions on the psychrometric chart during heating, cooling, and non-heating-cooling periods from January through December for Houston, Texas. The indoor conditions are displayed as small circles and the outdoor conditions are displayed as solid dots. The blue, red, and green represent heating, cooling, and non heating-cooling periods; respectively. The circles and the dots do not show frequency of occurrence.

The figures show that the heating period appears from November-March. The frequency of the occurrence is highest in December to February when outdoor conditions fall below 45 °F. During this period, the outdoor temperatures and humidity levels are very low. The heating system maintains the indoor temperature within the comfort zone. Unfortunately, the heating system does not provide humidification. Therefore, there are many hours in this period that the indoor humidity levels fall below the comfort zone.

The non-heating-cooling period occurs from October through May when the outdoor temperature is slightly colder and therefore to the left of the comfort zone. From November through March, the figures show that non-heating-cooling is usually found in between heating and cooling hours or during the daytime. From April through May and in October, the figures show the non-heating-cooling period falls within the lower temperature region or occurs at night. During the non-heating-cooling period the indoor temperature floats between heating and cooling temperature setpoints. Unfortunately, the indoor humidity is not very well maintained. Therefore, there are significant hours above or below the humidity constraints of the comfort zone (i.e., above 60% relative humidity and below 36 °F dewpoint).

The figures show that the cooling period appears all year from January through December. From June through September, the cooling system is constantly activated.

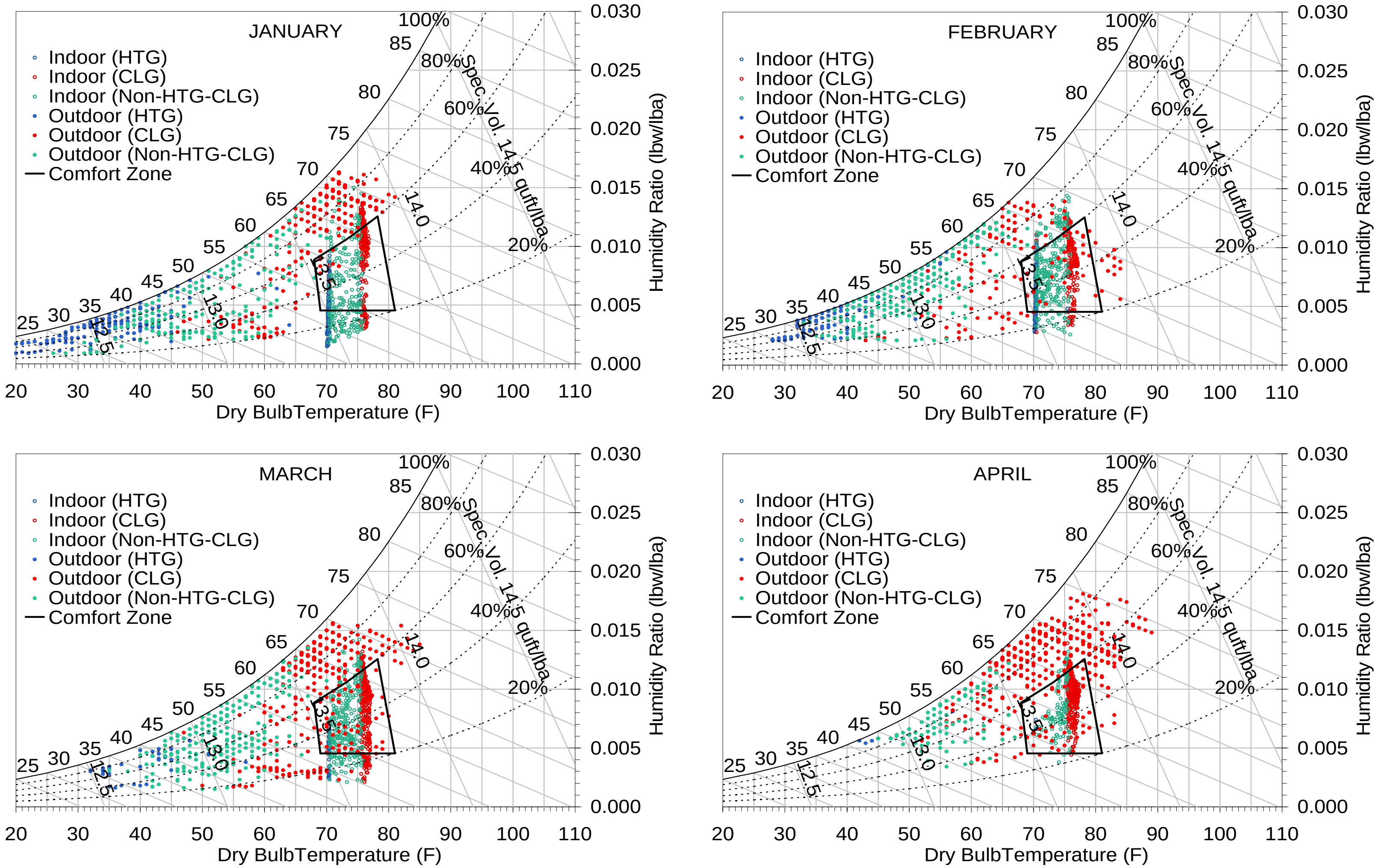


Figure 5.20 *Hourly indoor and outdoor conditions of the lightweight house (base case) in January, February, March, and April during the heating, cooling, and non-heating periods in the hot-humid climate, Houston, Texas.*

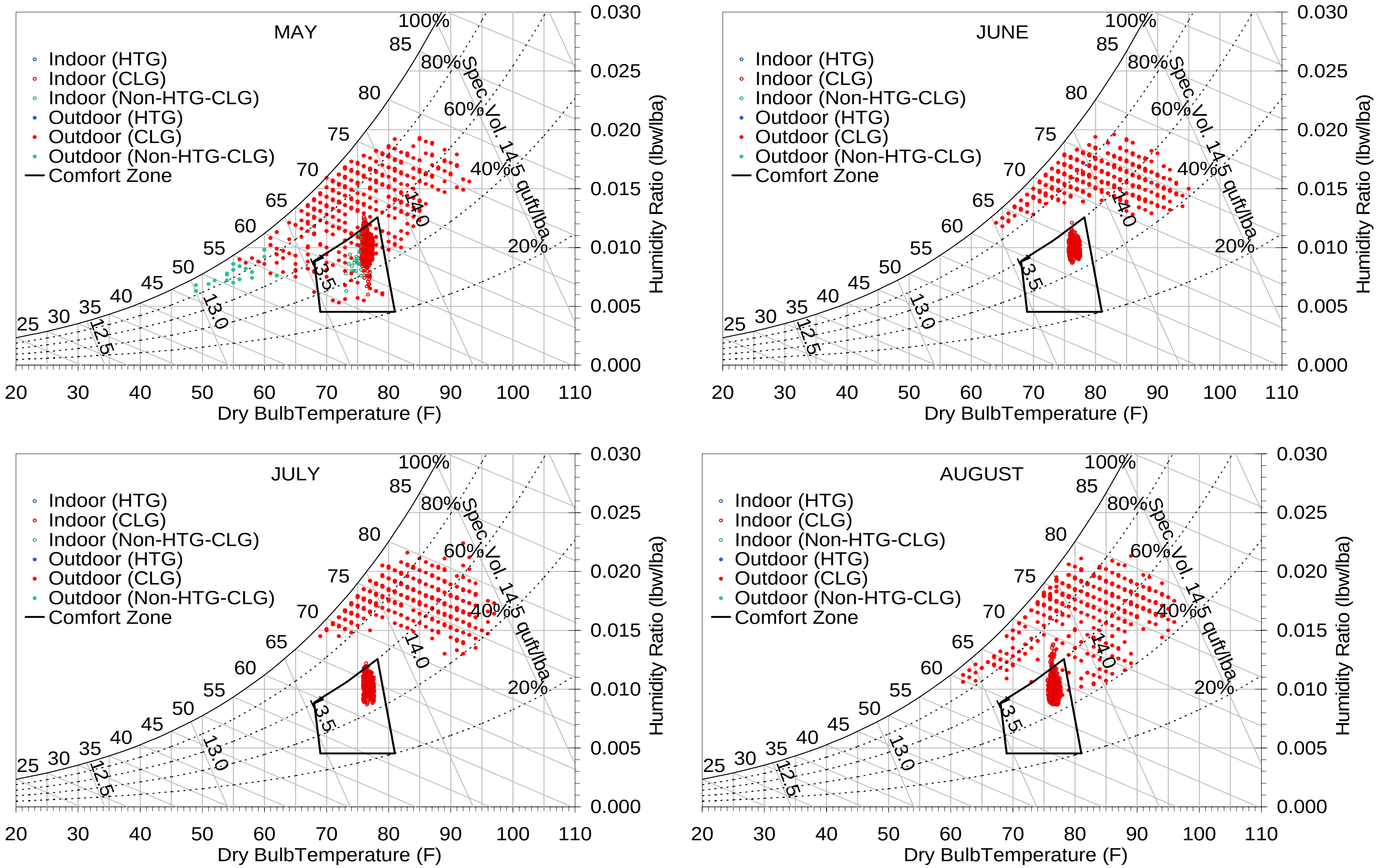


Figure 5.21 *Hourly indoor and outdoor conditions of the lightweight house (base case) in May, June, July, and August during the heating, cooling, and non-heating periods in the hot-humid climate, Houston, Texas.*

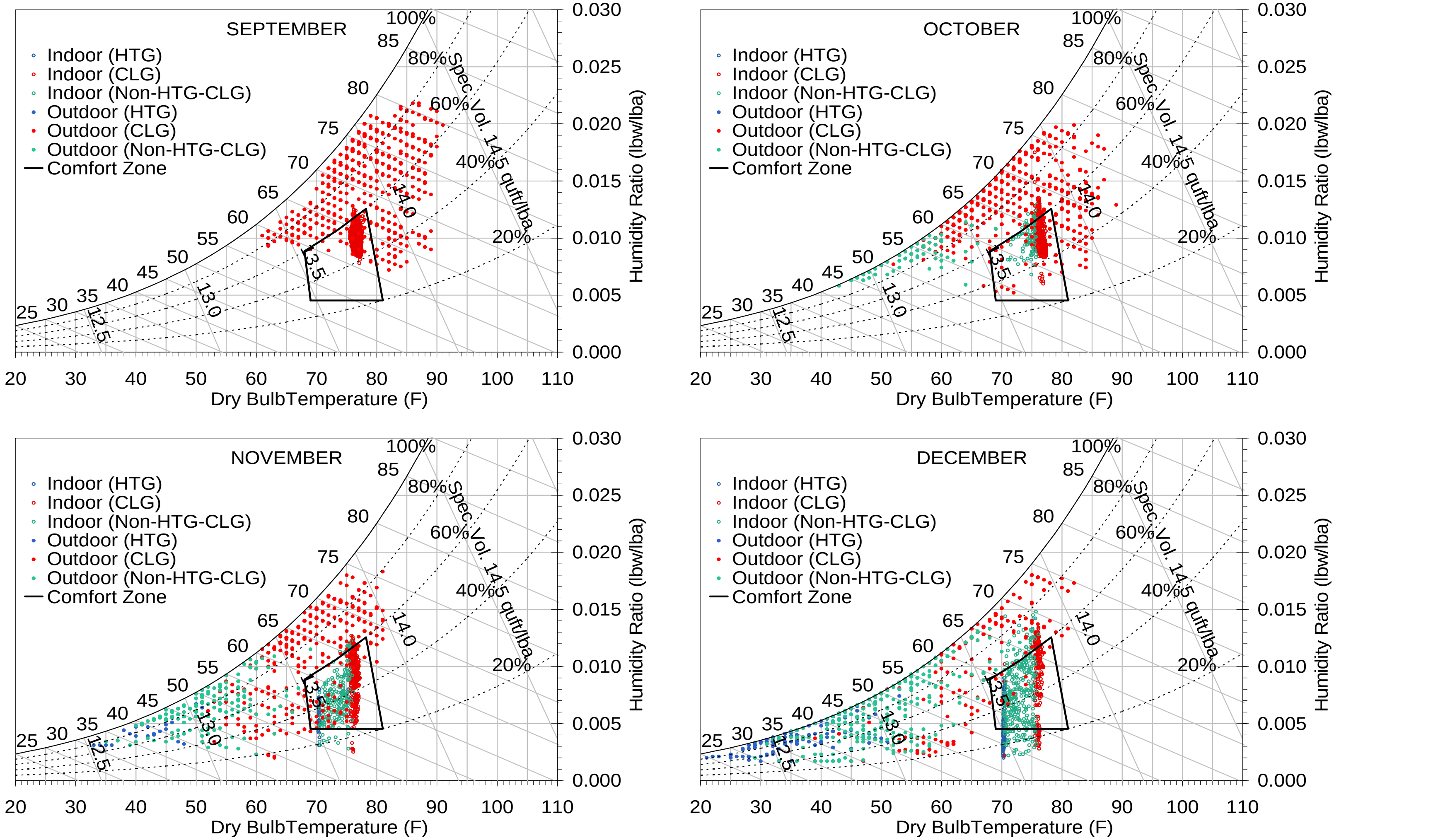


Figure 5.22 *Hourly indoor and outdoor conditions of the lightweight house (base case) in September, October, November, and December during the heating, cooling, and non-heating periods in the hot-humid climate, Houston, Texas.*

Although the outdoor temperatures and humidity levels are significantly higher than the comfort zone, the indoor conditions are very well maintained by the cooling system. However, the indoor humidity levels are sometimes higher or lower than the comfort zone limits.

The figures show that indoor humidity ratio is very close to or a little higher than the outdoor humidity ratio during all periods except when the cooling system is constantly activated. During constant cooling periods, the indoor humidity is very well maintained within the comfort zone. In the figures, when the outdoor humidity ratio falls below 36 °F dewpoint, the indoor humidity ratio is also below the lower level of the comfort zone. This indicates that humidification could be used to maintain the indoor humidity level when the outdoor condition falls below 36 °F dewpoint, which usually occurs in the winter.

Figure 5.23 shows three dimensional surface plots of the annual hourly indoor (upper figure) and outdoor (lower figure) dry-bulb temperatures. In these plots the x-axis represents the day of the year. The y-axis represents hour of the day and the z-axis represents the dry-bulb temperature (°F), which are displayed ranges of temperature in different colors as shown in the legend.

The upper figure shows that the indoor temperature is very well maintained in the summer when the cooling system is activated most of the time. During the winter, spring, and fall the indoor temperature fluctuates between heating and cooling temperature setpoints. This figure clearly shows that the cooling period in winter occurs in the daytime and a few hours at night. The sloped portions of the graph between the upper and lower levels represent the non-heating-cooling period, with short periods in April through May and longer periods in March and October at night. The time of occurrence during November through February is usually in early morning and late evening. The lower figure shows the outdoor temperature and is similar to Figure 5.4 (upper figure). The results are discussed in the Thermal Data Section (Section 5.1.1).

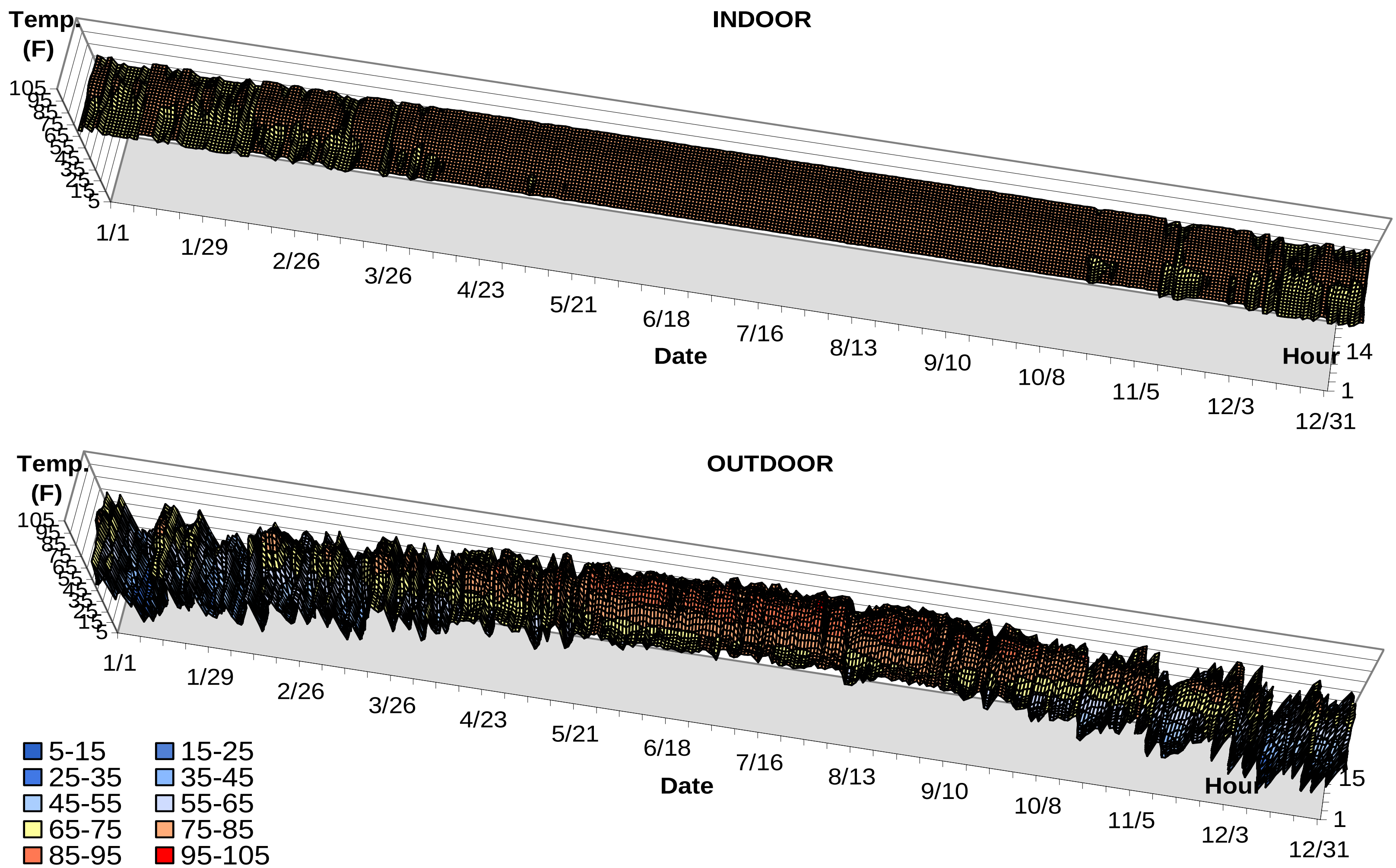


Figure 5.23 *Three dimensional surface plots of hourly indoor and outdoor temperature of the lightweight house (base case) in the hot-humid climate, Houston, Texas.*

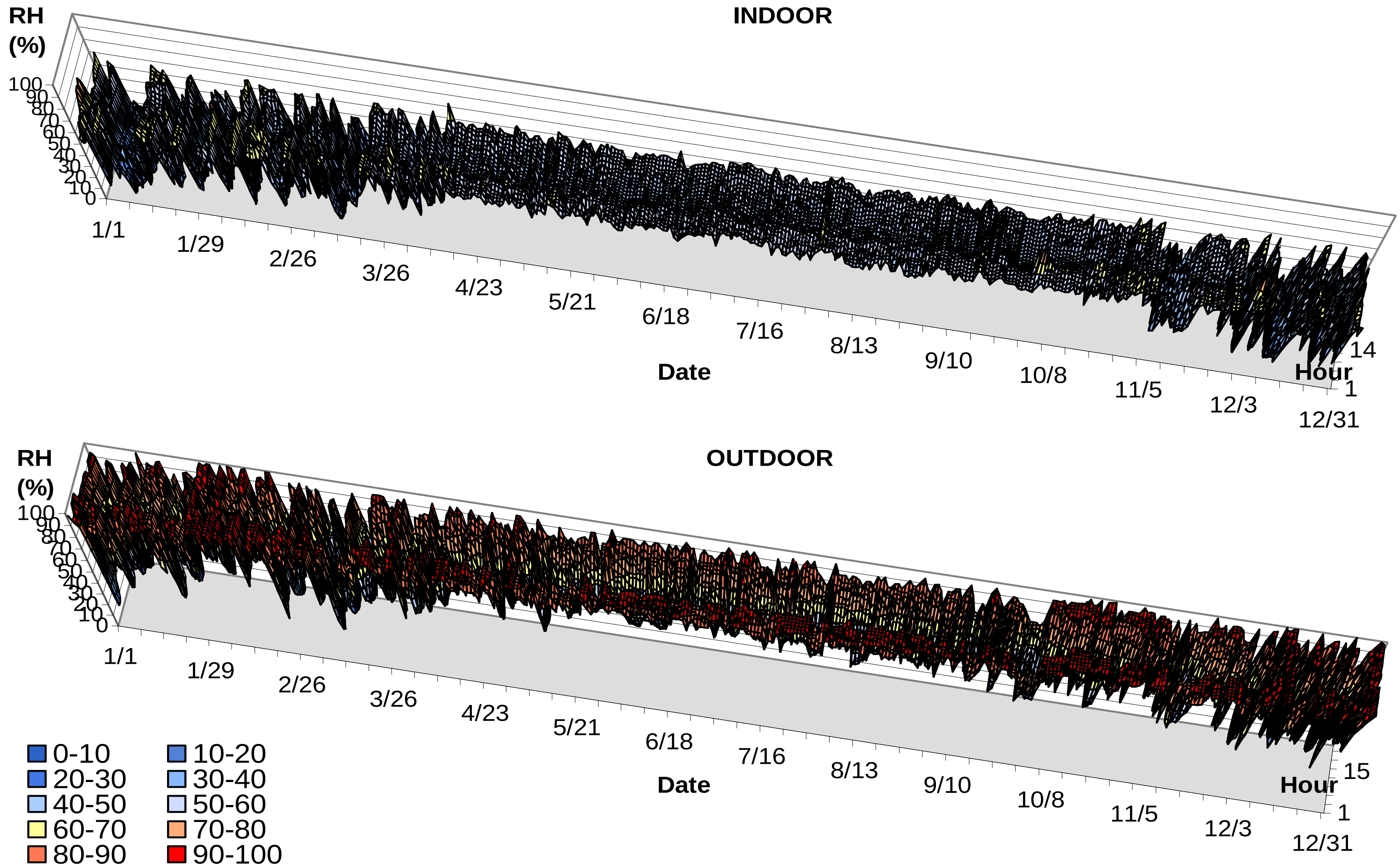


Figure 5.24 *Three dimensional surface plots of hourly indoor and outdoor relative humidity of the lightweight house (base case) in the hot-humid climate, Houston, Texas.*

Figure 5.24 displays three dimensional surface plots of the annual hourly indoor (upper figure) and outdoor (lower figure) relative humidity. The x-axis represents the day of the year. The y-axis represents the hour of the day and the z-axis represents the relative humidity (%), which displays the ranges of the relative humidity (%) in different colors as shown in the legend.

The upper figure shows the indoor relative humidity, which is reasonably well maintained in the summer when the cooling system is activated most of the time. The indoor relative humidity fluctuates over wide range during the other periods. The upper figure shows significant hours when the humidity levels are too high or too low. The lower figure shows the outdoor relative humidity. This figure is similar to Figure 5.4 (lower figure). The results are discussed in the Thermal Data Section (Section 5.1.1.1).

Summary and discussion: A lightweight house (base case) was simulated using the TMY2 weather data for Houston, Texas (hot-humid climate). The results showed that the range of the outdoor conditions (dry-bulb temperature and relative humidity was much wider in the winter than in the summer. The cooling period occurred all year round and all day long in the summer when the temperature was above 60 ºF and the humidity ratio was above 0.010 lbw/lba. The heating period occurred occasionally in the winter. This period often occurred after sunset or when solar radiation was low. There was a short time when the heating system was activated all day long, which was when the outdoor temperature fell below 30 °F. The non-heating-cooling hours usually fell between the heating and cooling hours. This period occurred during the night of a warm day or early in the morning and late evening of a normal cold day when solar radiation was high. The indoor conditions were controlled by the heating and cooling thermostat setpoints of 68 °F and 78 °F, therefore the indoor temperature stayed close to the temperature setpoint of each respective heating or cooling period. For the non-heating-cooling period, the indoor temperature floated between 68 to 78 °F.

The indoor conditions were very well maintained within the comfort zone when the cooling system was activated. Humidity levels were sometimes too high or too low in the non-heating-cooling periods. Unfortunately, controlling the indoor humidity with the DOE-2 simulation caused unexpectedly large amounts of energy use, which could not be resolved. Therefore, it was not included in this study. In the heating and cooling periods, there were very short periods when the indoor temperature did not stay close to it the temperature setpoint; which were most likely due to the indoor temperature fluctuations of a lightweight house. In this study, the energy used for heating and cooling was one of the primary focuses of the study. The total annual energy use for the lightweight house (base case) in Houston, Texas, was 108.1 MBtu. The cooling energy needed is high (25.3 MBtu), almost twice that of the heating energy needed (14.6 MBtu). Therefore, the design strategies for cooling should be considered a priority.

Next, the results from the DOE-2 simulation for heating, cooling, and non-heating-cooling periods were compared with the results from the G-M bioclimatic chart analysis. The DOE-2 simulation results showed that the outdoor conditions during the heating period covered the comfort zone from regions 0 to 5. The majority of the hours fell within regions 0 to 4. The outdoor conditions during the cooling period fell into the comfort zone and were spread-out to the right, the left, and above the comfort zone. Most of this period covered regions 2 to 12 and 15. Only a small portion fell within regions 1, 6, and 16. The frequency of occurrence was very high in regions 5, 8, and 15A. In the non-heating-cooling period, the outdoor conditions covered the psychrometric chart to the left of the comfort zone within regions 1 to 5. There was a small portion of the hours that fell within regions 0, 7, and 8. The frequency of occurrence was high in regions 2 to 4. In the G-M Chart, the effective design strategy regions for heating, cooling, and non-heating-cooling periods were: regions 0 and 1, regions 8 to 17, and regions 2 to 7; respectively.

In the heating period, the DOE-2 simulation yielded 8.42% of the hours for the year. This was slightly less than the results from the G-M Chart, which showed 9.49%. In the conventional heating design strategy (region 0), the results from the DOE-2 simulation were very close to the results from the G-M Chart. In the active solar design strategy (region 1), the results from the DOE-2 simulation were less than the results from the G-M Chart. The DOE-2 results showed a portion of the heating period in passive solar and internal gains design strategies (regions 2 to 4 and 5), which were the effective design strategies for non-heating-cooling periods in the G-M Chart analysis.

In the cooling period, the DOE-2 simulation showed 74.18% of the hours for the year versus the G-M Chart showing only 50.43%. In regions 8 to 17, which were the design strategies for cooling, the results from the DOE-2 simulation corresponded to the results from the G-M Chart analysis, with the major differences in regions 1 to 7. The DOE-2 simulation showed that a significant portion fell within the internal gains region of the G-M comfort zone (regions 5 and 7), which the G-M Chart analysis considered to be the effective design strategies for heating and non-heating-cooling periods; respectively.

In the non-heating-cooling period, the DOE-2 simulation showed 17.40% of the annual hours versus the G-M Chart showing 40.08%, which was more than twice of the results from the DOE-2 simulation. The DOE-2 simulation showed a small amount of time occurred in conventional heating and active solar design strategies (regions 0 and 1), which in the G-M Chart analysis were considered to be the design strategies for the heating period. In the passive solar design strategy (region 2 to 4) results from the DOE-2 simulation were less than results from the G-M Chart. The significant differences were in the internal gains and G-M comfort zone design strategies, where the G-M Chart results are much more than the DOE-2 simulation results.

Comparing the indoor humidity level versus the outdoor humidity level, the indoor humidity level was a little higher than the outdoor humidity level. This resulted from the latent loads from the occupants and equipment that were part of the DOE-2 input file. Humidification could be used to maintain the indoor humidity level in the comfort range when the outdoor temperature fell below 36 °F dewpoint.

5.2.1.2 Lightweight house (base case) in the warm-marine climate of San Francisco, California

The results of the base-case house in the representative warm-marine climate of San Francisco, California, are presented in Figures 5.25 and 5.26. In a similar fashion as

Figures 5.16 and 5.17, Figure 5.25 consists of three plots and a bar chart (Figures 5.25a through 5.25d). Figure 5.26 consists of three plots and a table (Figures 5.26a through 5.26d). Figure 5.25a shows a narrow range of outdoor temperature for the whole year, which is in the temperature range of 30 to 80 °F. There are only a few hours in the summer that the outdoor temperature goes beyond 80 °F and reaches the maximum temperature at 95 °F. The outdoor temperature in the summer, in the range of 50 to 80 °F; is a little narrower than the range in the winter, which is in the range of 30 to 65°F. The indoor temperature in the cooling periods (mid-June through October) and heating periods (November through mid-June) fluctuates between heating and cooling setpoints (68 to 78 °F), which correspond to the activation of the cooling or heating between 20 to 70% except in February, October, and November, where some portions of the indoor relative humidity reach 80 to 90%.

Figure 5.25c shows that the outdoor conditions for the whole year stay under the 60 °F dewpoint line (0.012 lbw/lba, 14.5 mm Hg) and above the 20% relative humidity line, with the majority of the hours covering an area to the left of the comfort zone. There is a small portion of the hours in the year where the outdoor conditions cover areas to the right of the comfort zone. The frequency of occurrence is highest in the areas of 40 to 65 °F when the relative humidity is above 60%, which are the G-M areas of passive solar and internal gains (regions 2, 3, 4 and 5). The indoor temperature falls within the comfort zone, where the temperatures stay between the heating and cooling temperature setpoints (68 to 78 ºF). However, there are many hours of the year where the indoor conditions fall above or below the humidity constraints of the comfort zone (i.e., above 60 % relative humidity line and below 36 °F dewpoint).

Figure 5.25d shows that the total annual energy use is 97.9 MBtu. The energy use includes: domestic hot water (14.4 MBtu), space heating (31.5 MBtu), space cooling (1.7 MBtu), ventilation fans (23.4 MBtu), pump and miscellaneous (0.2 MBtu), heat rejection (0.3 MBtu), miscellaneous equipment (13.2 MBtu), and lights (13.2 MBtu). From the results, the energy use for space heating is the highest and significantly higher than the

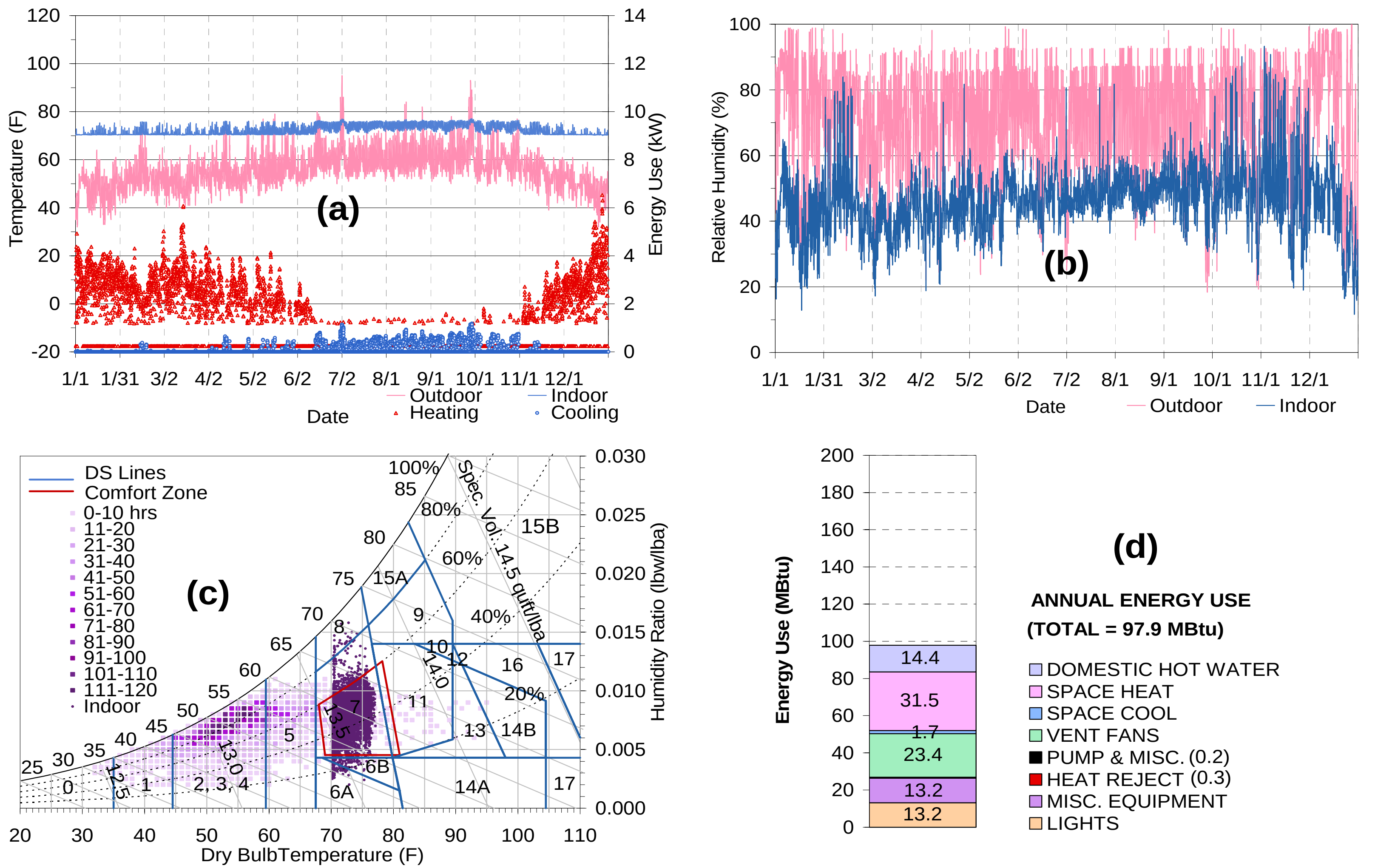
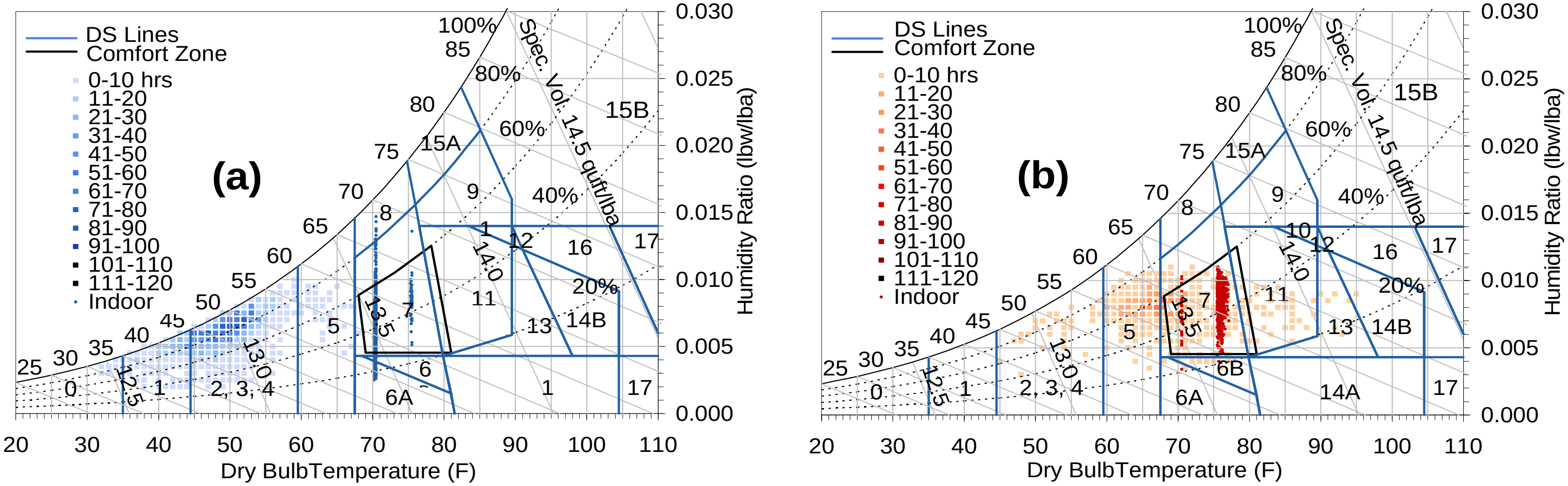
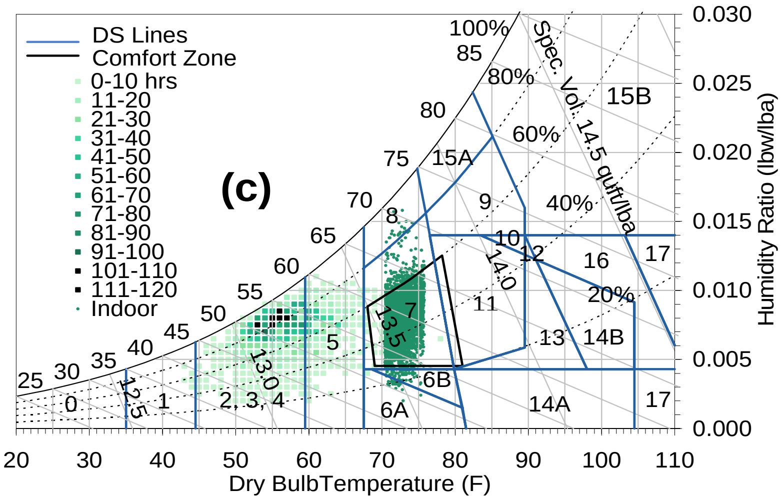


Figure 5.25 *Hourly indoor and outdoor conditions and energy use of the lightweight house (base case) in the warm-marine climate San Francisco, California. (a) Indoor and outdoor dry-bulb temperature and energy use of gas and electricity, (b) Indoor and outdoor relative humidity, (c) Indoor and outdoor conditions on the G-M Chart, and (d) Energy use of each category.*





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(d)

Design Strategies	Regions	G-M Bio-Chart (%)	DOE-2 Simulation HTG (%)	DOE-2 Simulation CLG (%)	DOE-2 Simulation N-H-C (%)
Conventional Heating	0	0.15	0.15	0.00	0.00
Active Solar	1	5.43	5.35	0.00	0.08
Passive Solar	2,3,4	68.33	27.53	0.53	40.27
Internal Gains	5	19.02	0.53	6.14	12.35
Humidification	6A, 6B	0.21	0.00	0.17	0.03
Comfort Zone	7	6.18	0.01	5.71	0.46
Dehumidification	8	0.00	0.00	0.00	0.00
Ventilation	9,10,11	0.59	0.00	0.59	0.00
Evaporative Cooling	6B,11,13,14A,14B	0.84	0.00	0.82	0.02
High Thermal Mass	10,11,12,13	0.67	0.00	0.67	0.00
High Thermal Mass with Night Ventilation	16, 14B	0.01	0.00	0.01	0.00
Air-Conditioning	17	0.00	0.00	0.00	0.00
Air-Conditioning & Dehumidification	15A,15B	0.00	0.00	0.00	0.00
Number of Hours/Year		8760	2941	1159	4660
Percentage of Hours/Year		100.00	33.57	13.23	53.20

Region	0	1	2	3	4	5	6A	6B	7	8	9	10	11	12	13	14A	14B	15A	15B	16	17	Total
Hours	13	476	1170	2506	2310	1666	4	14	541	0	0	0	52	0	7	0	1	0	0	0	0	8760
G-M (%)	0.1	5.4	13.4	28.6	26.4	19.0	0.0	0.2	6.2	0.0	0.0	0.0	0.6	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	100.00
DOE-2 (%)		5.58							93.73												0.68	100.00

Figure 5.26 *Daytime and nighttime hourly indoor and outdoor conditions of the lightweight house (base case) in the warm-marine climate, San Francisco, California, on the G-M Chart. (a) Heating period, (b) Cooling period, (c) Non-heating-cooling period, and (d) Comparison of the results from the G-M Chart vs. the DOE-2 simulation.*

energy use for space cooling. Therefore, the design strategies for heating should be considered a priority.

In a similar fashion as Figure 5.17, Figure 5.26 consists of Figures 5.26a through 5.26d, which shows the daytime and nighttime annual hourly indoor and outdoor conditions on the G-M Chart during the heating period (Figure 5.26a), cooling period (Figure 5.26b), non-heating period (Figure 5.26c), and a comparison table of the results from the G-M Chart and the DOE-2 simulation (Figure 5.26d).

Figure 5.26a shows that most of the outdoor conditions during the heating period cover an area to the left of the comfort zone. The majority of the hours involve the G-M definitions of active solar and passive solar design strategies (regions 1 and 2 to 4). Only a few hours fall upon conventional heating and internal gains design strategies (regions 0 and 5). Most of the indoor temperatures stay close to the heating temperature setpoint of 68 °F. A small portion of the heating hours that stay close to the cooling temperature setpoint of 78 °F occur individually right after the hours that the cooling system was continuously activated (see the DOE-2 HOURLY-REPORT, Appendix B). These are most likely due to the indoor temperature fluctuations of a lightweight house. In Figure 5.26a, there are many hours in this period that the indoor conditions fall above or below the humidity constraints of the ASHRAE comfort zone.

Figure 5.26b shows that the outdoor conditions during the cooling period fall into the comfort zone and are spread-out to the right and left of the comfort zone. The cooling data covers regions of heating design strategy, which are passive solar and internal gains (regions 2 to 5); the G-M comfort zone (region 7); and the cooling design strategy regions, which include ventilation, evaporative cooling, and high thermal mass (regions 6B and 9 to 14). A small portion of the cooling data falls within the areas of humidification and high thermal mass with night ventilation design strategies (regions 6 and 14B). The frequency of occurrence is high in the areas of internal gains design strategy and the G-M comfort zone (regions 5 and 7). Most indoor temperatures fall into the area of comfort zone and stay close to the cooling temperature setpoint of 78 °F. Only a few hours of the cooling period that stays close to the heating temperature setpoint of 68 °F. These hours occur individually right after the hours that the heating system was continuously activated (see the DOE-2 HOURLY-REPORT, Appendix B). These are most likely due to the indoor temperature fluctuations of a lightweight house.

Figure 5.26c shows that majority of the outdoor conditions during the non-heating-cooling period fall mostly to the left of the comfort zone, which include areas of passive solar and internal gains design strategies (regions 2 to 4 and 5). Only a small portion falls within the area of active solar, humidification, G-M comfort zone, and evaporative cooling (regions 1, 6, 7, and 14B). The frequency of occurrence is high in the area of internal gains design strategy (region 5) and highest in the area of passive solar design strategies (regions 2 to 4). The indoor temperatures mostly float between the heating and cooling temperature setpoints (68 to 78 °F). There are many hours in this period that the indoor conditions fall above or below the humidity constraints of the comfort zone.

In Figure 5.26d, the results from the DOE-2 simulation show that there are 2,941 hours (33.57%) of the year that the heating system is activated. The cooling system is activated for 1,159 hours (13.23%) and there are 4,660 hours (53.20%) when neither the heating nor cooling systems is activated. The results from the G-M Chart analysis show that there are 489 hours (5.58%) in the heating period. There are 60 hours (0.68%) in the cooling period, and 8,211 hours (93.73%) in the non-heating-cooling period. The criteria used to identify the effective design strategies for heating, cooling, and non-heating-cooling periods in the G-M Chart analysis are described in Section 5.2.1.1 (see the last paragraph of p. 149)

Figure 5.26d allows the results from the DOE-2 simulation to be compared to the G-M bioclimatic chart. As mentioned in the previous paragraphs, the DOE-2 simulation showed 33.57% of the time in heating period, which is significantly different from the G-M Chart results (5.58%). In this period, DOE-2 shows that 0.15% of the time falls into conventional heating design strategy (region 0) and 5.35% of the time falls into active solar design strategy (region 1). These are also very close to the results from the G-M Chart, which show 0.15% in conventional heating design strategy and 5.43% in active solar design strategy. However, DOE-2 shows that there is a significant portion of heating hours in passive solar (regions 2 to 4, 27.53%) and a small portion in internal gains design strategy (region 5, 0.53%) and the G-M comfort zone (region 7, 0.01%).

In the cooling period (Figure 5.26d), DOE-2 calculated 13.23% of the hours-per-year in several regions including passive solar, internal gains, humidification, the G-M comfort zone, ventilation, evaporative cooling and high thermal mass design strategies (regions 2 to 7, 11, 13, and 14B). The G-M Chart shows only 0.68% is in this period. In regions 11, 13, and 14B, the results from the DOE-2 simulation correspond to the results from the G-M Chart analysis. However, the differences are in regions 2 to 7. In Figure 5.26d, DOE-2 shows that a significant portion falls into region 5 (internal gains, 6.14%) and region 7 (the G-M comfort zone, 5.71%). Unfortunately, in the G-M Chart analysis, regions 2 to 5 and 7 are not usually considered cooling periods.

In the non-heating-cooling period (Figure 5.26d), the results from the DOE-2 simulation are much different from the results from the G-M Chart. The DOE-2 simulation shows 53.20% of the hours in the year in this period while the G-M Chart shows as much as 93.73%. DOE-2 shows a small portion occurs in region 1 (active solar, 0.08%), where for this period are not included in the G-M Chart analysis. In regions 2 to 4 (passive solar), the results from the DOE-2 simulation (40.27%) are significantly less than the results from the G-M Chart analysis (68.33%). The differences are also shown in regions 5 through 7 (internal gains, humidification, and the G-M comfort zone). In these regions the DOE-2 shows only 12.35% (region 5), 0.03% (region 6), and 0.46% (region 7) versus the G-M Chart which shows 19.02%, 0.21%, and 6.18% in regions 5, 6, and 7; respectively.

Summary and discussion: A lightweight house (base case) was simulated using the TMY2 weather data for San Francisco, California (warm-marine climate). The results showed the narrow range of the outdoor conditions (dry-bulb temperature and relative humidity), which in the summer was narrower than in the winter. The cooling period was twice as short as the heating period. The cooling period occurred mostly in the summer while the heating period occurred mostly in the winter and the non-heatingcooing period occurred all year long. The indoor temperature stayed close to the temperature setpoint of each respective heating (68 °F) or cooling period (78 °F). For the non-heating-cooling period, the indoor temperature floated between 68 to 78 °F.

The indoor conditions were very well maintained within the comfort zone when the cooling system was activated. In the heating and cooling periods, there were very short periods when the indoor temperature did not stay close to their temperature setpoints; which were most likely due to the indoor temperature fluctuations that were usually found in a lightweight house. The total annual energy use for the lightweight house (base case) in San Francisco, California, was 97.9 MBtu. The cooling energy needed was very low (1.7 MBtu), while the heating energy needed was significantly higher (31.5 MBtu). Therefore, the design strategies for heating should be considered a priority.

The DOE-2 simulation results show that the outdoor conditions during the heating period covered the area to the left of the comfort zone from regions 0 through 5 (conventional heating, active solar, passive solar, and internal gains). The majority of the hours fell within regions 1 to 4. The outdoor conditions during the cooling period fell into the comfort zone and were spread-out to the right and the left of the comfort zone. The frequency of occurrence of this period was high in regions 5 and 7 (internal gains and the G-M comfort zone). In the non-heating-cooling period, the outdoor conditions covered a part of comfort zone and the area to the left of the comfort zone from regions 1 to 5, 6 (humidification), and 7. Most of the non-heating-cooling hours fell into regions 2 to 5, where the frequency of occurrence was significantly high in regions 2 to 4.

In the heating period, the DOE-2 simulation yielded 33.57% of the hours for the year. This was significantly higher than the results from the G-M Chart, which showed 5.58%. In the conventional heating and active solar design strategies (regions 0 and 1), the DOE-2 simulation results were very close to the G-M Chart results. However, the DOE-2 simulation showed a significant portion of heating period in passive solar design strategy (regions 2 to 4, 27.53%); which these regions, in the G-M Chart analysis, were not included in the heating periods.

In the cooling period, the DOE-2 simulation showed 13.23% of the hours for the year versus the G-M Chart showing only 0.68%. DOE-2 showed that small portions of cooling period occurred in regions 11, 13, and 14B, which corresponded to the results from the G-M Chart analysis. However, the differences were in regions 2 to 7 especially regions 5 (internal gains, 6.14%) and 7 (the G-M comfort zone, 5.71%). Unfortunately, in a G-M Chart analysis, these regions were not usually considered cooling periods.

In the non-heating-cooling period, the DOE-2 simulation showed 53.20% of the hours in the year, which was significantly less than the G-M Chart results (93.73%). The differences were obviously shown in regions 2 to 4 (passive solar) as well as regions 5 (internal gains) and 7 (the G-M comfort zone).

5.2.1.3 Lightweight house (base case) in the hot-dry climate of Phoenix, Arizona

The results of the base-case house in the representative hot-dry climate of Phoenix, Arizona, are presented in Figures 5.27. The Figures 5.27 consists of Figures 5.27a to 5.25d; and Figure 5.28, which consists of Figures 5.28a to 5.28d. Figure 5.27a shows a wide range of the outdoor temperature for the whole year, which mostly is in the temperature range between 35 to 110 °F. There are only a few hours in the summer that the outdoor temperature goes beyond 110 °F through the maximum temperature at 115 °F and a few hours in the winter that the outdoor temperature dips below 35 °F through the minimum temperature at 27 °F. The range of the outdoor temperature is in the range of 50 to 110 °F in the summer and 35 to 75 °F in the winter. The indoor temperature of the cooling periods is very well maintained at the cooling setpoint (78 °F) when the cooling system is continuously activated (May through October). However, in the other mixed-periods, the indoor temperature fluctuates between heating and cooling setpoints (68 to 78 °F). The heating periods is short and occasionally occurs during December to mid-March. As expected, the energy use for cooling in Phoenix is significantly higher than the energy use for heating.

Figure 5.27b shows significant variation in the outdoor relative humidity for the whole year, which is in the 10 to almost 100% relative humidity range. In the winter (mid-November through mid-March), the outdoor relative humidity and its range is higher and wider than the other periods. The outdoor relative humidity is significantly lower in April to June and from mid-October to mid-November. The range of outdoor relative humidity during these periods stays in the 5 to 60% relative humidity. The indoor relative humidity from July through October is well maintained between 20 to 50% relative humidity. However, in the other periods of the year the indoor relative humidity fluctuates between 10 to 60%. There is a significant portion of the hours in these periods that the indoor relative humidity falls below 20%, which indicates a need for humidification.

Figure 5.27c shows that the outdoor conditions for the whole year are widely spread-out under the 73 °F dewpoint line, and cover areas to the left and to the right of the comfort zone (from 25 °F to 115 °F). The frequency of occurrence is a little higher in the areas of 40 to 90 °F where the humidity ratio is below 0.008 lbw/lba (50 °F dewpoint temperature). Most of the indoor temperature falls within and below the comfort zone, where the temperatures stay between the heating and cooling temperature setpoints (68 to 78 ºF). There is a significant portion of the hours in the year where the indoor conditions fall below the humidity constraints of the comfort zone (i.e., below 36 °F dewpoint temperature).

Figure 5.27d shows that the total annual energy use is 100.0 MBtu. The energy use includes: domestic hot water (10.6 MBtu), space heating (8.2 MBtu), space cooling (25.6 MBtu), ventilation fans (23.4 MBtu), pump and miscellaneous (2.2 MBtu), heat rejection (3.6 MBtu), miscellaneous equipment (13.2 MBtu), and lights (13.2 MBtu). From the results, the energy use for space cooling is the highest and significantly higher than the energy use for space heating. Therefore, the design strategies for cooling should be considered a priority.

In a similar fashion as Figure 5.17, Figure 5.28 consists of Figures 5.28a through 5.28d, which shows the daytime and nighttime annual hourly indoor and outdoor conditions on the G-M Chart during the heating period (Figure 5.28a), cooling period

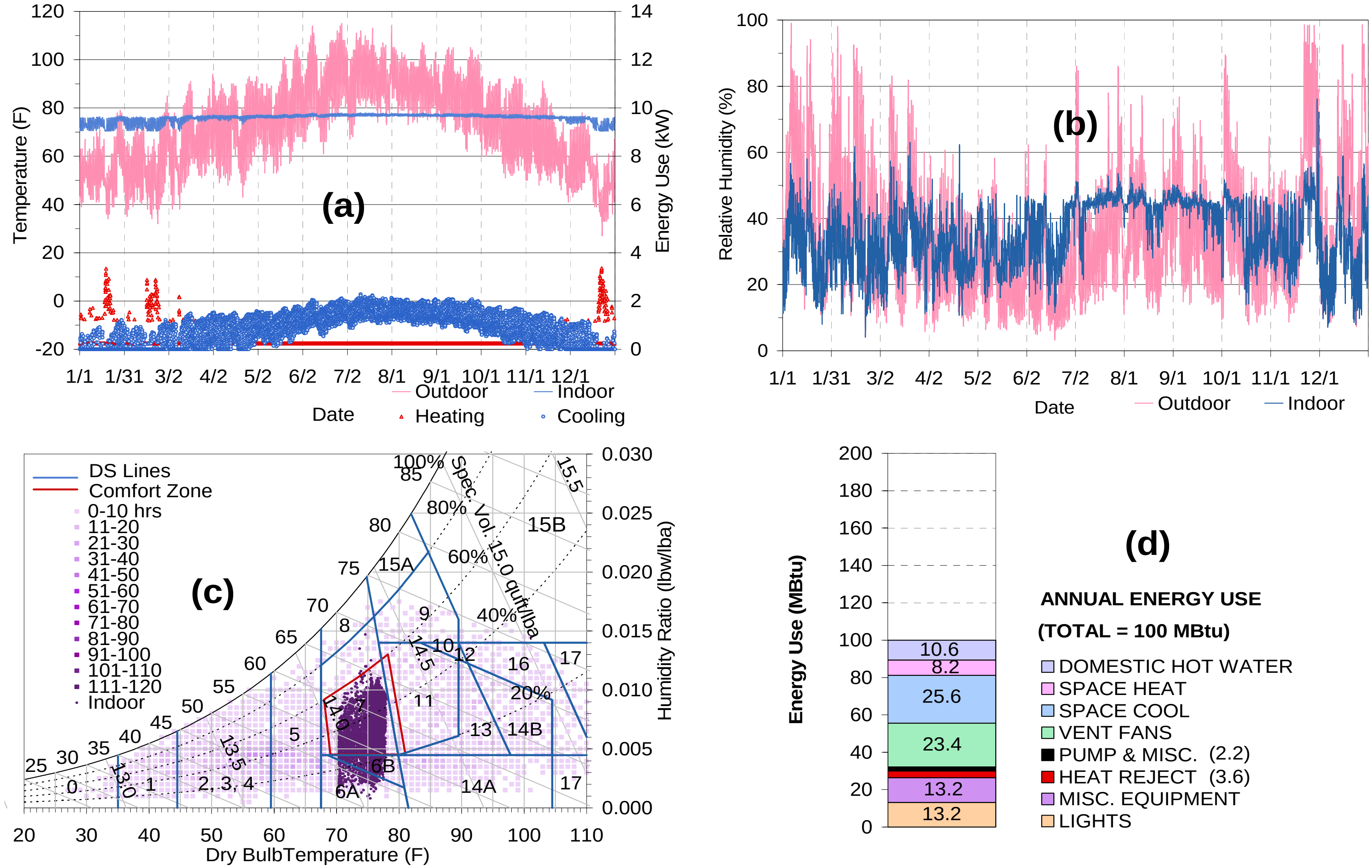
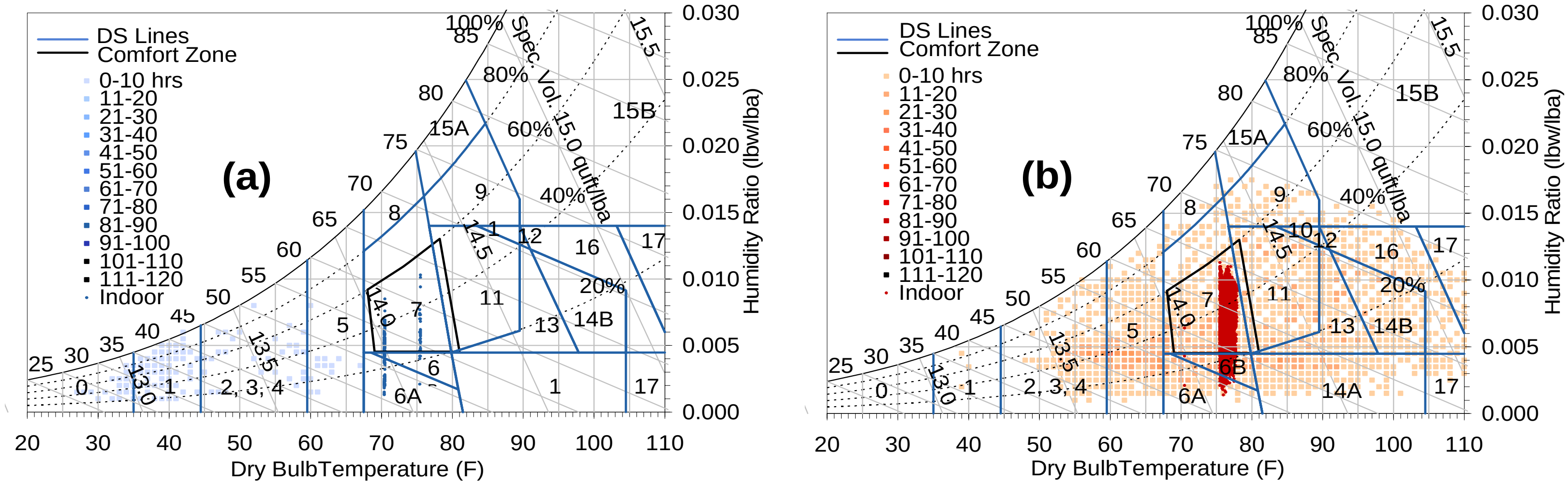
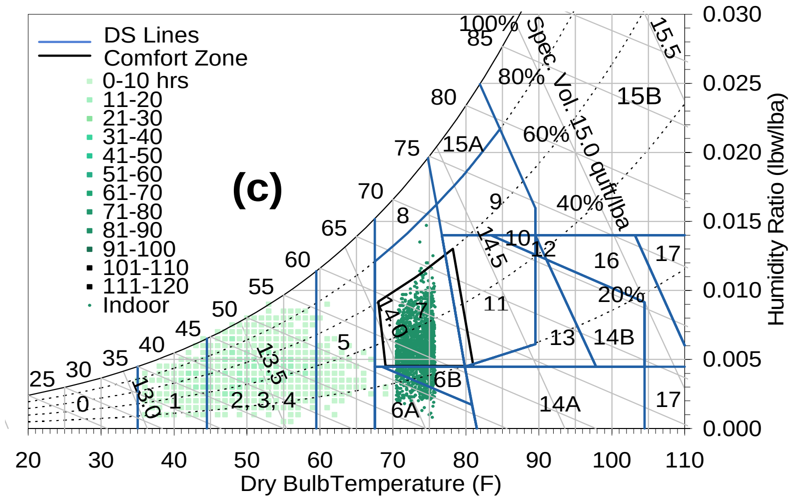


Figure 5.27 *Hourly indoor and outdoor conditions and energy use of the lightweight house (base case) in the hot-dry climate, Phoenix, Arizona. (a) Indoor and outdoor dry-bulb temperature and energy use of gas and electricity, (b) Indoor and outdoor relative humidity, (c) Indoor and outdoor conditions on the G-M Chart, and (d) Energy use of each category.*





(d)

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Design Strategies	Regions	G-M Bio-Chart (%)	DOE-2 Simulation HTG (%)	DOE-2 Simulation CLG (%)	DOE-2 Simulation N-H-C (%)
Conventional Heating	0	0.35	0.35	0.00	0.00
Active Solar	1	4.73	1.35	0.03	3.34
Passive Solar	2,3,4	22.04	0.46	6.18	15.41
Internal Gains	5	14.03	0.14	12.21	1.68
Humidification	6A, 6B	8.31	0.00	8.28	0.03
Comfort Zone	7	11.69	0.00	11.69	0.00
Dehumidification	8	0.21	0.00	0.21	0.00
Ventilation	9,10,11	13.22	0.00	13.22	0.00
Evaporative Cooling	6B,11,13,14A,14B	34.38	0.00	34.38	0.00
High Thermal Mass	10,11,12,13	18.84	0.00	18.84	0.00
High Thermal Mass with Night Ventilation	16, 14B	10.01	0.00	10.01	0.00
Air-Conditioning	17	1.26	0.00	1.26	0.00
Air-Conditioning & Dehumidification	15A,15B	0.34	0.00	0.34	0.00
Number of Hours/Year		8760	201	6766	1793
Percentage of Hours/Year		100.00	2.29	77.24	20.47

Region	0	1	2	3	4	5	6A	6B	7	8	9	10	11	12	13	14A	14B	15A	15B	16	17	Total
Hours	31	414	483	664	784	1229	340	388	1024	18	124	55	979	18	598	594	453	6	24	424	110	8760
G-M (%)	0.4	4.7	5.5	7.6	8.9	14.0	3.9	4.4	11.7	0.2	1.4	0.6	11.2	0.2	6.8	6.8	5.2	0.1	0.3	4.8	1.3	100.00
DOE-2 (%)		5.08							56.07												38.85	100.00

Figure 5.28 *Daytime and nighttime hourly indoor and outdoor conditions of the lightweight house (base case) in the hot-dry climate, Phoenix, Arizona, on the G-M Chart. (a) Heating period, (b) Cooling period, (c) Non-heating-cooling period, and (d) Comparison of the results from the G-M Chart vs. the DOE-2 simulation.*

(Figure 5.28b), non-heating period (Figure 5.28c), and a comparison table of the results from the G-M Chart and the DOE-2 simulation (Figure 5.28d).

Figure 5.28a shows that most of the outdoor conditions during the heating period cover an area to the left of the comfort zone. The majority of the hours involve the G-M definitions of active solar design strategies (regions 1). Only a few hours fall upon conventional heating, passive solar and internal gains design strategies (region 0, 2 to 4, and 5). Usually the indoor temperature stays close to the heating temperature setpoint of 68 °F. A very small portion of the heating hours that stay close to the cooling temperature setpoint of 78 °F occur individually right after the hours that the cooling system was continuously activated (see the DOE-2 HOURLY-REPORT, Appendix B). These are most likely due to the indoor temperature fluctuations of a lightweight house. In Figure 5.28a, there are many hours in this period that the indoor conditions fall below the humidity constraints of the ASHRAE comfort zone.

Figure 5.28b shows that the outdoor conditions during the cooling period fall into the comfort zone and are widely spread-out to the right and the left of the comfort zone. The cooling data covers all regions except region 0 (conventional heating). These regions include heating design strategy regions; which are active solar (region 1), passive solar (regions 2 to 4) and internal gains design strategies (region 5); humidification (region 6a and 6b); the G-M comfort zone (region 7); dehumidification (region 8); and the cooling design strategy regions, which are ventilation, evaporative cooling, high thermal mass (with and without night ventilation), and air-conditioning (with and without dehumidification) (regions 6B and 9 to 17). Figure 5.28b shows that the frequency of occurrence is high in the areas of passive solar (regions 2 to 4), internal gains (region 5), humidification (regions 6a and 6b), the G-M comfort zone (region 7), ventilation (regions 9 to 11), high thermal mass (regions 10 to 13) and high thermal mass with night ventilation (regions 14b and 16). The frequency of occurrence is highest in the area of evaporative cooling design strategy (regions 6b, 11, 13, 14a and 14b). Most of the indoor temperatures stay close to the cooling temperature setpoint of 78 °F. Only a few hours of the cooling periods that stays close to the heating temperature setpoint of

68 °F. There are many hours in this period that the indoor conditions fall below the humidity constraints of the comfort zone (below 36 °F dewpoint line).

Figure 5.28c shows that majority of the outdoor conditions during the non-heating-cooling period fall to the left side of the comfort zone, which include areas of active solar, passive solar, and internal gains design strategies (regions 2 to 5). Only a small portion falls within the area of humidification design strategy (regions 6). The frequency of occurrence is highest in the area of passive solar design strategies (regions 2 to 4). The indoor temperature mostly floats between the heating and cooling temperature setpoints (68 to 78 °F). There is a significant portion of the hours in this period that the indoor conditions fall below the humidity constraints of the comfort zone.

In Figure 5.28d, the results from the DOE-2 simulation show that there are 201 hours (2.29%) of the year that the heating system is activated. The cooling system is activated for 6,766 hours (77.24%) and there are 1,793 hours (20.47%) when neither the heating nor cooling systems is activated. The results from the G-M Chart analysis show that there are 445 hours (5.08%) in the heating period. There are 3,403 hours (38.85%) in the cooling period, and 4,912 hours (56.07%) in the non-heating-cooling period. The criteria used to identify the effective design strategies for heating, cooling, and non-heating-cooling periods in the G-M Chart analysis are described in Section 5.2.1.1 (see the last paragraph of p. 149).

Figure 5.28d allows the results from the DOE-2 simulation to be compared to the G-M bioclimatic chart. As mentioned in the previous paragraphs, the DOE-2 simulation shows 2.29% of the time in heating period, which is different from the G-M Chart results (5.08%). In this period, DOE-2 shows that 0.35% of the hours fall into conventional heating (region 0), which is similar to the G-M results. However, DOE-2 shows 1.35%, 0.46%, and 0.14% of the hours in the year in active solar (region 1), passive solar (regions 2 to 4), and internal gains (region 5); respectively. These are different from the G-M Chart results, which show 4.73% in active solar design strategy (region 1). In addition, passive solar and internal gains design strategies (regions 2 to 4 and 5) are not usually considered heating periods.

In the cooling period (Figure 5.28d), DOE-2 calculated 77.24% of the hours-per-year in several regions from regions 1 to 17 including active solar (region 1, 0.03%), passive solar (region 2 to 4, 6.18%), internal gains (region 5, 12.21%), humidification (regions 6a and 6b, 8.28%), the G-M comfort zone (region 7, 11.69%), dehumidification (region 8, 0.21%), ventilation (regions 9 to 11, 13.22%), evaporative cooling (regions 6b, 11, 13, 14a, 14b; 34.38%), high thermal mass (regions 10 to 13, 18.84%), high thermal mass with night ventilation (regions 14b and 16, 10.01%), air-conditioning (region 17, 1.26%) and air-conditioning with dehumidification (regions 15a and 15b, 0.34%) design strategies. Surprisingly, the G-M Chart shows only 38.85% is in the cooling period. In regions 8 to 17, the results from the DOE-2 simulation correspond to the results from the G-M Chart analysis. However, DOE-2 shows a significant portion of the cooling period in regions 1 to 7, which are not usually considered to be cooling periods in the G-M Chart analysis.

In the non-heating-cooling period (Figure 5.28d), the results from the DOE-2 simulation are also far from the same results of the G-M Chart. The DOE-2 simulation shows 20.47% of the hours in the year in this period while the G-M Chart shows as much as 56.07%. DOE-2 shows a portion of the hours occurs in regions 1 (active solar), which is not considered to be a non-heating-cooling period in the G-M Chart analysis. The significant differences are shown in regions 5 (internal gains), where the DOE-2 simulation shows only 1.68% of the time in this region versus the G-M Chart showing 14.03%. In regions 2 to 4 (passive solar) and 6a (humidification), the results from the DOE-2 simulation (15.41% and 0.03%) are also less than the G-M Chart analysis results (22.04%, 3.88%). In regions 6b (humidification/ evaporative cooling) and 7 (the G-M comfort zone), the DOE-2 simulation shows no hours in this period that fall into these regions versus the G-M Chart showing 4.43% in region 6b and 11.69% in region 7.

Summary and discussion: A lightweight house (base case) was simulated using the TMY2 weather data for Phoenix, Arizona (hot-dry climate). The results showed a wide range of the outdoor temperature, which was slightly wider in the winter than in other periods. The range of the relative humidity (RH) for the whole year was significantly wide especially during the winter when the outdoor relative humidity was higher than the other periods. From April to June and mid-October to mid-November, the outdoor relative humidity was significantly low and stayed between 5 to 60% relative humidity. The cooling period occurred all year round while the heating and non-heating-cooling periods occurred during the winter. The indoor temperature fluctuated between heating and cooling setpoints (68 to 78 °F). The indoor relative humidity floated between 10 to 60% relative humidity. During May through October, when the cooling system was continuously activated, the indoor temperature was very well maintained near the cooling setpoint (78 °F). However, there was a small portion of the hours during this period and a significant portion of the hours during the other periods that the indoor relative humidity fell below the humidity constraints of the comfort zone (i.e., below 36 °F dewpoint). The total annual energy use for the lightweight house (base case) in Phoenix, Arizona, was 100.0 MBtu. The cooling energy use (25.6 MBtu) was significantly higher than the heating energy use (8.2 MBtu). Therefore, the design strategies for cooling should be considered a priority.

The DOE-2 simulation results showed that the outdoor conditions during the heating period covered the area to the left of the comfort zone from regions 0 through 5 (conventional heating, active solar, passive solar, and internal gains design strategies). The majority of the hours fell within regions 1 (active solar). The outdoor conditions during the cooling period fell into the comfort zone and were spread-out to the right and the left of the comfort zone. The frequency of occurrence of this period was high in several regions (regions 2 to 7, 11, 13, 14 and 16), which were the areas of passive solar, internal gains, humidification, ventilation, evaporative cooling and high thermal mass (with and without night ventilation) design strategies. In the non-heating-cooling period, most of the hours during this period fell into regions 1 to 5 (active solar, passive solar, and internal gains), where the frequency of occurrence was significantly high in regions 2 to 4 (passive solar).

In the heating period, the DOE-2 simulation yielded 2.29% of the hours for the year. This was less than the G-M Chart results, which showed 5.08%. In the conventional heating design strategy (region 0), the DOE-2 simulation results corresponded to the G-M Chart results. The differences were in active solar design strategy (region 1), where the DOE-2 simulation showed only 1.35%, while the G-M Chart showed 4.73%. DOE-2 showed small portions of the hours in passive solar (regions 2 to 4) and internal gains (region 5) design strategies. However, in the G-M Chart analysis, these regions were not usually considered heating periods.

In the cooling period, the DOE-2 simulation showed 77.24% of the hours for the year versus the G-M Chart showing only 38.85%. In region 8 to 17, the DOE-2 simulation results corresponded to the G-M results. However, the differences were in regions 1 to 7 especially regions 5 (internal gains, 12.21%) and 7 (the G-M comfort zone, 11.69%). Unfortunately, in a G-M Chart analysis, these regions were not usually considered cooling periods.

In the non-heating-cooling period, the DOE-2 simulation showed 20.47% of the annual hours, which was significantly less than the G-M Chart result (56.07%). The DOE-2 simulation showed a portion of the hours in regions 1 (active solar), which was not considered to be a non-heating-cooling period in the G-M Chart analysis. The differences were also shown in regions 2 to 4 (passive solar), 5 (internal gains) and 6a (humidification); where the results from the DOE-2 simulation (15.41%, 1.68%, and 0.03%) were less than the G-M results (22.04%, 14.03%, and 3.88%); respectively. The DOE-2 simulation showed that there were no hours that fell in the regions 6b (humidification/ evaporative cooling) and 7 (the G-M comfort zone), which the G-M Chart usually considers to be a non-heating-cooling period.

5.2.2 Lightweight House without Internal Loads

This section presents the simulated results and discussion of the lightweight house without internal loads in the hot-humid climate of Houston, Texas.

5.2.2.1 Lightweight house without internal loads in the hot-humid climate of Houston, Texas

The results of the lightweight house without internal loads in the representative hot-humid climate of Houston, Texas, are presented in Figures 5.29 (Figures 5.29a through 5.29d) and Figure 5.30 (Figures 5.30a through 5.30d). In a similar fashion as Figure 5.16a (Section 5.2.1.1), Figure 5.29a shows a wide range of the outdoor temperature for the whole year, which is in 20 to 95 °F range. The indoor temperature during the cooling periods (April through October) is well maintained and stays close to the cooling temperature setpoint of 78 °F, especially from June to mid-September when the cooling system is activated most of the time. During all other periods, the indoor temperature fluctuates between heating and cooling setpoints (68 to 78 °F), which correspond to the activation of the cooling or heating systems. As expected, the cooling energy use in Houston occurs throughout the year, while the heating energy use occurs from mid-October through mid-April.

In a similar fashion as Figure 5.16b (Section 5.2.1.1), Figure 5.29b shows significant variation in the outdoor relative humidity for the whole year, in the range of 20 to 100%; which is narrower in the summer than in the winter. The indoor relative humidity in the summer is well maintained between 40 to 70%. However, during the other periods of the year the indoor relative humidity is not very well maintained and fluctuates between 10 to 80%. There are a few hours in the year that the indoor relative humidity reaches 80 to 90 % or falls below 10%.

In a similar fashion as Figure 5.16c (Section 5.2.1.1), Figure 5.29c shows that the outdoor conditions for the whole year are widely spread-out above the 20% relative humidity line. The indoor temperature falls within the comfort zone, where the temperatures stay between the heating and cooling temperature setpoints (68 to 78 ºF). However, there are significant hours of the year where the indoor conditions fall above or below the humidity constraints of the comfort zone (i.e., above 60% relative humidity line and below 36 °F dewpoint).

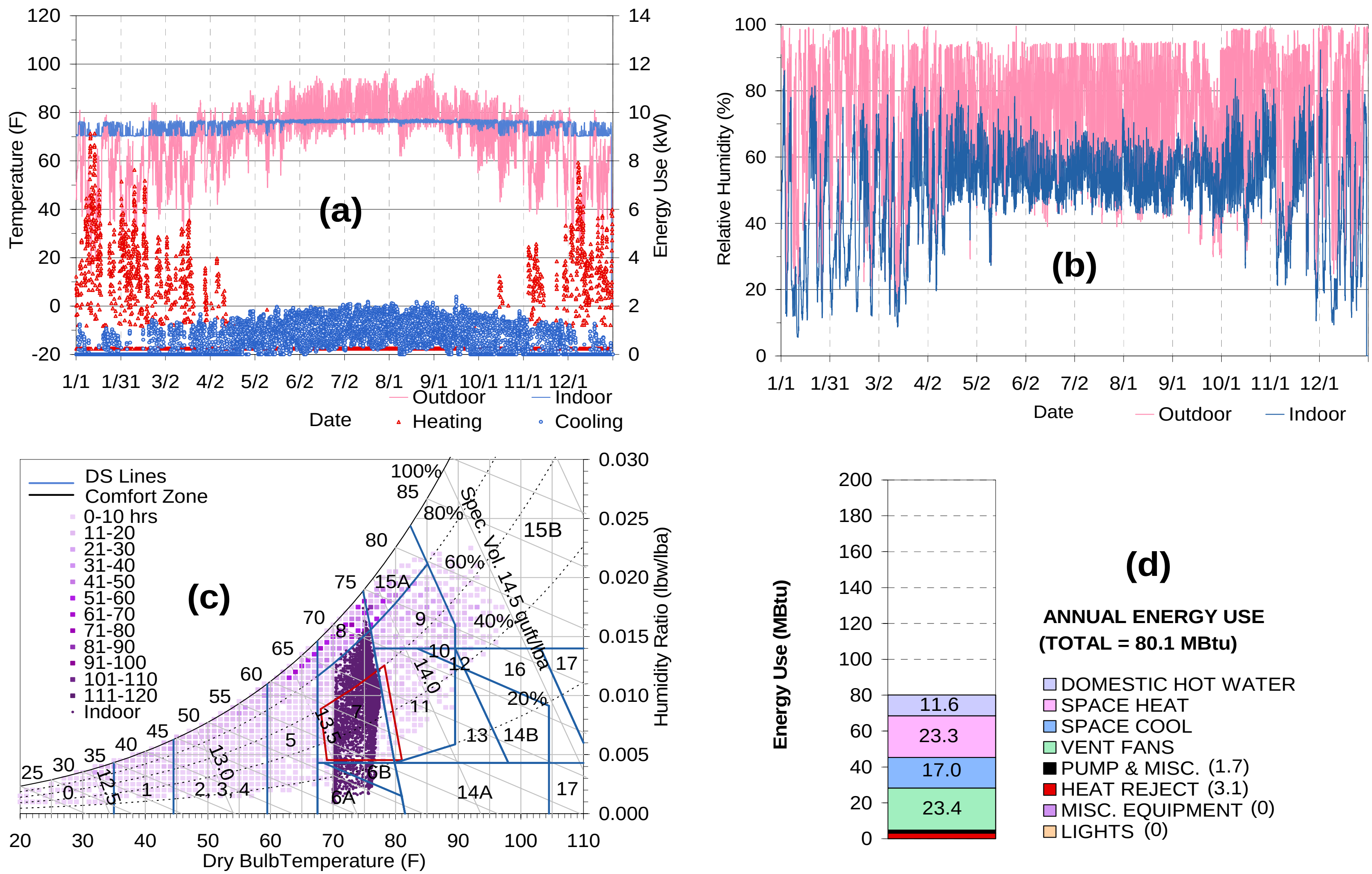
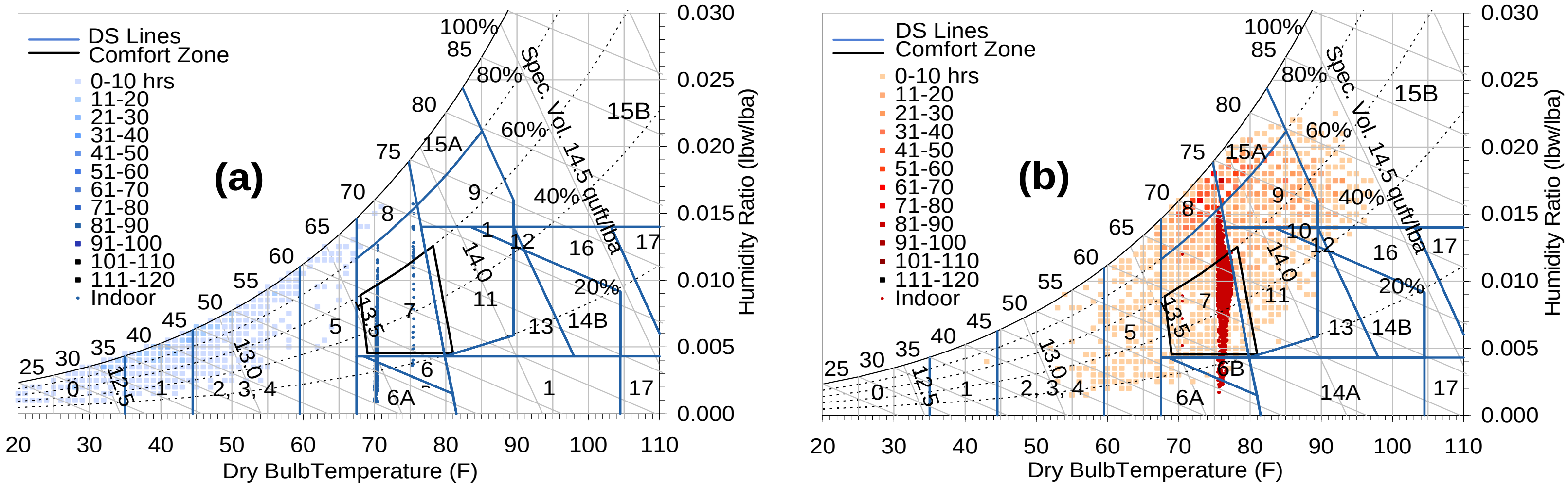
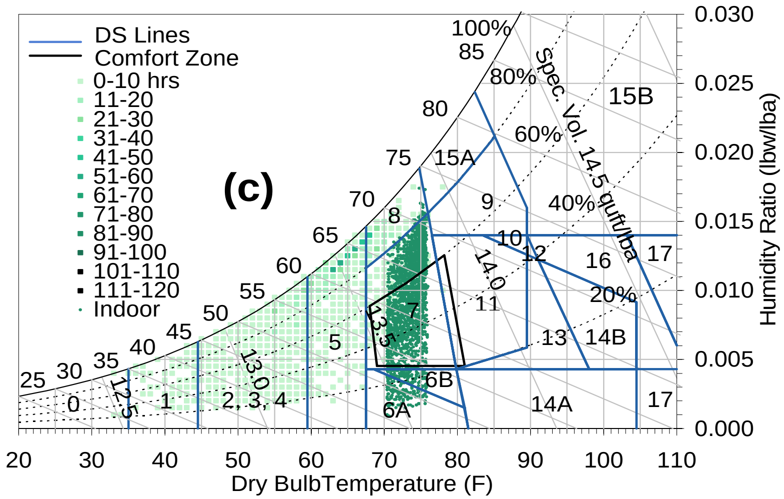


Figure 5.29 *Hourly indoor and outdoor conditions and energy use of the lightweight house without internal loads in the hot-humid climate, Houston, Texas. (a) Indoor and outdoor dry-bulb temperature and energy use of gas and electricity, (b) Indoor and outdoor relative humidity, (c) Indoor and outdoor conditions on the G-M Chart, and (d) Energy use of each category.*





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Design Strategies	Regions	G-M Bio-Chart (%)	DOE-2 Simulation HTG (%)	DOE-2 Simulation CLG (%)	DOE-2 Simulation N-H-C (%)
Conventional Heating	0	2.81	2.77	0.00	0.03
Active Solar	1	6.68	5.78	0.01	0.89
Passive Solar	2,3,4	16.07	6.50	0.53	9.05
Internal Gains	5	13.89	0.42	2.72	10.75
Humidification	6A, 6B	0.17	0.00	0.17	0.00
Comfort Zone	7	9.94	0.00	8.22	1.72
Dehumidification	8	16.72	0.09	13.36	3.28
Ventilation	9,10,11	19.76	0.00	19.75	0.01
Evaporative Cooling	6B,11,13,14A,14B	5.92	0.00	5.91	0.01
High Thermal Mass	10,11,12,13	6.48	0.00	6.47	0.01
High Thermal Mass with Night Ventilation	16, 14B	0.15	0.00	0.15	0.00
Air-Conditioning	17	0.00	0.00	0.00	0.00
Air-Conditioning & Dehumidification	15A,15B	13.78	0.00	13.77	0.01
Number of Hours/Year		8760	1363	5141	2256
Percentage of Hours/Year		100.00	15.56	58.69	25.75

Region	0	1	2	3	4	5	6A	6B	7	8	9	10	11	12	13	14A	14B	15A	15B	16	17	Total
Hours	246	585	368	478	562	1217	10	5	871	1465	1165	52	514	2	0	0	0	781	426	13	0	8760
G-M (%)	2.8	6.7	4.2	5.5	6.4	13.9	0.1	0.1	9.9	16.7	13.3	0.6	5.9	0.0	0.0	0.0	0.0	8.9	4.9	0.1	0.0	100.00
DOE-2 (%)	9.49		16.07			13.89	10.11				50.43											100.00

Figure 5.30 *Daytime and nighttime hourly indoor and outdoor conditions of the lightweight house without internal loads in the hot-humid climate, Houston, Texas, on the G-M Chart. (a) Heating period, (b) Cooling period, (c) Non-heating-cooling period, and (d) Comparison of the results from the G-M Chart vs. the DOE-2 simulation.*

Figure 5.29d shows that the total annual energy use is 80.1 MBtu. The energy use includes: domestic hot water (11.6 MBtu), space heating (23.3 MBtu), space cooling (17.0 MBtu), ventilation fans (17.0 MBtu), pump and miscellaneous (1.7 MBtu), heat rejection (3.1 MBtu), miscellaneous equipment (0 MBtu), and lights (0 MBtu). From the results, the energy use for space cooling is slightly less than the energy use for space heating.

In a similar fashion as Figure 5.17, Figure 5.30 consists of Figures 5.30a through 5.30d, which shows the daytime and nighttime annual hourly indoor and outdoor conditions on the G-M Chart during the heating period (Figure 5.30a), cooling period (Figure 5.30b), non-heating period (Figure 5.30c), and a comparison table of the results from the G-M Chart and the DOE-2 simulation (Figure 5.30d).

Figure 5.30a shows that most of the outdoor conditions during the heating period cover an area to the left of the comfort zone. The majority of the hours involve the G-M definitions of, conventional heating, active solar, and passive solar design strategies (regions 0 to 4). Only a few hours fall upon internal gains design strategy (region 5). Usually the indoor temperatures stay close to the heating temperature setpoint of 68 °F. A small portion of the heating hours that stay close to the cooling temperature setpoint of 78 °F occur individually right after the hours that the cooling system was continuously activated (see the DOE-2 HOURLY-REPORT, Appendix B). These are most likely due to the indoor temperature fluctuations of a lightweight house. In Figure 5.30a, there are many hours in this period that the indoor conditions fall above or below the humidity constraints of the ASHRAE comfort zone.

Figure 5.30b shows that the outdoor conditions during the cooling period fall into the comfort zone and are spread-out to the right, left, and above the comfort zone. The cooling data covers regions of heating design strategy, which are active solar, passive solar and internal gains (regions 1 to 5); the G-M comfort zone (region 7); and the cooling design strategy regions, which include dehumidification, ventilation, evaporative cooling, high thermal mass, and A/C with dehumidification (regions 8, 9 to 11, 10 to 12, and 15). A small portion of the cooling data falls within the areas of active solar, humidification, and high thermal mass with night ventilation design strategies (regions 1, 6, and 16). The frequency of occurrence is very high in the areas of dehumidification, ventilation, and A/C with dehumidification design strategies (regions 8 to 11, and 15A). Most indoor temperatures stay close to the cooling temperature setpoint of 78 °F. However, a very few hours stay close to the heating temperature setpoint of 68 °F. Most of these hours occur individually right after the hours that the heating system was continuously activated (see the DOE-2 HOURLY-REPORT, Appendix B). These are most likely due to the indoor temperature fluctuations of a lightweight house. There are significant hours in this period that the indoor conditions fall above or below the humidity constraints of the comfort zone.

Figure 5.30c shows that majority of the outdoor conditions during the non-heating-cooling period fall to the left of the comfort zone, which include areas of active solar, passive solar, and internal gains, the G-M comfort zone, and dehumidification design strategies (regions 1 to 5 and 7 to 8). The frequency of occurrence is high in the area of passive solar, internal gains, and dehumidification design strategies (regions 2 to 5 and 8). The indoor temperatures mostly float between the heating and cooling temperature setpoints (68 to 78 °F). There is a significant portion of the hours in this period that the indoor conditions fall above or below the humidity constraints of the comfort zone.

In Figure 5.30d, the results from the DOE-2 simulation show that there are 1,363 hours (15.56%) of the year that the heating system is activated. The cooling system is activated for 5,141 hours (58.69%) and there are 2,256 hours (25.75%) when neither the heating nor cooling systems is activated. The results from the G-M Chart analysis show 2,048 hours (23.38%) in the heating period, 4,418 hours (50.43%) in the cooling period, and 2,294 hours (26.19%) in the non-heating-cooling period.

In this simulation, the criteria used to identify the effective design strategies for heating, cooling, and non-heating-cooling periods in the G-M Chart analysis are similar to the criteria that are described in Section 5.2.1.1 (see the last paragraph of p. 149), except that there is no influence from internal loads. Therefore, the internal gains design strategy is excluded from non-heating-cooling period and is added to the heating period.

Figure 5.30d allows the results from the DOE-2 simulation to be compared to the results from the G-M bioclimatic chart. As mentioned in the previous paragraphs, the DOE-2 simulation shows 15.56% of the time in heating period, which is different from the G-M Chart result (23.38%). In this period, DOE-2 shows 2.77% and 5.78% of the hours in the year in conventional heating (region 0) and active solar (region 1) design strategies. These results are close to the G-M results, which show 2.81% in conventional heating and 6.68% in active solar design strategies. However, DOE-2 shows 6.5% and 0.42% of the hours-per-year in passive solar and internal gains (regions 2 to 5), which are significantly different from the G-M Chart results that show 16.07% and 13.89% in passive solar and internal gains. In addition, in this simulation the passive solar design strategy is not usually considered heating periods.

In the cooling period (Figure 5.30d), DOE-2 calculated 58.69% of the hours-per-year in several regions from regions 1 to 16 including active solar (region 1, 0.01%), passive solar (region 2 to 4, 0.53%), internal gains (region 5, 2.72%), humidification (regions 6a and 6b, 0.17%), the G-M comfort zone (region 7, 8.22%), dehumidification (region 8, 13.36%), ventilation (regions 9 to 11, 19.75%), evaporative cooling (regions 6b, 11, 13, 14a, 14b; 5.91%), high thermal mass (regions 10 to 13, 6.47%), high thermal mass with night ventilation (regions 14b and 16, 0.15%), and air-conditioning with dehumidification (regions 15a and 15b, 13.77%) design strategies. In regions 9 to 16, the results from the DOE-2 simulation correspond to the results from the G-M Chart analysis. However, in region 8, the results from DOE-2 simulation (13.36%) are slightly less than the results from the G-M Chart (16.72%). The other differences are in regions 1 to 7, which are not usually considered to be cooling periods in the G-M Chart analysis.

In the non-heating-cooling period (Figure 5.30d), the data of this period shown in DOE-2 (25.75%) is slightly different from the data of this period shown in the G-M Chart (26.19%). However, there are some differences in the regions of the occurrences and the number of the hours shown in each region. The DOE-2 simulation shows 9.05%

of the hours occur in region 2 to 4 (passive solar) versus the G-M Chart, which shows 16.07%. In region 6 and 7, DOE-2 shows that there are no hours in this period that fall upon the region 6 (humidification) and there is a small portion of the hours that falls upon region 7 (the G-M comfort zone, 3.28%) versus the G-M Chart showing 0.17% and 9.94% of the hours in region 6 and 7. In addition, the DOE-2 shows a small portion of the hours occurs in region 0 (conventional heating, 0.03%), region 1 (active solar, 0.89%), and region 8 (dehumidification, 3.28%) and there is a significant portion of the hours occurs in region 5 (internal gains, 10.75%). Unfortunately, in the G-M Chart analysis, these regions (0, 1, 5, and 8) are not considered non-heating-cooling period.

Summary and discussion: A lightweight house without internal loads was simulated using the TMY2 weather data for Houston, Texas (hot-humid climate). The results showed a wide range of the outdoor temperature (20 to 95 °F) and relative humidity (20 to 100%), which was narrower in the summer than in the winter. The cooling period occurred all year round while the heating period occurred from October through April and the non-heating-cooling period usually occurred in September through May. The indoor temperature fluctuated between heating and cooling setpoints (68 to 78 °F) and was very well maintained near the 78 °F during the summer. The indoor relative humidity floated between 10 to 80%. Although the indoor relative humidity was well maintained during the cooling period (only) than the mixed-period, there were many hours in this cooling period that the indoor relative humidity was above 60% and there was a significant portion of the hours that the indoor relative humidity fell above or below the humidity constraints of the comfort zone (i.e., above 60% relative humidity line or below 36 °F dewpoint). The total annual energy use for the lightweight house without internal loads in Houston, Texas, was 80.1 MBtu. The cooling energy use (17.0 MBtu) was slightly less than the heating energy use (23.3 MBtu). This was due to the missing of heat sources from the internal loads. Therefore, the design strategies for cooling and space heating should be equally considered.

The DOE-2 simulation results showed that the outdoor conditions during the heating period covered the area to the left of the comfort zone from regions 0 through 5 (conventional heating, active solar, passive solar, and internal gains design strategies). The majority of the hours fell within regions 0 to 4. The outdoor conditions during the cooling period fell into the comfort zone and were spread-out to the right and the left of the comfort zone. The frequency of occurrence of this period was high in the areas of dehumidification (region 8), ventilation (regions 9 to 11), and A/C with dehumidification design strategies (region 15A). In the non-heating-cooling period, most of the hours during this period covered from regions 0 to 5 (conventional heating, active solar, passive solar, internal gains) and 7 to 8 (the G-M comfort zone and dehumidification), where the frequency of occurrence was significantly high in regions 2 to 4 (passive solar) and 5 (internal gains).

In the heating period, the DOE-2 simulation yielded 15.56% of the hours for the year, which was less than the G-M Chart results (23.38%). In the conventional heating and active solar design strategies (regions 0 and 1), the DOE-2 simulation results were close to the G-M Chart results. DOE-2 showed 6.5% of the hours-per- year in regions 2 to 4 (passive solar). However, in the G-M Chart analysis, passive solar design strategy was not usually considered heating period. In region 5 (internal gains), the DOE-2 simulation results (0.42%) were significantly less than the G-M Chart results (13.89%).

In the cooling period, the DOE-2 simulation showed 58.69% of the hours-per-year, which was slightly more the G-M Chart results (50.43%). In region 9 to 17, the DOE-2 simulation results corresponded to the G-M results. However, in region 8, the results from DOE-2 simulation (13.36%) were slightly less than the G-M Chart results (16.72%). DOE-2 showed a small portion of the hours in region 1 to 7; which these regions, in the G-M Chart analysis, were not usually considered to be cooling periods.

In the non-heating-cooling period, although the DOE-2 simulation results (25.75%) were close to the G-M Chart results (26.19%), the data of this period in each region shown in the DOE-2 simulations were different from the G-M Chart results. the DOE-2 simulation showed 9.05% and 1.72% of the hours-per-year in region 2 to 4 (passive solar) and 7 (the G-M comfort zone), which were significantly less than the G-M Chart results (regions 2 to 4, 16.05% and region 7, 9.94%). In addition, DOE-2 showed a small portion of the hours in regions 0 (conventional heating), 1 (active solar) and 8 (dehumidification); and a significant portion of the hours occurred in region 5 (internal gains, 10.75%). Unfortunately, in the G-M Chart analysis, these regions (0, 1, 5, and 8) were not considered non-heating-cooling period.

5.2.3 High Thermal Mass House

This section presents the simulated results and discussion of the high thermal mass house in two different climates, which are: 1) the hot-humid climate of Houston, Texas; and 2) the hot-dry climate of Phoenix, Arizona.

5.2.3.1 High thermal mass house in the hot-humid climate of Houston, Texas

The results of the high thermal mass house in the representative hot-humid climate of Houston, Texas, are presented in Figures 5.31 (Figures 5.31a through 5.31d) and Figure 5.32 (Figures 5.32a through 5.32d). In a similar fashion as Figure 5.16a (Section 5.2.1.1), Figure 5.31a shows a wide range of the outdoor temperature for the whole year, in the range of 20 to 95 °F; which is narrower in the summer than in the winter. The indoor temperature during the cooling dominated periods (mid-April through October) is very well maintained and stays close to the cooling temperature setpoint of 78 °F. During all other periods, the indoor temperature fluctuates between heating and cooling setpoints (68 to 78 °F), which correspond to the activation of the cooling or heating systems. As expected, the cooling energy use of the high thermal mass house in Houston occurs throughout the year, while the heating energy use occurs from December through March.

In a similar fashion as Figure 5.16b (Section 5.2.1.1), Figure 5.31b shows significant variation in the outdoor relative humidity for the whole year, in the range of 20 to 100%; which is narrower in the summer than in the winter. The indoor relative humidity in the summer is very well maintained between 40 to 65%, especially when the

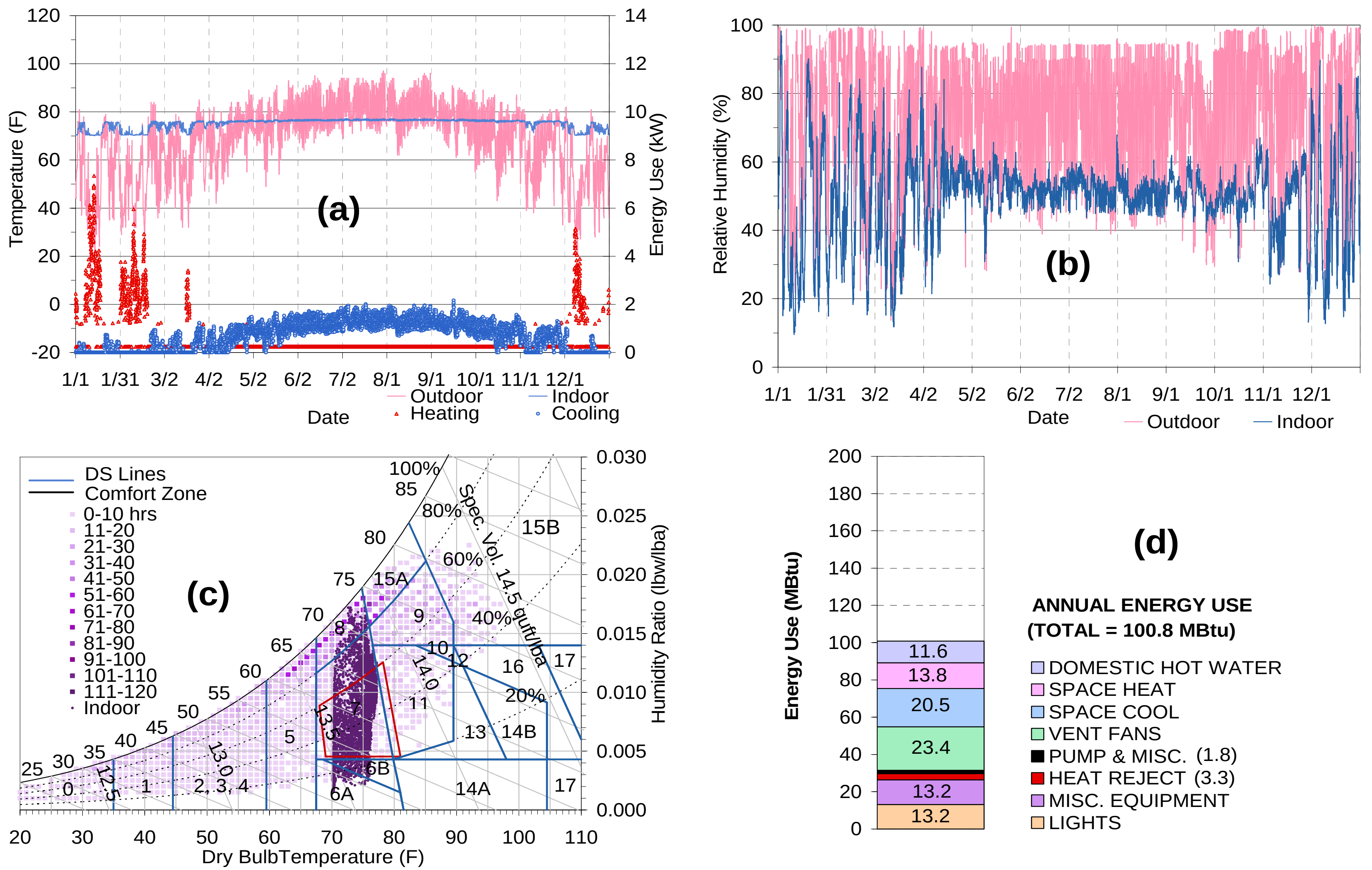
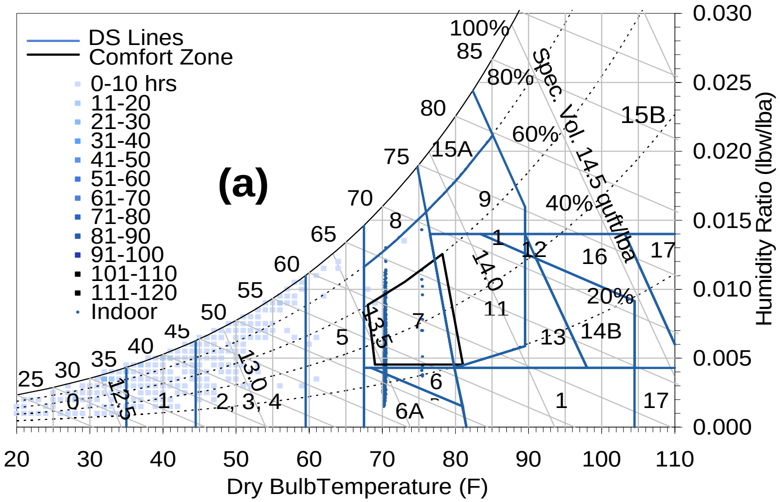
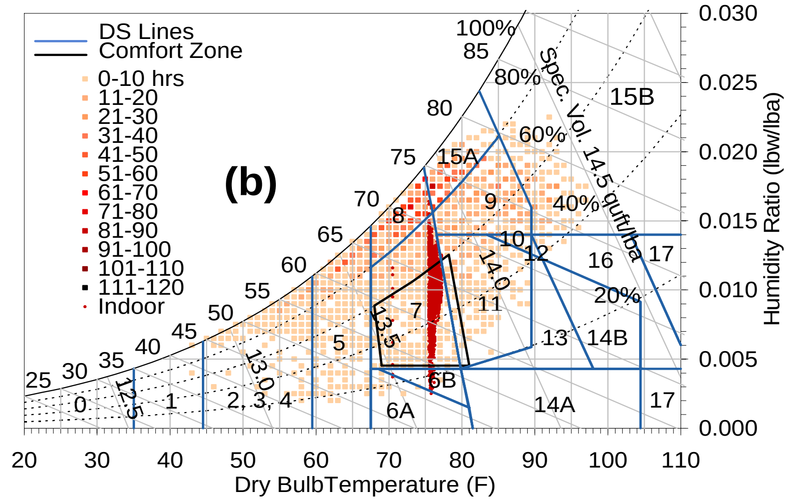
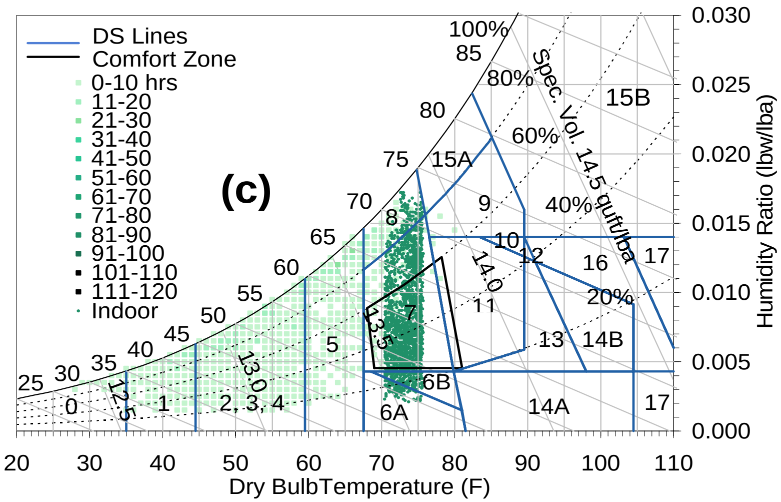


Figure 5.31 *Hourly indoor and outdoor conditions and energy use of the high thermal mass house in the hot-humid climate, Houston, Texas. (a) Indoor and outdoor dry-bulb temperature and energy use of gas and electricity, (b) Indoor and outdoor relative humidity, (c) Indoor and outdoor conditions on the G-M Chart, and (d) Energy use of each category.*







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Design Strategies	Regions	G-M Bio-Chart (%)	DOE-2 Simulation HTG (%)	DOE-2 Simulation CLG (%)	DOE-2 Simulation N-H-C (%)
Conventional Heating	0	2.81	2.43	0.00	0.38
Active Solar	1	6.68	3.53	0.02	3.13
Passive Solar	2,3,4	16.07	2.50	3.04	10.54
Internal Gains	5	13.89	0.09	8.31	5.49
Humidification	6A, 6B	0.17	0.00	0.17	0.00
Comfort Zone	7	9.94	0.03	8.57	1.34
Dehumidification	8	16.72	0.00	15.13	1.60
Ventilation	9,10,11	19.76	0.00	19.70	0.06
Evaporative Cooling	6B,11,13,14A,14B	5.92	0.00	5.90	0.02
High Thermal Mass	10,11,12,13	6.48	0.00	6.46	0.02
High Thermal Mass with Night Ventilation	16, 14B	0.15	0.00	0.15	0.00
Air-Conditioning	17	0.00	0.00	0.00	0.00
Air-Conditioning & Dehumidification	15A,15B	13.78	0.00	13.77	0.01
Number of Hours/Year		8760	752	6034	1974
Percentage of Hours/Year		100.00	8.58	68.88	22.53

Region	0	1	2	3	4	5	6A	6B	7	8	9	10	11	12	13	14A	14B	15A	15B	16	17	Total
Hours	246	585	368	478	562	1217	10	5	871	1465	1165	52	514	2	0	0	0	781	426	13	0	8760
G-M (%)	2.8	6.7	4.2	5.5	6.4	13.9	0.1	0.1	9.9	16.7	13.3	0.6	5.9	0.0	0.0	0.0	0.0	8.9	4.9	0.1	0.0	100.00
DOE-2 (%)		9.49							40.08		30.02				6.48						13.93	100.00

Figure 5.32 *Daytime and nighttime hourly indoor and outdoor conditions of the high thermal mass house in the hot-humid climate, Houston, Texas, on the G-M Chart. (a) Heating period, (b) Cooling period, (c) Non-heating-cooling period, and (d) Comparison of the results from the G-M Chart vs. the DOE-2simulation.*

cooling system is continuously activated (mid-May through mid-October). However, during the other periods of the year, when the air-conditioner is not running, the indoor relative humidity is not very well maintained and fluctuates between 10 to 90%.

In a similar fashion as Figure 5.16c (Section 5.2.1.1), Figure 5.31c shows that the outdoor conditions for the whole year are widely spread-out above the 20% relative humidity line, and cover areas to the left and to the right of the comfort zone. The frequency of occurrence is highest in the areas of 60 to 85 ºF when the relative humidity is above 80%. The indoor temperature falls within the comfort zone, where the temperatures stay between the heating and cooling temperature setpoints (68 to 78 ºF). However, there are significant hours of the year where the indoor conditions fall above or below the humidity constraints of the comfort zone (i.e., above 60% relative humidity line and below 36 °F dewpoint). Moreover, there are many hours during the winter (December through February) when the indoor relative humidity falls above the 80% relative humidity line.

Figure 5.31d shows that the total annual energy use is 100.8 MBtu. The energy use includes: domestic hot water (11.6 MBtu), space heating (13.8 MBtu), space cooling (20.5 MBtu), ventilation fans (23.4 MBtu), pump and miscellaneous (1.8 MBtu), heat rejection (3.3 MBtu), miscellaneous equipment (13.2 MBtu), and lights (13.2 MBtu). In the results, it is interesting to note that the energy use for space cooling is more than the energy use for space heating.

In a similar fashion as Figure 5.17, Figure 5.32 consists of Figures 5.32a through 5.32d, which shows the daytime and nighttime annual hourly indoor and outdoor conditions on the G-M Chart during the heating period (Figure 5.32a), cooling period (Figure 5.32b), non-heating period (Figure 5.32c), and a comparison table of the results from the G-M Chart and the DOE-2 simulation (Figure 5.32d).

Figure 5.32a shows that most of the outdoor conditions during the heating period cover an area to the left of the comfort zone. The majority of the hours involve the G-M definitions of: conventional heating, active solar, and passive solar design strategies (regions 0 to 4). Only a few hours fall into the internal gains design strategy (region 5, 0.09%) and the G-M comfort zone (region 7, 0.03%). Usually the indoor temperatures stay close to the heating temperature setpoint of 68 °F. There are very few hours of heating that the indoor temperatures stay close to the cooling temperature setpoint of 78 °F (see the DOE-2 HOURLY-REPORT, Appendix B). These are most likely due to the indoor temperature fluctuations, which rarely occur in a high thermal mass house. In Figure 5.32a, there are many hours in this period that the indoor conditions fall above or below the humidity constraints of the ASHRAE comfort zone (i.e., above 60% relative humidity line and below 36 °F dewpoint temperature).

Figure 5.32b shows that the outdoor conditions during the cooling period fall into the comfort zone and are spread-out to the right, left, and above the comfort zone. The cooling data covers regions of heating design strategy, which are passive solar and internal gains (regions 2 to 5); the G-M comfort zone (region 7); and the cooling design strategy regions, which include dehumidification, ventilation, evaporative cooling, high thermal mass, and A/C with dehumidification (regions 8 to 12, and 15). A small portion of the cooling data falls within the areas of active solar, humidification, and high thermal mass with night ventilation design strategies (regions 1, 6, and 16). The frequency of occurrence is very high in the areas of dehumidification, ventilation, and A/C with dehumidification design strategies (regions 8 to 11, and 15A) as expected. Most indoor temperatures stay close to the cooling temperature setpoint of 78 °F. There are a very few hours of this period that the indoor temperatures stay close to the heating temperature setpoint of 68 °F (see the DOE-2 HOURLY-REPORT, Appendix B). These are most likely due to the indoor temperature fluctuations, which rarely occur in a high thermal mass house. There are portions of the hours in this period that the indoor conditions fall above or below the humidity constraints of the comfort zone.

Figure 5.32c shows that majority of the outdoor conditions during the non-heating-cooling period fall to the left of the comfort zone, which include areas of conventional heating, active solar, passive solar, and internal gains, the G-M comfort zone, and dehumidification design strategies (regions 0 to 5 and 7 to 8). The frequency of occurrence is high in the area of active solar, passive solar, and internal gains design strategies (regions 1 to 5). The indoor temperatures mostly float between the heating and cooling temperature setpoints (68 to 78 °F). There is a significant portion of the hours in this period that the indoor conditions fall above or below the humidity constraints of the comfort zone.

In Figure 5.32d, the results from the DOE-2 simulation show that there are 752 hours (8.58%) in the year when the heating system is activated. The cooling system is activated for 6,034 hours (68.88%) and there are 1,974 hours (22.53%) when neither the heating nor cooling systems is activated. The results from the G-M Chart analysis show 831 hours (9.49%) in the heating period, 3,850 hours (43.95%) in the cooling period, and 4,079 hours (46.56%) in the non-heating-cooling period.

In this simulation, the criteria used to identify the effective design strategies for heating, cooling, and non-heating-cooling periods in the G-M Chart analysis are similar to the criteria that are described in Section 5.2.1.1 (see the last paragraph of p. 149), except that there are some influences from high thermal mass. Therefore, the high thermal mass design strategy becomes the effective design strategy region for the non-heating-cooling period.

Figure 5.32d compares the results from the DOE-2 to the results from the G-M bioclimatic chart. As mentioned in the previous paragraphs, the DOE-2 simulation shows 8.58% of the time in heating period, which is slightly less than the G-M Chart results (9.49%). In this period, DOE-2 shows 2.43% of the hours in the year in conventional heating (region 0), which is close to the G-M results (2.81%). In the active solar (region 1), the DOE-2 simulation results (3.53%) are almost 50% less than the G-M chart results (6.68%). In addition, DOE-2 shows portions of the hours-per-year in the passive solar (region 2 to 4, 2.5%), internal gains (region 5, 0.09%), and the G-M comfort zone (region 7, 0.03%). Unfortunately, in the G-M chart analysis these regions are not usually considered heating periods.

In the cooling period (Figure 5.32d), DOE-2 calculated 68.88% of the hours-per-year in several regions from regions 1 to 16 including active solar (region 1, 0.02%), passive solar (region 2 to 4, 3.04%), internal gains (region 5, 8.31%), humidification (regions 6a and 6b, 0.17%), the G-M comfort zone (region 7, 8.57%), dehumidification (region 8, 15.13%), ventilation (regions 9 to 11, 19.70%), evaporative cooling (regions 6b, 11, 13, 14a, 14b; 5.90%), high thermal mass (regions 10 to 13, 6.46%), high thermal mass with night ventilation (regions 14b and 16, 0.15%), and air-conditioning with dehumidification (regions 15a and 15b, 13.77%) design strategies. In regions 9 and 14 to 16, the results from the DOE-2 simulation are similar or very close to the results from the G-M Chart analysis. In region 8, the results from DOE-2 simulation (15.13%) are slightly less than the results from the G-M Chart (16.72%). However, significant differences are in regions 1 to 7 and 10 to 13, which are not usually considered to be cooling periods in the G-M Chart analysis.

In the non-heating-cooling period (Figure 5.32d), the results from the DOE-2 simulation (22.53%) are almost 50% less than the results from the G-M Chart (46.56%). The DOE-2 simulation results in regions 2 to 4 (passive solar, 10.54%), 5 (internal gains, 5.49 %), 7 (the G-M comfort zone, 1.34%). Regions 10 to 13 (high thermal mass, 0.02%) are significantly less than the G-M Chart results; which show as much as 16.07%, 13.89%, 9.94%, and 6.48%; respectively. In addition, DOE-2 shows portions of the hours-per-year in conventional heating (region 0, 0.38%), active solar (region 1, 3.13%), dehumidification (region 8, 1.6%), and ventilation (region 9, 0.06%); which these regions are not usually considered to be a non-heating-cooling period in the G-M chart analysis.

Summary and discussion: A high thermal mass house was simulated using the TMY2 weather data for Houston, Texas (hot-humid climate). The results showed a wide range of the outdoor temperature (20 to 95 °F) and relative humidity (20 to 100%), which was narrower in the summer than in the winter. The cooling period occurred all year round while the heating period occurred from December through March and the non-heating-cooling period usually occurred from November through April. The indoor temperature fluctuated between heating and cooling setpoints (68 to 78 °F) and was very well maintained near the 78 °F when the cooling system was continuously activated (mid-April through October). The indoor relative humidity floated between 10 to 90%.

The indoor relative humidity was well maintained during the cooling period. There was a significant portion of the hours in the other periods, especially non-heating-cooling period that the indoor relative humidity fell above or below the humidity constraints of the comfort zone (i.e., above 60% relative humidity line or below 36 °F dewpoint). The total annual energy use for the high thermal mass house in Houston, Texas, was 100.8 MBtu. The cooling energy use (20.5 MBtu) was more than the heating energy use (13.8 MBtu). Therefore, the design strategies for cooling should be considered a priority.

The DOE-2 simulation results show that the outdoor conditions during the heating period covered the area to the left of the comfort zone from regions 0 through 5 (conventional heating, active solar, passive solar, and internal gains design strategies), and region 7 (the G-M comfort zone). The majority of the hours fell within regions 0 to 4. The outdoor conditions during the cooling period fell into the comfort zone and were spread-out to the right and the left of the comfort zone. The frequency of occurrence of this period was high in the areas of dehumidification (region 8), ventilation (regions 9 to 11), and A/C with dehumidification design strategies (region 15A). In the non-heating-cooling period, most of the hours during this period covered from regions 0 to 5 (conventional heating, active solar, passive solar, internal gains) and 7 to 8 (the G-M comfort zone and dehumidification), where the frequency of occurrence was high in regions 1 (active solar) and 5 (internal gains) and significantly high in region 2 to 4 (passive solar).

In the heating period, the DOE-2 simulation yielded 8.58% of the hours for the year, which was slightly less than the G-M Chart results of the high thermal mass (9.49%). In the conventional heating (regions 0), the results from the DOE-2 simulation were slightly less than the results from the G-M Chart. In active solar (region 1), the DOE-2 simulation results were 50% less than the G-M chart results. In addition, DOE-2 showed a portion of the hours in passive solar (regions 2 to 4) and a few hours in internal gains (region 5) and the G-M comfort zone (region 7). Unfortunately, in the G-M chart analysis these regions were not usually considered heating periods.

In the cooling period, the DOE-2 simulation of the thermal mass showed 68.88% of the hours-per- year in regions 1 to 16, which was more than the G-M Chart results (43.95%). In regions 9 (a part of ventilation) and 14 to 16 (evaporative cooling and high thermal mass with night ventilation), results from the DOE-2 simulation corresponded or were very close to the results from the G-M Chart analysis. In region 8 (dehumidification), results from the DOE-2 simulation were slightly less than results from the G-M Chart. However, significant differences were in regions 1 to 7 (active solar, passive solar, internal gains, humidification, and the G-M comfort zone) as well as regions 10 to 13 (high thermal mass), which were not usually considered to be cooling periods in the G-M Chart analysis.

In the non-heating-cooling period, the results of the high thermal mass from the DOE-2 simulation were almost 50% less than the results from the G-M Chart. The DOE-2 simulation results in regions 2 to 4 (passive solar), 5 (internal gains), 7 (the G-M comfort zone), and 10 to 13 (high thermal mass) were significantly less than the G-M Chart results. In addition, DOE-2 showed a portion of the hours-per-year in conventional heating (region 0), active solar (region 1), dehumidification (region 8), and ventilation (region 9); which these regions, in the G-M chart analysis, were not usually considered to be a non-heating-cooling period.

5.2.3.2 High thermal mass house in the hot-dry climate of Phoenix, Arizona

The results of the high thermal mass house in the representative hot-dry climate of Phoenix, Arizona, are presented in Figures 5.33 (Figures 5.33a through 5.33d) and Figure 5.34 (Figures 5.34a through 5.34d). In a similar fashion as Figure 5.27a (Section 5.2.1.3), Figure 5.33a shows a wide range of the outdoor temperature for the whole year, in the temperature range of 35 to 110 °F. The indoor temperature of the cooling periods is very well maintained at the cooling setpoint (78 °F) when the cooling system is continuously activated (May through October). However, in the other periods, the indoor temperature fluctuates between heating and cooling setpoints (68 to 78 °F), which correspond to the intermittent activation of the cooling or heating systems. The heating

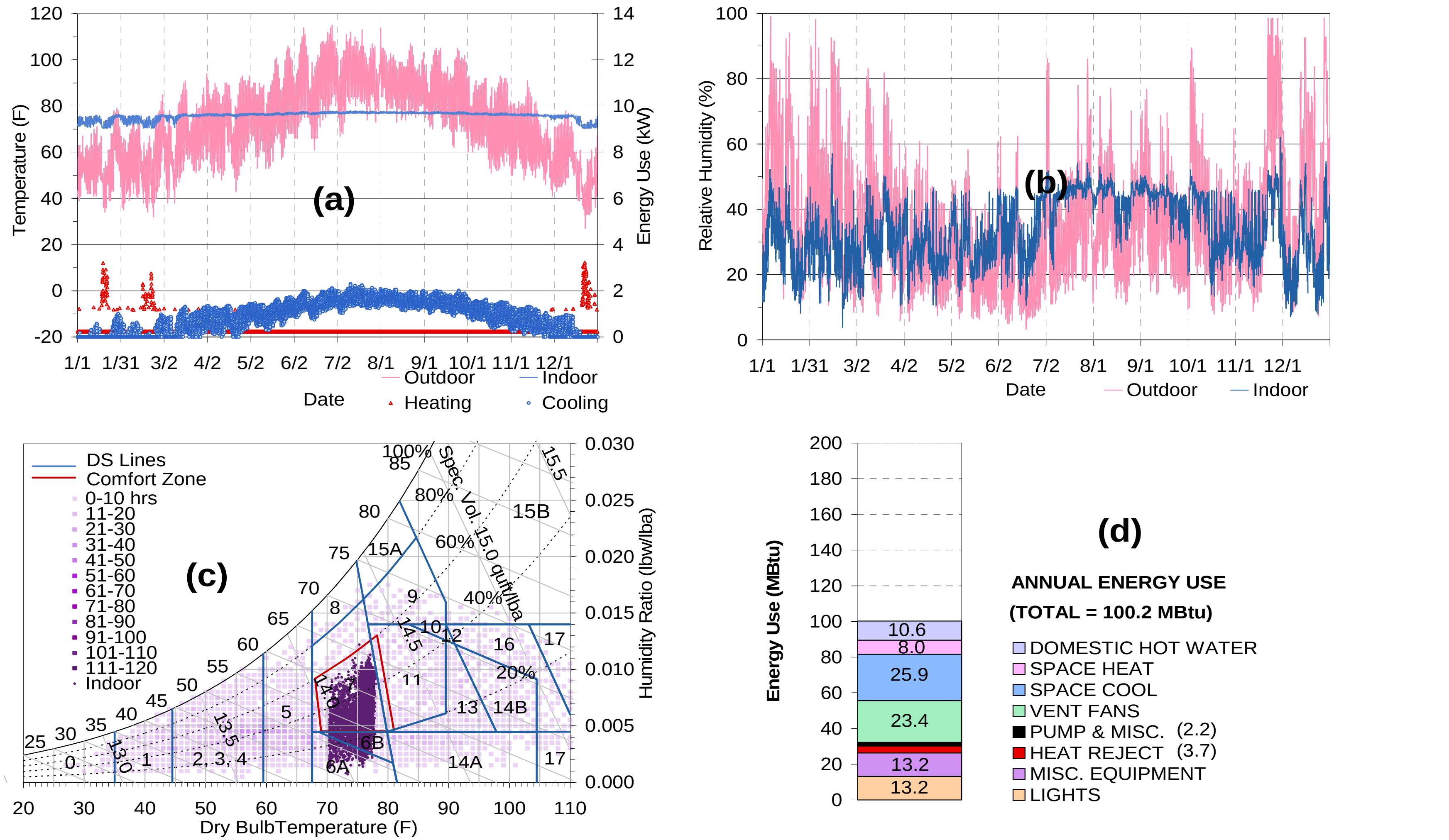
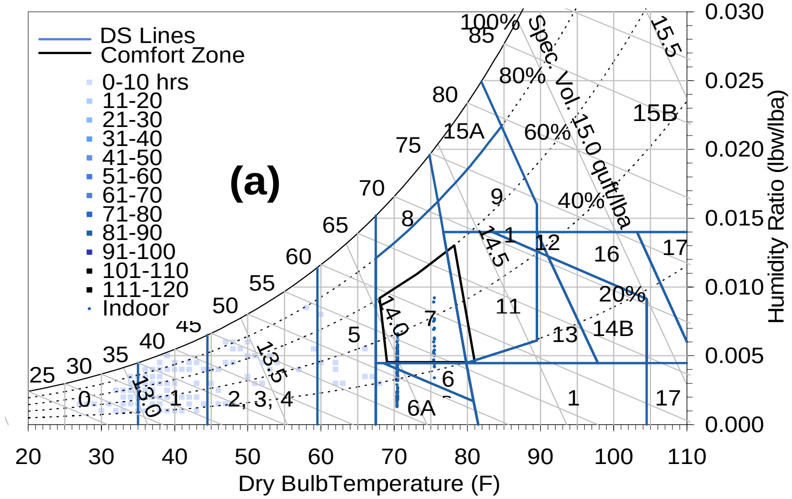
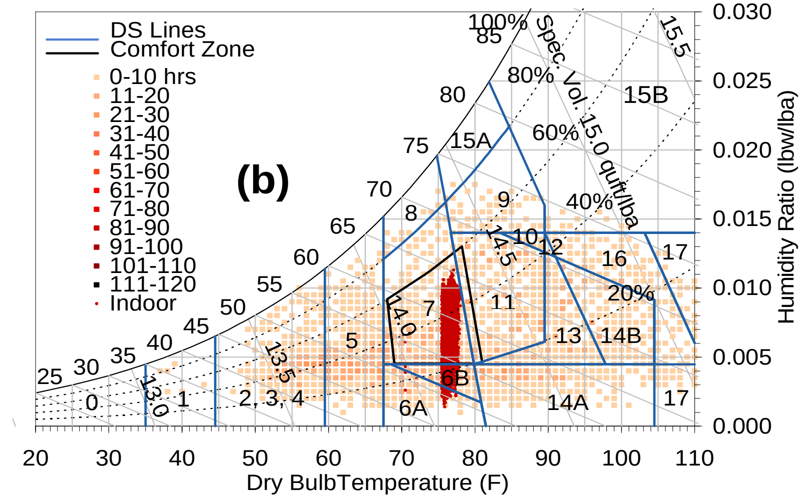
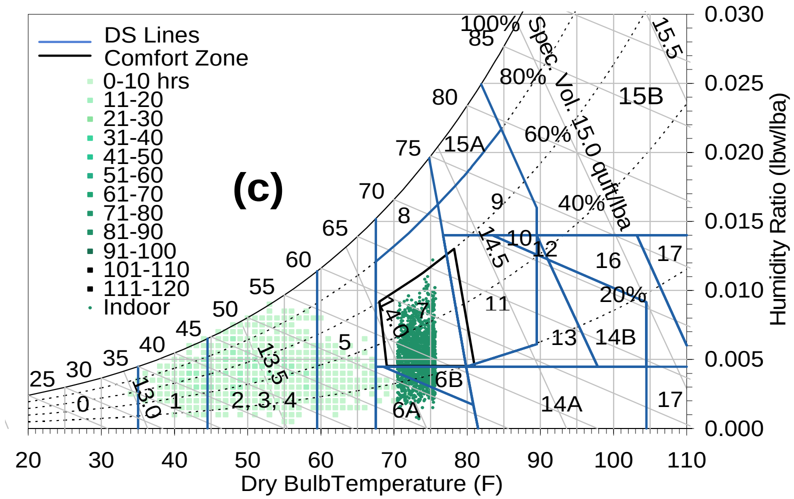


Figure 5.33 *Hourly indoor and outdoor conditions and energy use of the high thermal mass house in the hot-dry climate, Phoenix, Arizona. (a) Indoor and outdoor dry-bulb temperature and energy use of gas and electricity, (b) Indoor and outdoor relative humidity, (c) Indoor and outdoor conditions on the G-M Chart, and (d) Energy use of each category.*







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Design Strategies	Regions	G-M Bio-Chart (%)	DOE-2 Simulation HTG (%)	DOE-2 Simulation CLG (%)	DOE-2 Simulation N-H-C (%)
Conventional Heating	0	0.35	0.34	0.00	0.01
Active Solar	1	4.73	1.18	0.07	3.48
Passive Solar	2,3,4	22.04	0.39	7.88	13.78
Internal Gains	5	14.03	0.13	11.40	2.50
Humidification	6A, 6B	8.31	0.01	8.17	0.13
Comfort Zone	7	11.69	0.00	11.69	0.00
Dehumidification	8	0.21	0.00	0.21	0.00
Ventilation	9,10,11	13.22	0.00	13.22	0.00
Evaporative Cooling	6B,11,13,14A,14B	34.38	0.00	34.38	0.00
High Thermal Mass	10,11,12,13	18.84	0.00	18.84	0.00
High Thermal Mass with Night Ventilation	16, 14B	10.01	0.00	10.01	0.00
Air-Conditioning	17	1.26	0.00	1.26	0.00
Air-Conditioning & Dehumidification	15A,15B	0.34	0.00	0.34	0.00
Number of Hours/Year		8760	179	6838	1743
Percentage of Hours/Year		100.00	2.04	78.06	19.90

Region	0	1	2	3	4	5	6A	6B	7	8	9	10	11	12	13	14A	14B	15A	15B	16	17	Total
Hours	31	414	483	664	784	1229	340	388	1024	18	124	55	979	18	598	594	453	6	24	424	110	8760
G-M (%)	0.4	4.7	5.5	7.6	8.9	14.0	3.9	4.4	11.7	0.2	1.4	0.6	11.2	0.2	6.8	6.8	5.2	0.1	0.3	4.8	1.3	100.00
DOE-2 (%)		5.08							56.07		1.62				18.84						18.39	100.00

Figure 5.34 *Daytime and nighttime hourly indoor and outdoor conditions of the high thermal mass house in the hot-dry climate, Phoenix, Arizona, on the G-M Chart. (a) Heating period, (b) Cooling period, (c) Non-heating-cooling period, and (d) Comparison of the results from the G-M Chart vs. the DOE-2 simulation.*

periods is short and occurs during December through mid-March. As expected, the cooling energy usage in Phoenix is significantly higher than energy use for heating.

In a similar fashion as Figure 5.27b (Section 5.2.1.3), Figure 5.33b shows significant variation in the outdoor relative humidity (RH) for the whole year, which ranges from 10% to nearly 100% range; which is higher and wider in the winter than in the other periods. The outdoor relative humidity is significantly low in April to June and from mid-October to mid-November. The range of outdoor relative humidity during these periods stays in the 5 to 60%. The indoor relative humidity from July through October is well maintained between 20 to 50%. However, in the other periods of the year the indoor relative humidity fluctuates between 10 to 60%. There is a significant portion of the hours in these periods that the indoor relative humidity falls below 20%.

In a similar fashion as Figure 5.27c (Section 5.2.1.3), Figure 5.33c shows that the outdoor conditions for the whole year are widely spread-out under the 73 °F dewpoint line covering the comfort zone and the areas to the left and to the right of the comfort zone (from 25 to 115 ºF). The frequency of occurrence is slightly higher in the areas of 40 to 90 ºF, when the humidity ratio is below 0.008 lbw/lba (50 ºF dewpoint temperature). Most of the indoor temperature falls within and below the comfort zone, where the temperatures stay between the heating and cooling temperature setpoints (68 to 78 ºF). There is a significant portion of the hours in the year where the indoor conditions fall below the humidity constraints of the comfort zone (i.e., below 36 °F dewpoint).

Figure 5.33d shows that the total annual energy use is 100.2 MBtu. The energy use includes: domestic hot water (10.6 MBtu), space heating (8.0 MBtu), space cooling (25.9 MBtu), ventilation fans (23.4 MBtu), pump and miscellaneous (2.2 MBtu), heat rejection (3.7 MBtu), miscellaneous equipment (13.2 MBtu), and lights (13.2 MBtu). From the results, the energy use for space cooling is the highest and significantly higher than the energy use for space heating. The total energy use associated with cooling is actually larger than this since it includes the fan energy use during the cooling period, which is not proportioned by DOE-2.

In a similar fashion as Figure 5.17, Figure 5.34 consists of Figures 5.34a through 5.34d, which shows the daytime and nighttime annual hourly indoor and outdoor conditions on the G-M Chart during the heating period (Figure 5.34a), cooling period (Figure 5.34b), non-heating period (Figure 5.34c), and a comparison table of the results from the G-M Chart and the DOE-2 simulation (Figure 5.34d).

Figure 5.34a shows that most of the outdoor conditions during the heating period cover an area to the left of the comfort zone. The majority of the hours involve the G-M definitions of active solar design strategies (regions 1). Only a few hours fall into the conventional heating, passive solar, internal gains design strategies, and humidification strategies (region 0, 2 to 4, 5 and 6). Usually the indoor temperatures stay close to the heating temperature setpoint of 68 °F. The small portion of the heating hours that approach cooling temperature setpoint of 78 °F occur individually right after the hours that the cooling system was continuously activated (see the DOE-2 HOURLY-REPORT, Appendix B). These are most likely due to the indoor temperature fluctuations, which rarely occur in a high thermal mass house. In Figure 5.34a, there are many hours in this period that the indoor conditions fall below the humidity constraints of the ASHRAE comfort zone.

Figure 5.34b shows that the outdoor conditions during the cooling period fall into the comfort zone and are widely spread-out to the right and the left of the comfort zone. The cooling data covers all regions except region 0 (conventional heating). These regions include heating design strategy regions; which are active solar (region 1), passive solar (regions 2 to 4) and internal gains design strategies (region 5); humidification (region 6a and 6b); the G-M comfort zone (region 7); dehumidification (region 8); and the cooling design strategy regions, which are ventilation, evaporative cooling, high thermal mass (with and without night ventilation), and air-conditioning (with and without dehumidification) (regions 6B and 9 to 17).

Figure 5.34b shows that the frequency of occurrence is high in the areas of passive solar (regions 2 to 4), internal gains (region 5), humidification (regions 6a and 6b), the G-M comfort zone (region 7), ventilation (regions 9 to 11), high thermal mass (regions 10 to 13) and high thermal mass with night ventilation (regions 14b and 16). The frequency of occurrence is highest in the area of evaporative cooling design strategy (regions 6b, 11, 13, 14a and 14b). Most of the indoor temperatures stay close to the cooling temperature setpoint of 78 °F. Only a few hours of the cooling periods stays close to the heating temperature setpoint of 68 °F (see the DOE-2 HOURLY-REPORT, Appendix B). These are most likely due to the indoor temperature fluctuations, which rarely occur in a high thermal mass house. There are many hours in this period that the indoor conditions fall below the humidity constraints of the comfort zone (below 36 °F dewpoint line).

Figure 5.34c shows that majority of the outdoor conditions during the non-heating-cooling period fall to the left side of the comfort zone, which include areas of active solar, passive solar and internal gains design strategies (regions 2 to 5). Only a small portion falls within the area of humidification design strategy (regions 6). The frequency of occurrence is highest in the area of passive solar design strategies (regions 2 to 4). The indoor temperatures mostly float between the heating and cooling temperature setpoints (68 to 78 °F). There is a significant portion of the hours in this period that the indoor conditions fall below the humidity constraints of the comfort zone.

In Figure 5.34d, the results from the DOE-2 simulation show that there are 179 hours (2.04%) of the year that the heating system is activated. The cooling system is activated for 6,838 hours (78.06%) and there are 1,743 hours (19.90%) when neither the heating nor cooling systems is activated. The results from the G-M Chart analysis show that there are 445 hours (5.08%) in the heating period. There are 1,753 hours (20.01%) in the cooling period, and 6,562 hours (74.91%) in the non-heating-cooling period. The criteria used to identify the effective design strategies for heating, cooling, and non-heating-cooling periods in the G-M Chart analysis are described in Section 5.2.3.1 (see last paragraph of page 193).

Figure 5.34d allows the results from the DOE-2 simulation to be compared to the results from the G-M bioclimatic chart. As mentioned in the previous paragraphs, the DOE-2 simulation shows 2.04% of the time in heating period, which is different from the G-M Chart results (5.08%). In this period, DOE-2 shows that 0.34% of the hours fall into conventional heating (region 0), which is very close to the G-M results (0.35%). However, DOE-2 shows 1.18%, 0.39%, 0.13%, and 0.01% of the hours in the year in active solar (region 1), passive solar (regions 2 to 4), internal gains (region 5), and humidification (region 6); respectively. These are different from the G-M Chart results, which show 4.73% in active solar design strategy (region 1). In addition, passive solar, internal gains, and humidification design strategies (regions 2 to 4, 5, and 6) are not usually considered heating periods.

In the cooling period (Figure 5.34d), DOE-2 calculated 74.91% of the hours-per-year in several regions from regions 1 to 17 including active solar (region 1, 0.07%), passive solar (region 2 to 4, 7.88%), internal gains (region 5, 11.40%), humidification (regions 6a and 6b, 8.17%), the G-M comfort zone (region 7, 11.69%), dehumidification (region 8, 0.21%), ventilation (regions 9 to 11, 13.22%), evaporative cooling (regions 6b, 11, 13, 14a, 14b; 34.38%), high thermal mass (regions 10 to 13, 18.84%), high thermal mass with night ventilation (regions 14b and 16, 10.01%), air-conditioning (region 17, 1.26%) and air-conditioning with dehumidification (regions 15a and 15b, 0.34%) design strategies. Surprisingly, the G-M Chart shows only 20.01% is in the cooling period. In regions 8 to 9 and 14 to 17, the results from the DOE-2 simulation correspond to the results from the G-M Chart analysis. However, DOE-2 shows a significant portion of the cooling period in regions 1 to 7 and 10 to 13, which are not usually considered to be cooling periods in the G-M Chart analysis.

In the non-heating-cooling period (Figure 5.34d), the results from the DOE-2 simulation are also far from the same results from the G-M Chart. The DOE-2 simulation shows 19.90% of the hours in the year in this period while the G-M Chart shows as much as 74.91%. DOE-2 shows a portion of the hours occurs in region 0 and 1 (conventional heating and active solar), which is not considered to be a non-heating-cooling period in the G-M Chart analysis. The significant differences are shown in regions 5 (internal gains), where the DOE-2 simulation shows only 2.50% of the time in this region versus the G-M Chart showing 14.03%. In regions 2 to 4 (passive solar) and

6a (humidification), the results from the DOE-2 simulation (13.78% and 0.13%) are also less than the results from the G-M Chart analysis (22.04%, 3.88%). In regions 6b (humidification/ evaporative cooling), 7 (the G-M comfort zone), and 10 to 13 (high thermal mass), the DOE-2 simulation shows that there are no hours in this period that fall into these regions versus the G-M Chart showing 4.43%, 11.69%, 18.84% in regions 6b, 7 and 10 to 13; respectively.

Summary and discussion: A high thermal mass house was simulated using the TMY2 weather data for Phoenix, Arizona (hot-dry climate). The results showed a wide range of the outdoor temperature, which was slightly wider in the winter than in other periods. The range of the relative humidity (RH) for the whole year was significantly large especially during the winter when the outdoor relative humidity was higher than the other periods. From April to June and mid-October to mid-November, the outdoor relative humidity was significantly low and stayed between 5 to 60%. The cooling period occurred all year round while the heating and non-heating-cooling periods occurred during the winter. The indoor temperature fluctuated between heating and cooling setpoints (68 to 78 °F). The indoor relative humidity floated between 10 to 60%. During May through October, when the cooling system was continuously activated, the indoor temperatures were very well maintained near the cooling setpoint (78 °F). However, there was a small portion of the hours during this period and a significant portion of the hours during the other periods that the indoor relative humidity fell below the humidity constraints of the comfort zone (i.e., below 36 °F dewpoint temperature). The total annual energy use for the high thermal mass house in Phoenix, Arizona, was 100.2 MBtu. The cooling energy use (25.9 MBtu) was significantly higher than the heating energy use (8.0 MBtu). Therefore, the design strategies for cooling should be considered a priority.

The DOE-2 simulation results showed that the outdoor conditions during the heating period covered the area to the left of the comfort zone from regions 0 through 6 (conventional heating, active solar, passive solar, internal gains, and humidification design strategies). The majority of the hours fell within regions 1 (active solar). The outdoor conditions during the cooling period fell into the comfort zone and were spread-out to the right and the left of the comfort zone. The frequency of occurrence of this period was high in several regions (regions 2 to 7, 11, 13, 14 and 16), which were the areas of passive solar, internal gains, humidification, ventilation, evaporative cooling and high thermal mass (with and without night ventilation) design strategies. In the non-heating-cooling period, most of the hours during this period fell into regions 0 to 6 (conventional heating, active solar, passive solar, internal gains, and humidification), in which the frequency of occurrence was significantly high in regions 2 to 4 (passive solar).

In the heating period, the DOE-2 simulation yielded 2.04% of the hours for the year, which was less than the G-M Chart results (5.08%). In the conventional heating design strategy (region 0), results from the DOE-2 simulation corresponded to the results from the G-M Chart. The differences were in active solar design strategy (region 1), where DOE-2 showed only 1.18%, while the G-M Chart showed 4.73%. DOE-2 showed small portions of the heating hours in passive solar (regions 2 to 4), internal gains (region 5) and humidification (region 6) design strategies. However, in the G-M Chart analysis, these regions were not usually considered heating periods.

In the cooling period, the DOE-2 simulation showed 74.91% of the hours for the year versus the G-M Chart showing only 20.01%. In region 8 to 9 and 14 to 17, the DOE-2 simulation results corresponded to the G-M Chart results. However, the differences were in regions 1 to 7 and 10 to 13. Unfortunately, in a G-M Chart analysis, these regions were not usually considered cooling periods.

In the non-heating-cooling period, the DOE-2 simulation showed 19.90% of the annual hours, which was significantly less than the G-M Chart results (74.91%). DOE-2 showed a portion of the hours occurred in regions 0 and 1 (conventional heating and active solar), in which was not considered to be a non-heating-cooling period in the G-M Chart analysis. The differences were also shown in regions 2 to 4 (passive solar), region 5 (internal gains), and 6a (humidification); in which the DOE-2 simulation results (13.78%, 2.50%, and 0.13%) were less than the G-M results (22.04%, 14.03%, and

3.88%); respectively. The DOE-2 simulation showed that there were no hours that fell in the regions 6b (humidification/ evaporative cooling), 7 (the G-M comfort zone), and 10 through 13; which were usually considered to be a non-heating-cooling period in the G-M Chart.

5.2.4 Lightweight House with an Economizer

This section presents the simulated results and discussion of the lightweight house with an economizer in two different climates, which are: 1) the hot-humid climate of Houston, Texas; and 2) the warm-marine climate of San Francisco, California.

5.2.4.1 Lightweight house with an economizer in the hot-humid climate of Houston, Texas

The results of the lightweight house with an economizer in the hot-humid climate of Houston, Texas, are presented in Figures 5.35 (Figures 5.35a through 5.35d) and Figure 5.36 (Figures 5.36a through 5.36d). In a similar fashion as Figure 5.16a (Section 5.2.1.1), Figure 5.35a shows a wide range of the outdoor temperature for the whole year, in the range of 20 to 95 °F; which is narrower in the summer than in the winter. The indoor temperature during the cooling dominated periods (mid-April through mid-October) is very well maintained and stays close to the cooling temperature setpoint of 78 °F. During all other periods, the indoor temperature fluctuates between heating and cooling setpoints (68 to 78 °F), which correspond to the activation of the cooling or heating systems. As expected, the cooling energy use of the lightweight house with an economizer for Houston occurs throughout the year, while the heating energy use occurs from November through March. The non-heating-cooling period occurs during October through April. There are also small portions of the non-heating-cooling hours occurring in May, August and September.

In a similar fashion as Figure 5.16b (Section 5.2.1.1), Figure 5.35b shows significant variation in the outdoor relative humidity (RH) for the whole year, in the range of 20 to 100%; which is narrower in the summer than in the winter. The indoor

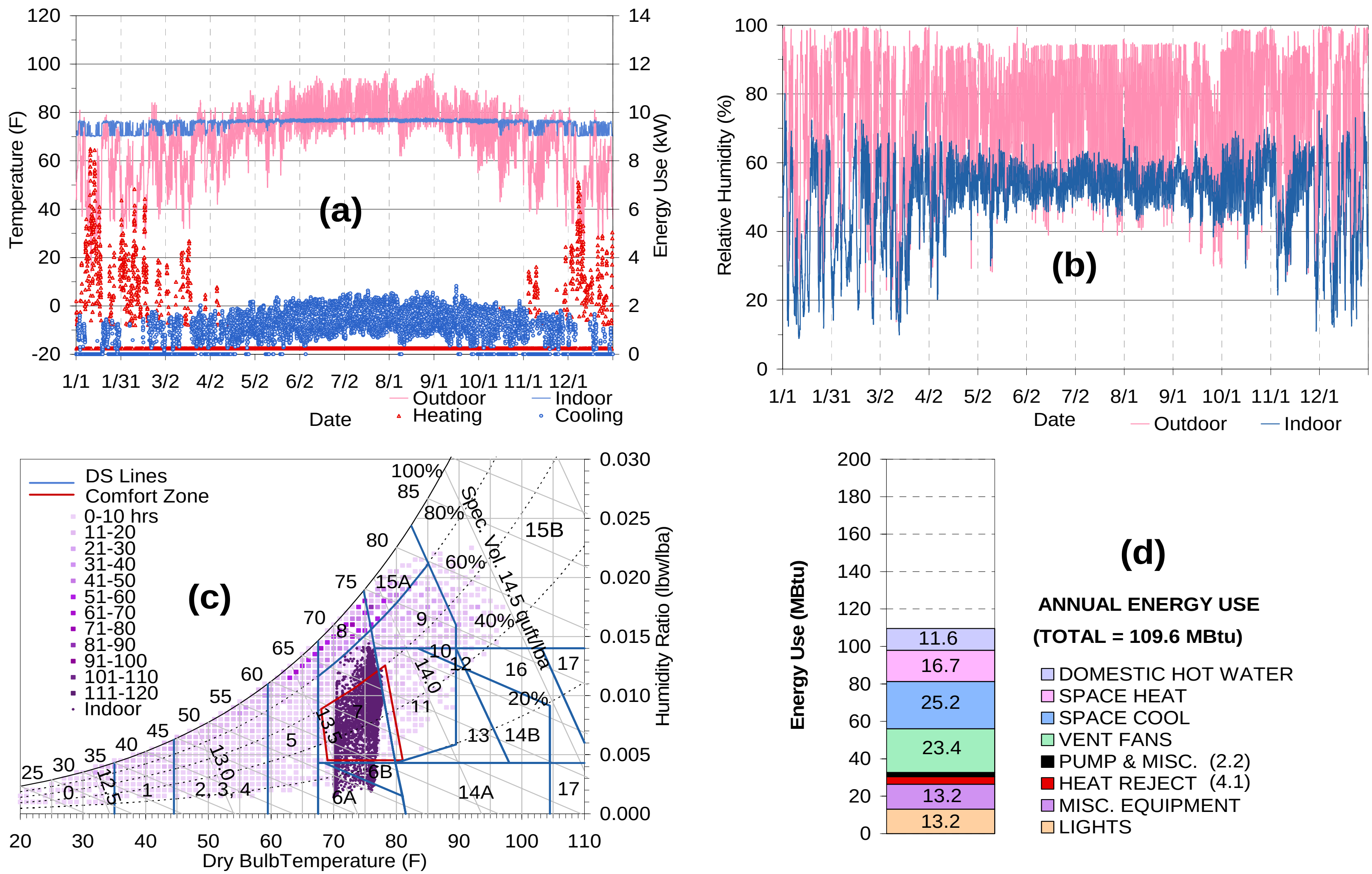
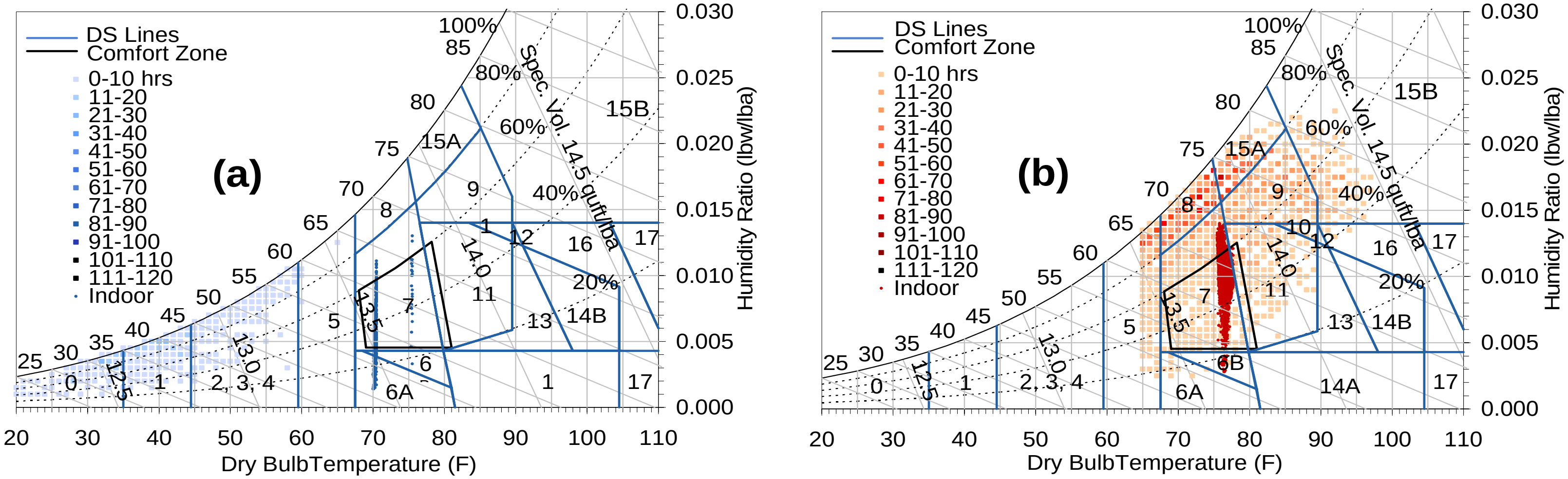
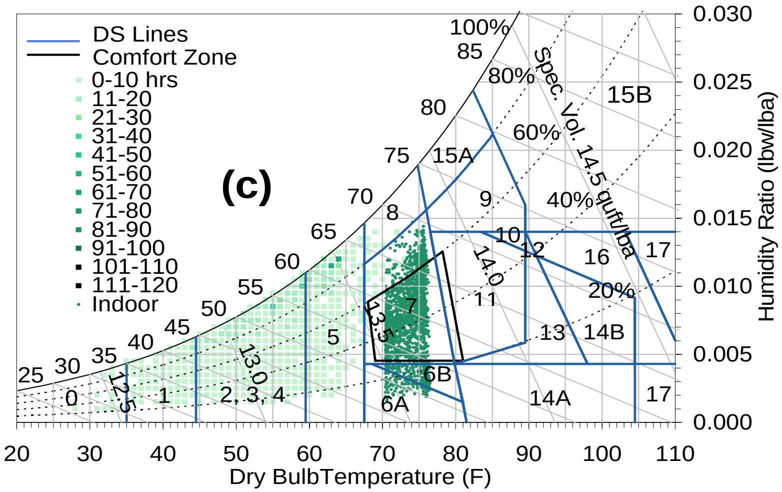


Figure 5.35 *Hourly indoor and outdoor conditions and energy use of the lightweight house with an economizer in the hot-humid climate, Houston, Texas. (a) Indoor and outdoor dry-bulb temperature and energy use of gas and electricity, (b) Indoor and outdoor relative humidity, (c) Indoor and outdoor conditions on the G-M Chart, and (d) Energy use of each category.*





HOUSTON (DT & NT) 2LIZ (65)

(d)

Design Strategies	Regions	G-M Bio-Chart (%)	DOE-2 Simulation HTG (%)	DOE-2 Simulation CLG (%)	DOE-2 Simulation N-H-C (%)
Conventional Heating	0	2.81	2.66	0.00	0.15
Active Solar	1	6.68	4.78	0.00	1.89
Passive Solar	2,3,4	16.07	2.53	0.00	13.54
Internal Gains	5	13.89	0.07	5.22	8.61
Humidification	6A, 6B	0.17	0.00	0.17	0.00
Comfort Zone	7	9.94	0.00	9.63	0.31
Dehumidification	8	16.72	0.00	16.63	0.09
Ventilation	9,10,11	19.76	0.00	19.76	0.00
Evaporative Cooling	6B,11,13,14A,14B	5.92	0.00	5.92	0.00
High Thermal Mass	10,11,12,13	6.48	0.00	6.48	0.00
High Thermal Mass with Night Ventilation	16, 14B	0.15	0.00	0.15	0.00
Air-Conditioning	17	0.00	0.00	0.00	0.00
Air-Conditioning & Dehumidification	15A,15B	13.78	0.00	13.78	0.00
Number of Hours/Year		8760	880	5726	2154
Percentage of Hours/Year		100.00	10.05	65.37	24.59

Region	0	1	2	3	4	5	6A	6B	7	8	9	10	11	12	13	14A	14B	15A	15B	16	17	Total
Hours	246	585	368	478	562	1217	10	5	871	1465	1165	52	514	2	0	0	0	781	426	13	0	8760
G-M (%)	2.8	6.7	4.2	5.5	6.4	13.9	0.1	0.1	9.9	16.7	13.3	0.6	5.9	0.0	0.0	0.0	0.0	8.9	4.9	0.1	0.0	100.00
DOE-2 (%)		9.49							40.08												50.43	100.00

Figure 5.36 *Daytime and nighttime hourly indoor and outdoor conditions of the lightweight house with an economizer in the hot-humid climate, Houston, Texas, on the G-M Chart. (a) Heating period, (b) Cooling period, (c) Non-heating-cooling period, and (d) Comparison of the results from the G-M Chart vs. the DOE-2 simulation.*

relative humidity in the summer is very well maintained between 40 to 65%, especially when the cooling system is continuously activated (mid-April through mid-October). However, during the other periods of the year the indoor relative humidity is not very well maintained and fluctuates between 10 to 80%.

In a similar fashion as Figure 5.16c (Section 5.2.1.1), Figure 5.35c shows that the outdoor conditions are widely spread-out above the 20% relative humidity line. The indoor temperature falls within the comfort zone, where the temperatures stay between the heating and cooling temperature setpoints (68 to 78 ºF). However, there are significant hours of the year where the indoor conditions fall above or below the humidity constraints of the comfort zone (i.e., above 60% relative humidity and below 36 °F dewpoint). Moreover, there are many hours during the winter (December through February) when the indoor relative humidity falls above the relative humidity line of 80%.

Figure 5.35d shows that the total annual energy use is 109.6 MBtu. The energy use includes: domestic hot water (11.6 MBtu), space heating (16.7 MBtu), space cooling (25.2 MBtu), ventilation fans (23.4 MBtu), pump and miscellaneous (2.2 MBtu), heat rejection (4.1 MBtu), miscellaneous equipment (13.2 MBtu), and lights (13.2 MBtu). From the results and as expected, the energy use for space cooling is more than the energy use for space heating.

In a similar fashion as Figure 5.17, Figure 5.36 consists of Figures 5.36a through 5.36d, which shows the daytime and nighttime annual hourly indoor and outdoor conditions on the G-M Chart during the heating period (Figure 5.36a), cooling period (Figure 5.36b), non-heating-cooling period (Figure 5.36c), and a comparison table of the results from the G-M Chart and the DOE-2 simulation (Figure 5.36d).

Figure 5.36a shows that most of the outdoor conditions during the heating period cover an area to the left of the comfort zone. The majority of the hours involve the G-M definitions of, conventional heating, active solar, and passive solar design strategies (regions 0 to 4). Only a few hours fall upon internal gains design strategy (region 5, 0.07%). Usually the indoor temperatures stay close to the heating temperature setpoint of

68 °F. There are only a few hours of the heating hours that the indoor temperatures stay close to the cooling temperature setpoint of 78 °F (see the DOE-2 HOURLY-REPORT, Appendix B), which are most likely due to the indoor temperature fluctuations of a lightweight house. In Figure 5.36a, there are many hours in this period that the indoor conditions fall above or below the humidity constraints of the ASHRAE comfort zone (i.e., above 60% relative humidity and below 36 ºF dewpoint).

Figure 5.36b shows that the outdoor conditions during the cooling period fall in the areas to the left of the 65 °F dry-bulb temperature line. This results from the economizer temperature setpoint which was set at 65 °F. This means that the economizer will be activated when the ambient dry-bulb temperatures fall at or below 65 °F. Most of the cooling data covers regions of heating design strategy, which is internal gains (regions 5); the G-M comfort zone (region 7); and the cooling design strategy regions, which include dehumidification, ventilation, evaporative cooling, high thermal mass, and Air-Conditioning with dehumidification (regions 8 to 12, and 15). A small portion of the cooling data falls within the areas of humidification and high thermal mass with night ventilation design strategies (regions 6 and 16). The frequency of occurrence is very high in the areas of dehumidification, ventilation, and Air-Conditioning with dehumidification design strategies (regions 8 to 11, and 15A). Most indoor temperatures stay close to the cooling temperature setpoint of 78 °F. There are a few hours of this period that the indoor temperatures stay close to the heating temperature setpoint of 68 °F (see the DOE-2 HOURLY-REPORT, Appendix B), which are most likely due to the indoor temperature fluctuations of a lightweight house. There are portions of the hours in this period that the indoor conditions fall above or below the humidity constraints of the comfort zone.

Figure 5.36c shows that majority of the outdoor conditions during the non-heating-cooling period fall to the left of the comfort zone, which include areas of conventional heating, active solar, passive solar, and internal gains, the G-M comfort zone, and dehumidification design strategies (regions 0 to 5 and 7 to 8). The frequency of occurrence is high in the area of passive solar and internal gains design strategies (regions 2 to 4 and 5). The indoor temperatures mostly float between the heating and cooling temperature setpoints (68 to 78 °F). There is a significant portion of the hours in this period that the indoor conditions fall above or below the humidity constraints of the comfort zone.

In Figure 5.36d, the results from the DOE-2 simulation show that there are 880 hours (10.05%) of the year that the heating system is activated. The cooling system is activated for 5,726 hours (65.37%) and there are 2,154 hours (24.59%) when neither the heating nor cooling systems is activated. The results from the G-M Chart analysis show 831 hours (9.49%) in the heating period, 3,511 hours (50.43%) in the cooling period, and 4,418 hours (40.08%) in the non-heating-cooling period. In this simulation, the criteria used to identify the effective design strategies for heating, cooling, and non-heating-cooling periods in the G-M Chart analysis are similar to the criteria that are described in Section 5.2.1.1 (see the last paragraph of p. 149).

Figure 5.36d allows the results from the DOE-2 simulation to be compared to the results from the G-M bioclimatic chart. As mentioned in the previous paragraphs, the DOE-2 simulation shows 10.05% of the time in heating period, which is slightly more than the G-M Chart results (9.49%). In this period, DOE-2 shows 2.66% and 4.78% of the hours in the year in conventional heating (region 0) and active solar (region 1) versus the G-M Chart results showing 2.81% (region 0) and 6.68% (region 1). DOE-2 also shows portions of the hours-per-year in passive solar (region 2 to 4, 2.53%), internal gains (region 5, 0.09%), and the G-M comfort zone (region 7, 0.07). Unfortunately, in the G-M chart analysis these regions are not usually considered heating periods.

In the cooling period (Figure 5.36d), DOE-2 calculated 65.37% of the hours-per-year in several regions from regions 5 to 16 including internal gains (region 5, 5.22%), humidification (regions 6a and 6b, 0.17%), the G-M comfort zone (region 7, 9.63%), dehumidification (region 8, 16.63%), ventilation (regions 9 to 11, 19.76%), evaporative cooling (regions 6b, 11, 13, 14a, 14b; 5.92%), high thermal mass (regions 10 to 13, 6.48%), high thermal mass with night ventilation (regions 14b and 16, 0.15%), and air-conditioning with dehumidification (regions 15a and 15b, 13.78%) design strategies. In region 8, the results from DOE-2 simulation (16.63%) are slightly less than the results from the G-M Chart (16.72%). In regions 9 to 16, the results from the DOE-2 simulation correspond to the results from the G-M Chart analysis. However, the differences are in regions 5 to 7, which is not usually considered to be cooling periods in the G-M Chart analysis.

In the non-heating-cooling period (Figure 5.36d), the results from the DOE-2 simulation (24.59%) are less than the results from the G-M Chart (40.08%). The DOE-2 simulation results in regions 2 to 4 (passive solar, 13.54%), and 5 (internal gains, 8.61 %) are less than the results from the G-M Chart; which show 16.07% in regions 2 to 4 and 13.89% in region 5. Significant differences are in region 7 (the G-M comfort zone), where the DOE-2 simulation shows only 0.31% of the hours-per-year versus the G-M Chart results showing as much as 9.94%. In addition, DOE-2 shows portions of the hours-per-year in conventional heating (region 0, 0.15%), active solar (region 1, 1.89%), and dehumidification (region 8, 0.09%); which these regions, in the G-M chart analysis, are not usually considered to be non-heating-cooling periods.

Summary and discussion: A lightweight house with an economizer was simulated using the TMY2 weather data for Houston, Texas (hot-humid climate). The results showed a wide range of the outdoor temperatures (20 to 95 °F) and relative humidity (20 to 100%), which was narrower in the summer than in the winter. The cooling period occurred all year round while the heating period occurred from November through March. The non-heating-cooling period usually occurred during October through April. The indoor temperature fluctuated between heating and cooling setpoints (68 to 78 °F) and was very well maintained near the 78 °F when the cooling system was continuously activated (mid-May through mid-October). In addition, the indoor relative humidity (RH) floated between 10 to 90%, and the indoor relative humidity was well maintained during the cooling period. During a significant portion of the hours in the other periods, especially in the non-heating-cooling period, the indoor relative humidity fell above or below the humidity constraints of the comfort zone (i.e., above 60% relative humidity or below 36 °F dewpoint). The total annual energy use for the lightweight house with an economizer in Houston, Texas, was 109.6 MBtu. The cooling energy use (25.2 MBtu) was more than the heating energy use (16.7 MBtu). Therefore, the design strategies for cooling should be considered a priority.

The DOE-2 simulation results showed that the outdoor conditions during the heating period covered the area to the left of the comfort zone from regions 0 through 5 (conventional heating, active solar, passive solar, and internal gains design strategies). The majority of the hours fell within regions 0 to 4. The outdoor conditions during the cooling period fell to the right of the 65 °F dry-bulb temperature line. The frequency of occurrence of this period was high in the areas of dehumidification (region 8), ventilation (regions 9 to 11), and air-conditioning with dehumidification design strategies (region 15A). In the non-heating-cooling period, most of the hours during this period covered regions 0 to 5 (conventional heating, active solar, passive solar, internal gains) and 7 to 8 (the G-M comfort zone and dehumidification), which have a high frequency of occurrence in regions 5 (internal gains), and significantly high in region 2 to 4 (passive solar).

In the heating period, the DOE-2 simulation yielded 10.05% of the hours for the year, which was slightly more than the G-M Chart results (9.49%). In the conventional heating (regions 0) and active solar (region 1) design strategies, the results from DOE-2 simulation were less than the results from the G-M Chart. In addition, The DOE-2 simulation showed a portion of the hours in the passive solar design strategy (regions 2 to 4) and a few hours in the internal gains design strategy (region 5) and the G-M comfort zone (region 7). Unfortunately, in the G-M chart analysis these regions were not usually considered heating periods.

In the cooling period, the DOE-2 simulation showed 65.37% of the hours-per-year in regions 5 to 16, which was more than the G-M Chart results (50.43%). In regions 9 to 16, which were ventilation, evaporative cooling, high thermal mass (with and without night ventilation), and air-conditioning with dehumidification design strategies, the results from the DOE-2 simulation corresponded to the results from the G-M Chart analysis. However, the differences were in regions 5 (internal gains), 6 (humidification), and 7 (the G-M comfort zone). In the G-M Chart analysis these regions were not usually considered cooling periods.

In the non-heating-cooling period, the results from the DOE-2 simulation (24.59%) were less than the results from the G-M Chart (40.08%). In regions 2 to 4 (passive solar) and 5 (internal gains), the DOE-2 simulation results were also less than the G-M Chart results. The differences were also in regions 7 (the G-M comfort zone), in which the results from the DOE-2 simulation were significantly less than the results from the G-M Chart. In addition, DOE-2 showed a portion of the hours each year in conventional heating (region 0), active solar (region 1), and dehumidification (region 8) design strategies. Unfortunately, in the G-M chart analysis these regions were not usually considered non-heating-cooling period.

5.2.4.2 Lightweight house with an economizer in the warm-marine climate of San Francisco, California

The results of the lightweight house with an economizer in the warm-marine climate of San Francisco, California, are presented in Figures 5.37 and 5.38. In a similar fashion as Figure 5.16 and 5.17, Figure 5.37 consists of three plots and a bar chart (Figures 5.37a through 5.37d) and Figure 5.38 consists of three plots and a table (Figures 5.38a through 5.38d). In a similar fashion as Figure 5.25a (Section 5.2.1.2), Figure 5.37a shows a narrow range of outdoor temperature for the whole year, in the range of 30 to 80 °F. The range of the outdoor temperature in the summer, in the range of 50 to 80 °F; is a little narrower than the range in the winter, which is in the range of 30 to 65 °F. The indoor temperature in the cooling periods (mid-June through October) and heating periods (November through mid-June) fluctuates between heating and cooling setpoints (68 to78 °F), which correspond to the activation of the cooling or heating systems. As expected, the cooling energy use in San Francisco is small and occurs mostly in the summer, while the heating energy use is large and occurs mostly in the winter.

In a similar fashion as Figure 5.25b (Section 5.2.1.2), Figure 5.37b shows variation in the outdoor relative humidity (RH) for the whole year, in the 20 to 100%

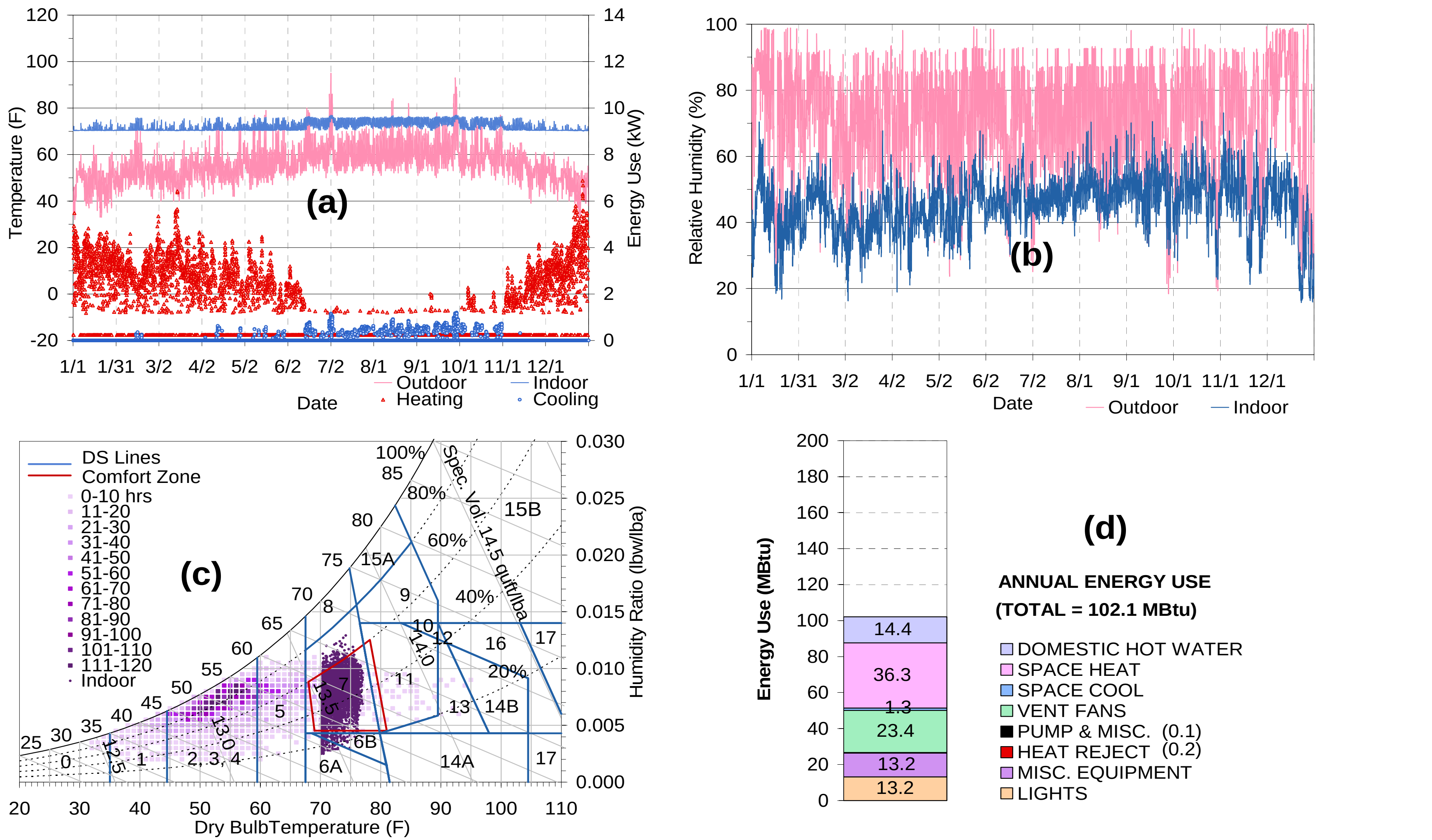
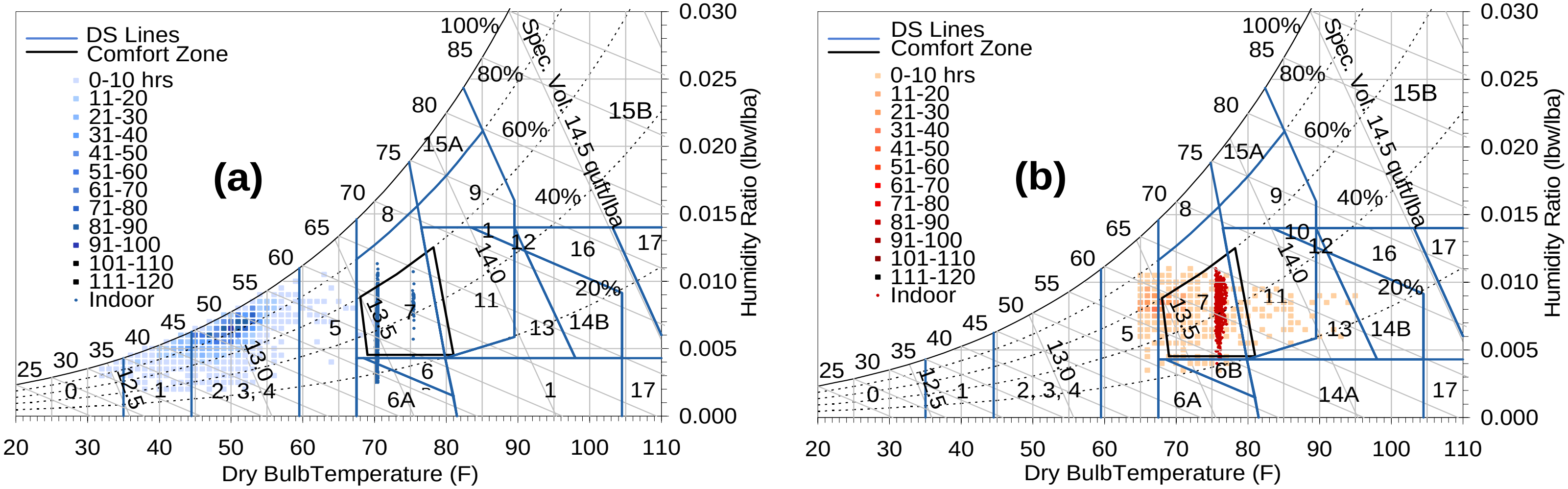
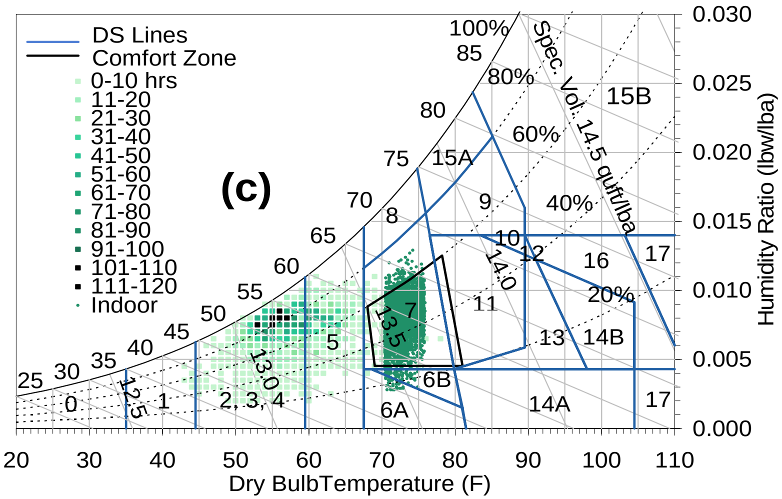


Figure 5.37 *Hourly indoor and outdoor conditions and energy use of the lightweight house with an economizer in the warm-marine climate, San Francisco, California. (a) Indoor and outdoor dry-bulb temperature and energy use of gas and electricity, (b) Indoor and outdoor relative humidity, (c) Indoor and outdoor conditions on the G-M Chart, and (d) Energy use of each category.*





SAN FRANCISCO (DT & NT) 4LIZ (65)

(d)

Design Strategies	Regions	G-M Bio-Chart (%)	DOE-2 Simulation HTG (%)	DOE-2 Simulation CLG (%)	DOE-2 Simulation N-H-C (%)
Conventional Heating	0	0.15	0.15	0.00	0.00
Active Solar	1	5.43	5.37	0.00	0.07
Passive Solar	2,3,4	68.33	31.04	0.00	37.29
Internal Gains	5	19.02	0.38	2.97	15.67
Humidification	6A, 6B	0.21	0.00	0.17	0.03
Comfort Zone	7	6.18	0.02	5.41	0.74
Dehumidification	8	0.00	0.00	0.00	0.00
Ventilation	9,10,11	0.59	0.00	0.59	0.00
Evaporative Cooling	6B,11,13,14A,14B	0.84	0.00	0.82	0.02
High Thermal Mass	10,11,12,13	0.67	0.00	0.67	0.00
High Thermal Mass with Night Ventilation	16, 14B	0.01	0.00	0.01	0.00
Air-Conditioning	17	0.00	0.00	0.00	0.00
Air-Conditioning & Dehumidification	15A,15B	0.00	0.00	0.00	0.00
Number of Hours/Year		8760	3237	809	4714
Percentage of Hours/Year		100.00	36.95	9.24	53.81

Region	0	1	2	3	4	5	6A	6B	7	8	9	10	11	12	13	14A	14B	15A	15B	16	17	Total
Hours	13	476	1170	2506	2310	1666	4	14	541	0	0	0	52	0	7	0	1	0	0	0	0	8760
G-M (%)	0.1	5.4	13.4	28.6	26.4	19.0	0.0	0.2	6.2	0.0	0.0	0.0	0.6	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	100.00
DOE-2 (%)		5.58							93.73												0.68	100.00

Figure 5.38 *Daytime and nighttime hourly indoor and outdoor conditions of the lightweight house with an economizer in the warm-marine climate, San Francisco, California, on the G-M Chart. (a) Heating period, (b) Cooling period, (c) Non-heating-cooling period, and (d) Comparison of the results from the G-M Chart vs. the DOE-2 simulation.*

range; which is narrower in the summer than in the winter. The indoor relative humidityin the summer is well maintained between 40 to 60%. However, in the other periods of the year the indoor relative humidity fluctuates between 20 to 70%.

In a similar fashion as Figure 5.25c (Section 5.2.1.2), Figure 5.37c shows that the outdoor conditions for the whole year stay under the 60 °F dewpoint line (0.012 lbw/lba, 14.5 mm Hg) and above the 20% relative humidity line, with the majority of the hours covering an area to the left of the comfort zone. The indoor temperature falls within the comfort zone, where the temperatures float between the heating and cooling temperature setpoints (68 to 78 ºF). However, there are many hours of the year where the indoor conditions fall above or below the humidity constraints of the comfort zone (i.e., above 60 % relative humidity line and below 36 °F dewpoint).

Figure 5.37d shows that the total annual energy use is 102.1 MBtu. The energy use includes: domestic hot water (14.4 MBtu), space heating (36.3 MBtu), space cooling (1.3 MBtu), ventilation fans (23.4 MBtu), pump and miscellaneous (0.1 MBtu), heat rejection (0.2 MBtu), miscellaneous equipment (13.2 MBtu), and lights (13.2 MBtu). From the results, the energy use for space heating is the highest and significantly higher than the energy use for space cooling.

In a similar fashion as Figure 5.17, Figure 5.38 consists of Figures 5.38a through 5.38d, which shows the daytime and nighttime annual hourly indoor and outdoor conditions on the G-M Chart during the heating period (Figure 5.38a), cooling period (Figure 5.38b), non-heating period (Figure 5.38c), and a comparison table of the results from the G-M Chart and the DOE-2 simulation (Figure 5.38d).

Figure 5.38a shows that most of the outdoor conditions during the heating period cover an area to the left of the comfort zone. The majority of the hours involve the G-M definitions of active solar and passive solar design strategies (regions 1 and 2 to 4). Only a few hours fall upon the conventional heating region (region 0), internal gains region (region 5), and the G-M comfort zone (region 7). Most of the indoor temperatures stay close to the heating temperature setpoint of 68 °F. A small portion of the heating hours that stay close to the cooling temperature setpoint of 78 °F occur individually right after the hours that the cooling system was continuously activated (see the DOE-2 HOURLY-REPORT, Appendix B). These are most likely due to the indoor temperature fluctuations of a lightweight house. In Figure 5.38a, there are portions of the hours in this period that the indoor conditions fall above or below the humidity constraints of the ASHRAE comfort zone.

Figure 5.38b shows that the outdoor conditions during the cooling period fall to the right of the 65 °F dry-bulb temperature line. The cooling data covers regions of heating design strategy, which is internal gains (region 5); the G-M comfort zone (region 7); and the cooling design strategy regions, which include ventilation, evaporative cooling, and high thermal mass (regions 6B and 9 to 14). A small portion of the cooling data falls within the areas of humidification and high thermal mass with night ventilation design strategies (regions 6 and 14B). The frequency of occurrence is high in the areas of internal gains design strategy and the G-M comfort zone (regions 5 and 7). Most of the indoor temperatures fall into the area of comfort zone and stay close to the cooling temperature setpoint of 78 °F. Only a few hours of the cooling periods that indoor relative humidity falls below the constraints of the comfort zone (i.e., below 36 °F dewpoint).

Figure 5.38c shows that majority of the outdoor conditions during the non-heating-cooling period fall to the left of the comfort zone, which include areas of passive solar and internal gains design strategies (regions 2 to 4 and 5). Only a small portion falls within the area of active solar, humidification, G-M comfort zone, and evaporative cooling (regions 1, 6, 7, and 14B). The frequency of occurrence is high in the area of internal gains design strategy (region 5) and highest in the area of passive solar design strategies (regions 2 to 4). The indoor temperatures mostly float between the heating and cooling temperature setpoints (68 to 78 °F). There are many hours in this period that the indoor conditions fall above or below the humidity constraints of the comfort zone.

In Figure 5.38d, the results from the DOE-2 simulation show that there are 3,237 hours (36.95%) of the year that the heating system is activated. The cooling system is activated for 809 hours (9.24%) and there are 4,714 hours (53.81%) when neither the heating nor cooling systems is activated. The results from the G-M Chart analysis show that in the year, there are 489 hours (5.58%) in the heating period, 60 hours (0.68%) in the cooling period, and 8,211 hours (93.73%) in the non-heating-cooling period. The criteria used to identify the effective design strategies for heating, cooling, and non-heating-cooling periods in the G-M Chart analysis are described in Section 5.2.1.1 (see the last paragraph of p. 149).

Figure 5.38d allows the results from the DOE-2 simulation to be compared to the results from the G-M bioclimatic chart. As mentioned in the previous paragraphs, the DOE-2 simulation showed 36.95% of the time in heating period, which is significantly different from the G-M Chart results (5.58%). In this period, DOE-2 shows that 0.15% of the time falls into conventional heating design strategy (region 0), which correspond to the G-M Chart results (0.15%). In active solar design strategy (region 1), the results from the DOE-2 simulation (5.37%) are very close to the results from the G-M Chart (5.43%). However, DOE-2 shows that there is a significant portion of heating hours in passive solar design strategy (regions 2 to 4, 31.04%) and a small portion in internal gains design strategy (region 5, 0.38%) and the G-M comfort zone (region 7, 0.02%).

In the cooling period, DOE-2 calculated 9.24% of the hours-per-year in several regions including internal gains, humidification, the G-M comfort zone, ventilation, evaporative cooling and high thermal mass design strategies (regions 2 to 7, 11, 13, and 14B). The G-M Chart shows only 0.68% is in this period. In regions 11, 13, and 14B, the results from the DOE-2 simulation correspond to the results from the G-M Chart analysis. However, the differences are in regions 5 to 7. In Figure 5.38d, DOE-2 shows that portions of cooling hours fall into region 5 (internal gains, 2.97%), region 6 (humidification, 0.17%), and region 7 (the G-M comfort zone, 5.41%). Unfortunately, in the G-M Chart analysis, regions 5 to 7 are not usually considered cooling periods.

In the non-heating-cooling period (Figure 5.38d), the results from the DOE-2 simulation are much different from the results from the G-M Chart. The DOE-2 simulation shows 53.81% of the hours in the year in this period while the G-M Chart shows as much as 93.73%. DOE-2 shows a small portion occurs in region 1 (active solar, 0.07%), which are not included in the G-M Chart analysis. In regions 2 to 4 (passive solar), the results from the DOE-2 simulation (37.29%) are significantly less than the results from the G-M Chart analysis (68.33%). The differences are also shown in regions 5 through 7 (internal gains, humidification, and the G-M comfort zone). In these regions the DOE-2 shows only 15.67% (region 5), 0.03% (region 6), and 0.74% (region 7) versus the G-M Chart which shows 19.02%, 0.21%, and 6.18% in regions 5, 6, and 7; respectively.

Summary and discussion: A lightweight house with an economizer was simulated using the TMY2 weather data of San Francisco, California (warm-marine climate). The results showed the narrow range of the outdoor conditions (dry-bulb temperature and relative humidity), which in the summer was narrower than in the winter. The cooling period was half as long as the heating period. The cooling period occurred mostly in the summer while the heating period occurred mostly in the winter and the non-heating-cooling period occurs all year long. The indoor temperatures stayed close to the temperature setpoint of each respective heating (68 °F) or cooling period (78 °F). For the non-heating-cooling period, the indoor temperatures floated between 68 to 78 °F.

The indoor conditions were very well maintained within the ASHRAE comfort zone when the cooling system was activated. In the heating period, there were very short periods when the indoor temperatures did not stay close to the heating temperature setpoint. These were most likely due to the indoor temperature fluctuations that were usually found in a lightweight house. The total annual energy use for the lightweight house with an economizer in San Francisco, California, was 102.1 MBtu. The cooling energy needed was very low (1.3 MBtu), while the heating energy needed was significantly higher (36.3 MBtu). Therefore, the design strategies for heating should be considered a priority.

The DOE-2 simulation results showed that most of the outdoor conditions during the heating period covered the area to the left of the comfort zone from regions 0 through 5 (conventional heating, active solar, passive solar, and internal gains). The majority of the hours fell within regions 1 (active solar) and 2 to 4 (passive solar). The outdoor conditions during the cooling period fell to the right of the 65 °F dry-bulb temperature line. The frequency of occurrence of this period was high in regions 5 and 7 (internal gains and the G-M comfort zone). In the non-heating-cooling period, most of the outdoor conditions covered a part of comfort zone and the area to the left of the comfort zone from regions 1 to 5, 6 (humidification) and 7. Most of the non-heating-cooling hours fell into regions 2 to 5, where the frequency of occurrence was significantly high in regions 2 to 4.

In the heating period, the DOE-2 simulation yielded 36.95% of the hours for the year, which was significantly higher than the G-M Chart results (5.58%). In the conventional heating and active solar design strategies (regions 0 and 1), the results from the DOE-2 simulation corresponded or were very close to the results from the G-M Chart. However, DOE-2 showed a significant portion of heating period in passive solar design strategy (regions 2 to 4); which these regions, in the G-M Chart analysis, were not included in the heating periods.

In the cooling period, the DOE-2 simulation showed 9.24% of the hours for the year versus the G-M Chart showing only 0.68%. The DOE-2 simulation showed that small portions of cooling period in regions 11, 13, and 14B, which corresponded to the results from the G-M Chart analysis. However, the differences were in regions 5 to 7 especially regions 5 (internal gains) and 7 (the G-M comfort zone). Unfortunately, in a G-M Chart analysis, these regions were not usually considered cooling periods.

In the non-heating-cooling period, the DOE-2 simulation showed 53.81% of the annual hours, which was significantly less than the G-M Chart results (93.73%). The differences were obviously shown in regions 2 to 4 (passive solar) as well as regions 5 (internal gains) and 7 (the G-M comfort zone).

5.2.5 Summary of the Results

Four prototype houses were simulated using TMY2 and IWEC weather data for the seven selected climates. The indoor and outdoor thermal conditions of each representative city were graphically reported as well as the annual energy use and the energy use of each category. The indoor and outdoor thermal data for each period (heating, cooling, and non-heating-cooling periods) were superimposed onto the G-M Chart and the number of hours-per-year calculated that fell upon the G-M Chart design strategy regions. These results were then compared with the results from the G-M bioclimatic chart analysis. The differences in the results from the DOE-2 simulation and the results from the G-M Chart analysis, which will be discussed more in the next Section (Section 5.3).

5.3 COMPARISON OF THE RESULTS

This section discusses the comparison of the results from the previous Section (Section 5.2.5) and Appendix D, which includes the indoor and outdoor conditions (Section 5.3.1), the annual energy use (Section 5.3.2), the DOE-2 simulation results versus the G-M Chart analysis results (Section 5.3.3), and the DOE-2 simulations results for all sites (Section 5.3.4).

5.3.1 Indoor and Outdoor Conditions

This comparison of the outdoor temperature of the representative cities for the seven selected climates includes: 1) Bangkok, Thailand (very hot-humid climate, Figure D.1); 2) Houston, Texas (hot-humid climate, Figure 5.16); 3) Phoenix, Arizona (hot-dry climate, Figure 5.27); 4) San Francisco, California (warm-marine climate, Figure 5.25); 5) Chicago, Illinois (cool-humid climate, Figure D.3); 6) Boston, Massachusetts (cool-humid climate, Figure D.5); and 7) Boise, Idaho (cool-dry climate, Figure D.7). As expected, the annual average outdoor temperature was high in the hot climates and low in the cool climates. The average outdoor relative humidity was also higher in the humid climates and lower in the dry climates. The range of the annual outdoor temperature for

Bangkok and San Francisco were narrow. For Houston and Phoenix, the range of the annual outdoor temperature was wide. The range of the annual outdoor temperature was significantly wide in Chicago, Boston, and especially in Boise. The range of the annual relative humidity in Bangkok, Houston, and San Francisco were narrower than the ranges of the relative humidity for the whole year in Phoenix, Chicago, Boston, and Boise. In Boise the range of the relative humidity was significantly wide.

The majority of the outdoor conditions for Bangkok (Figure D.1) covered the area above and to the right of the comfort zone. In Houston (Figure 5.16), the majority of the outdoor conditions covered the area above the comfort zone and were spread-out over the comfort zone, and the areas above 20% relative humidity line to right and the left of the comfort zone. For Phoenix (Figure 5.27), the outdoor conditions covered the comfort zone and the areas below the 0.014 (lbw/lba) humidity ratio line and were spread-out widely to the left and the right of the comfort zone. The majority of outdoor conditions for San Francisco (Figure 5.25) covered the area above 20% relative humidity line to the left of the comfort zone. The outdoor conditions for both Chicago (Figure D.3) and Boston (Figure D.5) covered the comfort zone and were spread-out to the left and the right of the comfort zone above the 20% relative humidity line, where the density was high at lower temperatures. In Boise (Figure D.7), the majority of the outdoor conditions covered the area to the left of the comfort zone, where the density of the outdoor conditions was high at the lower temperature, and spread-out widely and horizontally below the 0.014 (lbw/lba) humidity ratio line to the comfort zone and the area to the right of the comfort zone.

For the indoor conditions of all sites, the indoor temperatures of all sites (Figures 2.23, 2.25, 2.27, D.1, D.3, D.5, and D.7) mostly stayed or fluctuated between the heating and cooling temperature set-points of 68 °F through 78 °F, which corresponded to the activation of the heating or cooling systems in the simulation. The indoor temperature was very well maintained when the cooling system was continuously activated in the simulation. This could be seen in Bangkok, Thailand (Figure D.1), where the cooling system was continuously activated for the whole year. The fluctuation of the indoor temperature was less for the high thermal mass house. The majority of the indoor relative humidity for all sites stayed within the humidity constraint of the comfort zone (i.e., above 60% relative humidity line and under 36 °F dewpoint line). However, there were many hours-per-year for many sites that the indoor relative humidity was above or below the humidity constraint for the comfort zone. The indoor relative humidity was very well maintained in the comfort zone when the cooling system was continuously activated. This especially occurred with the house in Bangkok, Thailand, where the cooling system was continuously activated.

5.3.2 Annual Energy Use

Table 5.1 and Figure 5.39 show the annual energy use of the four prototype houses (lightweight, lightweight without internal loads, high thermal mass, and lightweight with an economizer) in the seven representative cities (Houston, Phoenix, San Francisco, Bangkok, Chicago, Boston, and Boise. The total annual energy use consists of the energy use for domestic hot water (DHW), space heating, space cooling, ventilation fans, pump and miscellaneous, heat rejection, equipment, and lights. The DOE-2 simulation results of the energy use of each category were then compared. With the exception of the Houston simulation without internal loads, the results showed the largest annual consumption for the same house when run at the Chicago and Boston locations, followed by the Boise location. Houston, San Francisco, Phoenix, and Bangkok all similar total annual energy use.

5.3.2.1 Domestic hot water (DHW)

Table 5.1 shows that the gas consumption for domestic hot water (DHW) of the four prototype houses for each site was very similar. As expected, the energy use for domestic hot water was higher in the cool climate cities (Chicago, Boston, and Boise) than in the very hot, hot, and warm climate cities (Bangkok, Houston, Phoenix, and San Francisco). Comparing all sites, the highest energy use for domestic hot water was found in Chicago (15.8 MBtu) and the lowest energy use for domestic hot water was found in

Table 5.1 *Comparison of the total annual energy use and the energy use of each category for all simulations.*

Prototype House (DOE-2 Simulations)	City	Climate	Domestic Hot Water (MBtu)	Space Heating (MBtu)	Space Cooling (MBtu)	Ventilation Fans (MBtu)	Pump & Miscellaneous (MBtu)	Heat Rejection (MBtu)	Equipment (MBtu)	Lights (MBtu)	Total (MBtu)
Lightweight (Base-case)	Houston	(Hot-humid)	11.6	14.6	25.3	23.4	2.4	4.4	13.2	13.2	**108.1**
	San Francisco	(Warm-Marine)	14.4	31.5	1.7	23.4	0.2	0.3	13.2	13.2	**97.9**
	Phoenix	(Hot-dry)	10.6	8.2	25.6	23.4	2.2	3.6	13.2	13.2	**100.0**
	Bangkok	(Very hot-humid)	8.2	7.0	42.3	23.4	2.7	6.0	13.2	13.2	**116.0**
	Chicago	(Cool-humid)	15.8	100.6	6.0	23.4	0.6	1.0	13.2	13.2	**173.8**
	Boston	(Cool-humid)	15.6	102.9	4.8	23.4	0.5	0.8	13.2	13.2	**174.4**
	Boise	(Cool-dry)	15.6	76.2	5.7	23.4	0.5	0.8	13.2	13.2	**148.6**
Lightweight without Internal Loads	Houston	(Hot-humid)	11.6	23.3	17.0	23.4	1.7	3.1	0.0	0.0	**80.1**
High Thermal Mass	Houston	(Hot-humid)	11.6	13.8	20.5	23.4	1.8	3.3	13.2	13.2	**100.8**
	Phoenix	(Hot-dry)	10.6	8.0	25.9	23.4	2.2	3.7	13.2	13.2	**100.2**
Lightweight with an Economizer	Houston	(Hot-humid)	11.6	16.7	25.2	23.4	2.2	4.1	13.2	13.2	**109.6**
	San Francisco	(Warm-Marine)	14.4	36.3	1.3	23.4	0.1	0.2	13.2	13.2	**102.1**

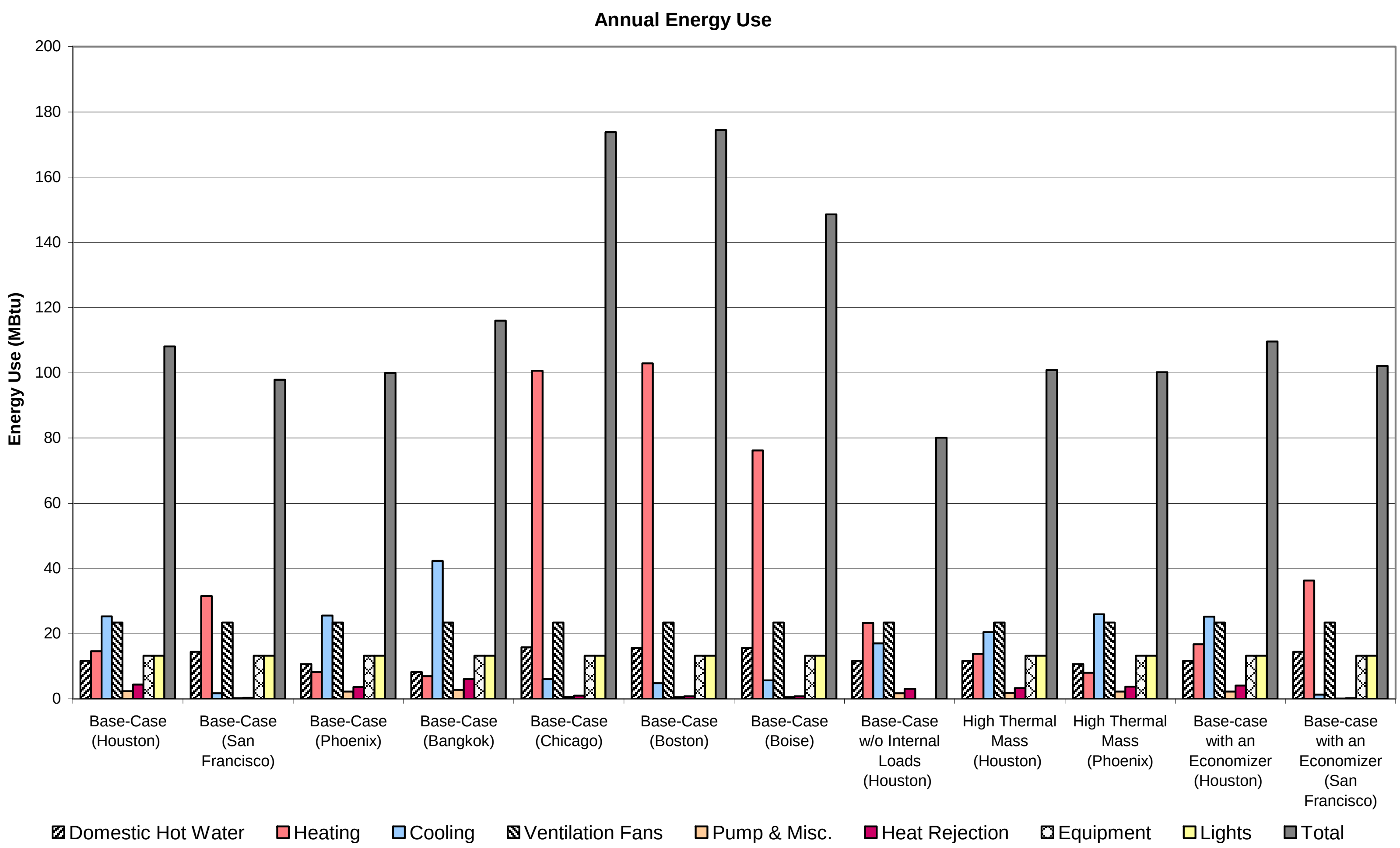


Figure 5.39 *Comparison of the total annual energy use and the energy use of each category for all simulations.*

Bangkok (8.2 MBtu). These could result from the different ground temperatures of each location, which is related to the average ambient temperature and affected the ground water temperatures (Kusuda and Achenbach, 1965).

5.3.2.2 Space heating

Comparing the heating energy use (gas consumption of the furnace) results of the lightweight house (base case) in the seven selected climates (Table 5.1 and Figure 5.39), the heating energy use of the lightweight house (base case) in cool climate cities (Chicago, Boston, and Boise) was significantly higher than the heating energy use of the lightweight house (base case) in hot and warm climates (Houston, Phoenix, and San Francisco). DOE-2 showed that there was no heating hours in Bangkok (very hot-humid climate). The highest heating energy use was shown in Boston. Although the average outdoor temperature of Chicago was lower than the average outdoor temperature of Boston, the availability of the solar radiation in Boston (215,915 Btu/ft^2-year; Appendix E, Table E.1) was slightly higher than in Chicago (211,303 Btu/ft^2-year; Appendix E, Table E.1). Therefore, the heating energy use in Boston (102.9 MBtu) was slightly higher than the heating energy use in Chicago (100.6 MBtu). This affected from the number of hours of the outdoor temperature at lower temperature or on the right side of the comfort zone (i.e., below 67.50 ºF, region 0 to 5) in Boston (91.91%) was more than in Chicago (88.36%). In contrast, even though the number of hours the outdoor temperature in Boise (92.57%) was slightly higher than that in Boston (91.91%), the heating energy use of the lightweight house (base case) in Boise was lower than in Boston. This is mostly due to the increased solar radiation availability during the heating period, which is higher in Boise (226,959 Btu ft^2-year; Appendix E, Table E.1) than in Boston (215,915 Btu ft^2-year; Appendix E, Table E.1).

Similarly, Table 5.1 also shows that the heating energy use of the lightweight house (base case) for the hot-humid climate (Houston, 14.6 MBtu) was higher than the use for hot-dry climate (Phoenix, 8.2 MBtu). The heating energy uses for the cool-humid climate cities (Boston, 102.9 MBtu; Chicago, 100.6 MBtu) were higher than the use for the cool-dry climate city (Boise, 76.2 MBtu). One of the major effects could be the results from the higher solar radiation in dry climates during the heating period (i.e., Hoston, 131,491 MBtu; Phoenix, 143,338 MBtu; Boston, 21,1303 MBtu; Chicago, 215,915 MBtu; and Boise, 226,959 MBtu; Appendix E, Table E.1).

For the lightweight cases with and without internal loads in Houston (Table 5.1), as expected, the heating energy use of the lightweight house without internal loads (23.3 MBtu) was more than the heating energy use of the lightweight house (14.6 MBtu) with internal loads. This is due to the removal of the heat sources (i.e., people, lights, and equipment).

Table 5.1 also shows a comparison of the heating energy use of the lightweight house (base case) and the high thermal mass house in Houston and Phoenix. For Houston, the heating energy use of the high thermal mass house (13.8 MBtu) was slightly less than the use for the lightweight house (base case) (14.6 MBtu). This is due to the effects from the high thermal mass of the house, which absorbed and delayed the heat from solar radiation during the daytime and released the heat to the environment during the nighttime. In a similar fashion as Houston, in Phoenix, the heating energy use for the high thermal mass house (8.0 MBtu) was less than the heating energy use for the lightweight house (base case) (8.2 MBtu). Surprisingly, comparing the effects of the high thermal mass house versus the lightweight house for Houston and Phoenix, the high thermal mass components used in this study (see Chapter IV, Section 4.2.1.3) can reduce more heating energy use in Houston than in Phoenix. To increase the effects of high thermal mass on heating energy use in Phoenix, the thickness of massive concrete wall and floor should be considered. Also, the orientation and location of the windows would need to be further studies.

Finally, Table 5.1 shows a comparison of the lightweight house with and without an economizer in Houston and San Francisco. Quite unexpectedly for Houston, the heating energy use of the lightweight house with an economizer (16.7 MBtu) was more than that use for the lightweight house (base case) (14.6 MBtu). This corresponded to the results shown for San Francisco, where the DOE-2 simulation showed that the heating energy use of the lightweight house with an economizer (36.3 MBtu) was more than the heating energy use of the lightweight house (base case) (31.5 MBtu). This was more likely due to more energy being required during the winter to compensate for the inappropriate cool air brought in by the economizer, which was set to activate when the outdoor air is below 65 ºF. Comparing the effect on the heating energy use of the lightweight houses with and without an economizer in Houston versus in San Francisco; the effect on heating energy use for the lightweight house with an economizer was more in San Francisco than in Houston. This could resulted from the number of hours at the temperature below 65 ºF (region 0 to 5, the right side of the comfort zone) in San Francisco was greater than that number of hours in Houston. To reduce the heating energy use of a lightweight house with an economizer, the economizer seasonal activation setting should be considered. Additional, simulation would be needed to determine a more appropriate cut-off temperature and to see how thermal mass effects the results.

5.3.2.3 Space cooling

In Table 5.1 and Figure 5.39, the cooling energy uses, which are the electrical consumption of the cooling equipment, for the lightweight house (base case) in the seven selected climates were compared. From the results, the cooling energy uses of the lightweight house (base case) in hot climates, especially in a very hot-humid climate (Bangkok, Thailand), were significantly higher than that uses in the cool climates. DOE-2 showed that the highest cooling energy use was in the very hot-humid climate (Bangkok, 42.3 MBtu); and the lowest cooling energy use is in the warm-marine climate (San Francisco, 1.7 MBtu). In hot climates, although the percentage of hours-per-year that the outdoor temperature was at the higher humidity or higher temperature (regions 8 to 17) was higher in Houston (hot-humid climate, 50.43%) than in Phoenix (hot-dry climate, 38.85%), the cooling energy use of the lightweight house (base case) in Houston (25.3 MBtu), which was slightly lower than the use in Phoenix (25.6 MBtu). This is most likely due to the solar radiation availability during the cooling period in Phoenix

(527,747 Btu ft²-year; Appendix E, Table E.1) was significant higher than in Houston (381,535 Btu ft²-year; Appendix E, Table E.1).

In cool climates, during the summer, the availability of the solar radiation in Boise (289,275 Btu/ft²-year; Appendix E, Table E.1) was higher than in Chicago (242,483 Btu/ft²-year; Appendix E, Table E.1) and in Boston (237,943 Btu/ft²-year; Appendix E, Table E.1). However, the cooling energy use of the lightweight house (base case) was higher in Chicago (6.0 MBtu) than in Boston (4.8 MBtu) and Boise (5.7 MBtu). This is most likely due to the number of hours-per-year at higher humidity and higher temperature (i.e., above 78 ET or above 80% RH, regions 8-17) for Chicago (11.63%) than that in Boston (8.09%) and Boise (7.43%).

Comparing the lightweight houses with and without internal loads in Houston, the cooling energy use of the lightweight house without internal loads (17.0 MBtu) was less than the heating energy use of the lightweight house (25.3 MBtu) with internal loads. This was due to the removal of the heat sources from people, lights, and equipment.

Table 5.1 also compares of the cooling energy use for the lightweight house (base case) and the high thermal mass house in Houston and Phoenix. In Houston, the cooling energy use of the high thermal mass house (20.5 MBtu) was less than the cooling energy use of the lightweight house (base case) (25.3 MBtu). This could be the effects from the high thermal mass of the house, with the ability to delay the heat from solar radiation during the daytime and dissipate it to the surroundings during the nighttime. In contrast, Table 5.1 shows that in Phoenix, the cooling energy use for the high thermal mass house (25.9 MBtu) was slightly higher than the heating energy use for the lightweight house (base case) (25.6 MBtu). Surprisingly, comparing the effects of the high thermal mass versus the lightweight house in Houston and Phoenix, the high thermal mass components used in this study (see Chapter IV, Section 4.2.1.3) reduced the cooling energy use in Houston. However, the high thermal mass could slightly increased the cooling energy use in Phoenix. It was possible that the high thermal mass might not only delay the solar radiation heat transferring to the house during the daytime, but also delay the interior heat dissipating to the environment during the nighttime when the outdoor temperature was cooler. The trade off of these effects on cooling energy use was useful for the high thermal mass house in Houston but not useful for the high thermal mass house in Phoenix. Most likely due to the thermal mass used in this study might not be enough to delay the solar radiation heat transferring to the house, where the intensity and the availability of solar radiation were significantly high in Phoenix. Therefore, additional simulation would need to resolve this.

Comparing the lightweight houses with and without an economizer in the hot-humid climate (Houston, Texas)), the differences between the cooling energy use of the lightweight houses with and without an economizer (25.2 and 25.3 MBtu) were insignificant. However, in the warm-marine climate (San Francisco, California), Table 5.1 showed a larger differences between the cooling energy use of the lightweight houses with and without an economizer, which are 1.7 and 2.3 MBtu; respectively. This may be a result at the economizer activations; which for Houston rarely occurred in the summer; versus in San Francisco, where it occurred more frequently in the summer, especially in the daytime when the availability of solar radiation was significantly higher than the other periods. To obtain a better result for San Francisco would need to be further investigated the economizer activation temperature.

5.3.2.4 Ventilation fans

In this study, the ventilation fans; which are the electrical consumption of the supply, return, and exhaust fans used to move air into and through the building; were set to run all of the time for all simulations because this setting was also used in the Energy Systems Laboratory’s emissions calculator (eCalc). Therefore, the energy use of the ventilation fans was 23.4 MBtu for all simulations. For future studies, in order to have a better picture of the simulation results, the ventilation fans could be set to activate only when heating or cooling systems are on.

5.3.2.5 The pump and miscellaneous equipment

Table 5.1 compares the electric consumption for the pump and miscellaneous equipment of each simulation. The results of the energy use for the pump and miscellaneous equipment for each simulation were related and proportional with its cooling energy use. Comparing the lightweight house (base case) in the seven selected climates, the pump and miscellaneous energy use for the lightweight house (base case) was higher in hot climates than in cool climates. DOE-2 showed that the highest cooling energy use was in the very hot-humid climate (Bangkok, 2.7 MBtu) and the lowest cooling energy use is in the warm-marine climate (San Francisco, 0.2 MBtu). In hot climates, the pump and miscellaneous energy use for the lightweight house (base case) was slightly higher in Houston (2.4 MBtu) than in Phoenix (2.2 MBtu). In cool climates, the pump and miscellaneous energy use of the lightweight house (base case) was slightly higher in Chicago (0.6 MBtu) than in Boston (0.5 MBtu) and in Boise (0.5 MBtu).

Table 5.1 also shows the pump and miscellaneous energy use of the lightweight houses with and without internal loads in Houston. In this simulation, DOE-2 showed that the pump and miscellaneous energy use of the lightweight house without internal loads (1.7 MBtu) was less than the heating energy use of the lightweight house (2.4 MBtu) with internal loads.

Table 5.1 shows that, for Houston, the pump and miscellaneous energy use of the high thermal mass house (1.8 MBtu) was less than the cooling energy use of the lightweight house (base case) (2.4 MBtu). The lightweight house (base case) and the high thermal mass house in Phoenix used the same amount of energy for pump and miscellaneous (2.2 MBtu).

Comparing the lightweight houses with and without an economizer in the hot-humid climate (Houston, Texas), the differences between the pump and miscellaneous energy use of the lightweight houses with and without an economizer (2.2 and 2.4 MBtu) was insignificant. In the warm-marine climate (San Francisco, California), DOE-2 showed that the cooling energy use of the lightweight houses with and without an economizer were 0.1 and 0.2 MBtu; respectively.

5.3.2.6 Heat rejection

Table 5.1 shows a comparison of the energy use for heat rejection, which is the electrical consumption of condenser fans, of each simulation. The energy use for heat rejection was related with its cooling energy use. The heat rejection of the lightweight house (base case) for each simulation include; Houston (4.4 MBtu), San Francisco (0.3 MBtu), Phoenix (3.6 MBtu), Bangkok (6.0 MBtu), Chicago (1.0 MBtu), Boston (0.8 MBtu), Boise (0.8 MBtu); respectively. For the lightweight house without internal loads in Houston, Table 5.1 shows 3.1 MBtu of the energy was used for heat rejection. The heat rejection energy use of the high thermal mass house in Houston and Phoenix were 3.3 MBtu and 3.7 MBtu. For the lightweight house with an economizer, Table 5.1 shows that the energy use for heat rejection were 4.1 MBtu for Houston and 0.2 MBtu for San Francisco.

5.3.2.7 Equipment

In this study, electrical consumption of all household equipment used in the space for all simulations was 13.2 MBtu except the lightweight house without internal loads, which had no equipment loads.

5.3.2.8 Lights

In a similar fashion as the electrical consumption of all lights except task lighting (area lights) for all simulations was 13.2 MBtu except the lightweight house without internal loads, which had no energy use for lights.

5.3.2.9 Total annual energy use

Table 5.1 shows the total annual energy use of the lightweight house (base case) in the seven selected climates; which include Houston (108.1 MBtu), San Francisco (97.9 MBtu), Phoenix (100.0 MBtu), Bangkok (116.0 MBtu), Chicago (173.8 MBtu), Boston (174.4 MBtu), and Boise (148.6 MBtu). For the lightweight house (base case) in the seven selected climates, the annual energy uses of the house in the cool climates

(Chicago, Boston, and Boise) were significantly higher than the annual energy uses of the house in the other climates. Boston had the highest annual energy use (174.4 MBtu) and San Francisco (warm-marine) had the lowest annual energy use (97.9 MBtu). The largest portion of the energy use for the house in the cool climates and the warm-marine climate was for space heating and the significant portion of the energy use for the house in the very hot and hot climates was for space cooling.

In Houston, comparing the annual energy use of the lightweight houses with and without internal loads, Table 5.1 shows that the annual energy use of the lightweight house (base case) (108.1 MBtu) was higher than the annual energy use of the lightweight house without internal loads (80.1 MBtu). Without the internal heat sources from people, equipment, and lights; the lightweight house used more energy for space heating but used less energy for space cooling. However, the majority of the energy reduction was due to the reduction of the energy used for equipment (13.2 MBtu) and lights (13.2 MBtu).

Table 5.1 shows a comparison of the annual energy use of the lightweight house (base case) and the high thermal mass houses in Houston and San Francisco. For Houston, the annual energy use of the high thermal mass house (100.8 MBtu) was less than the annual energy use of the lightweight house (base case) (108.1 MBtu). A small portion of the energy reduction was in the heating energy use, and a significant portion of the energy reduction was on the cooling energy use. For Phoenix, the high thermal mass house has slightly reduced heating energy use. However, the house had an increased portion of the energy use for cooling as previously mentioned and discussed in the Section 5.3.2.3. Therefore, the annual energy use for the high thermal mass house (100.2 MBtu) was slightly higher the annual energy use of the lightweight house (base case) (100.0 MBtu).

Next, comparing the annual energy use of the lightweight houses with and without an economizer in Houston and San Francisco, Table 5.1 shows that the annual energy use of the lightweight house with an economizer (109.6 MBtu) was slightly more than the annual energy use of the lightweight house (base case) (108.1 MBtu). For San

Francisco, in a similar fashion as Houston, the annual energy use of the lightweight house with an economizer (102.1 MBtu) was higher than the annual energy use of the lightweight house (base case) (97.9 MBtu). Table 5.1 shows that the lightweight house with an economizer had slightly reduced energy use for cooling. However, it increased the energy use for heating as previously discussed in the Section 5.3.2.2. These results from the economizer are surprising, although must likely realistic given the combination of tight thermostat control and night setback. Additional studies are needed to find a more optimal economizer setting that would yield savings and maintain comfort.

5.3.3 The DOE-2 Simulation Results versus the G-M Chart Results

Table 5.2 shows a comparison of the results from the DOE-2 simulation versus the results from the G-M Chart analysis as well as the differences of those results. The percentages of hours-per-year during the heating, cooling, and non-heating-cooling periods for all sites are presented. Table 5.3 through 5.5 show percentages of hours-per-year in each region during the heating (Table 5.3), cooling (Table 5.4), and non-heating-cooling (Table 5.5) periods.

5.3.3.1 Lightweight house (base case) in the seven selected climates

The DOE-2 simulation results of the lightweight house (base case) for Houston, Phoenix and San Francisco (Section 5.2.1) and the additional results for Bangkok, Chicago, Boston, and Boise (Appendix D) were compared with the G-M Chart analysis results. Table 5.2 shows that during the heating period, the DOE-2 simulation results (percentages of hours-per-year) of the lightweight house (base case) for the hot climates (Houston, 8.43% and Phoenix, 2.30%) were slightly less than the G-M Chart analysis results (Houston, 9.49% and Phoenix, 2.78%). However, DOE-2 showed more hours-per-year in the cool climate representative cities (Chicago, 53.32%; Boston, 55.66%; and Boise, 50.60%) than the G-M Chart showed (Chicago, 42.69%; Boston 40.22, and Boise 41.81%). In San Francisco, DOE-2 showed that there were 33.57% of the hours-per-year during the heating period, which was significantly more than the G-M Chart analysis showed (5.58%). In the heating period, Table 5.3 shows that the DOE-2 simulation results for all representative cities, except Bangkok (which has no heating period; in regions 0, conventional heating) corresponded or very close to the G-M Chart results. In region 1 (active solar), the DOE-2 simulation results for Houston, San Francisco, Chicago, Boston, and Boise corresponded or a little less than the G-M Chart results. For Houston, DOE-2 showed less heating hours in region 1 than the G-M Chart showed and for Phoenix, the DOE-2 simulation results in region 1 were significantly less than the G-M Chart results. In regions 2 to 4 (passive cooling), DOE-2 showed a small portion of the heating hours in Houston and Phoenix and showed a significant portion of the heating hours in San Francisco, Chicago, Boston, and Boise. Unfortunately, in a G-M Chart analysis, these regions (2 to 4, passive cooling) were not usually considered heating periods.

In the cooling period, Table 5.2 shows that the DOE-2 simulation results of the lightweight house (base case) for all sites were more than the results from the G-M Chart analysis. The differences were slightly less in the very hot-humid climate (Bangkok, Thailand) where the DOE-2 showed 100.00% of the hours-per-year and the G-M Chart analysis showed 94.00%. However, DOE-2 showed much difference of the hours-per-

Table 5.2 *Comparison of the DOE-2 simulation results and the G-M Chart results, the percentage of the hours-per-year during the heating, cooling, and non-heating-cooling periods.*

DOE-2 Simulation	City	Heating Period (%)			Cooling Period (%)			Non-Heating-Cooling Period (%)		
		DOE-2	G-M	(G-M) - (DOE-2)	DOE-2	G-M	(G-M) - (DOE-2)	DOE-2	G-M	(G-M) - (DOE-2)
Lightweight (Base-case)	Houston	8.43	9.49	1.06	74.17	50.43	-23.74	17.40	40.08	22.68
	Phoenix	2.30	5.08	2.78	77.25	38.87	-38.38	20.46	56.07	35.61
	San Francisco	33.57	5.58	-27.99	13.23	0.68	-12.55	53.20	93.75	40.55
	Bangkok	0.00	0.00	0.00	100.00	94.00	-6.00	0.00	6.00	6.00
	Chicago	53.32	42.69	-10.63	28.47	11.63	-16.84	18.19	45.67	27.48
	Boston	55.66	40.22	-15.44	24.94	8.09	-16.85	19.39	51.70	32.31
	Boise	50.60	41.81	-8.79	27.39	7.43	-19.96	22.02	50.76	28.74
Lightweight without Internal Loads	Houston	15.55	23.38	7.83	58.70	50.43	-8.27	25.74	26.19	0.45
High Thermal Mass	Houston	8.58	9.49	0.91	68.86	43.95	-24.91	22.54	46.56	24.02
	Phoenix	2.05	5.08	3.03	78.08	20.02	-58.06	19.90	74.92	55.02
Lightweight with an Economizer	Houston	10.05	9.49	-0.56	65.36	50.43	-14.93	24.59	40.08	15.49
	San Francisco	36.96	5.80	-31.16	9.23	0.68	-8.55	53.81	93.75	39.94

Table 5.3 *Comparison of the DOE-2 simulation results and the G-M Chart results during the heating period, the percentage of the hours-per-year in each region.*

DOE-2 Simulation	City	Climate	Results	Heating Period (%)																					Total
				0	1	2	3	4	5	6A	6B	7	8	9	10	11	12	13	14A	14B	15A	15B	16	17	(%)
Lightweight (Base-case)	Houston	(Hot-humid)	DOE-2	2.56	4.18	0.86	0.50	0.24	0.09																8.43
			G-M Chart	2.81	6.68																				9.49
	San Francisco	(Warm-Marine)	DOE-2	0.15	5.35	12.20	13.50	1.83	0.53			0.01													33.57
			G-M Chart	0.15	5.43																				5.58
	Phoenix	(Hot-dry)	DOE-2	0.35	1.35	0.21	0.09	0.16	0.14																2.30
			G-M Chart	0.35	4.73																				5.08
	Bangkok	(Very hot-humid)	DOE-2																						0.00
			G-M Chart																						0.00
	Chicago	(Cool-humid)	DOE-2	26.86	15.48	5.68	3.58	1.15	0.50			0.06	0.01												53.32
			G-M Chart	26.86	15.83																				42.69
	Boston	(Cool-humid)	DOE-2	21.27	18.95	7.43	5.10	2.24	0.64			0.03													55.66
			G-M Chart	21.27	18.95																				40.22
	Boise	(Cool-dry)	DOE-2	21.76	18.74	6.13	2.83	0.89	0.22	0.01		0.02													50.60
			G-M Chart	21.79	20.02																				41.81
Lightweight without Internal Loads	Houston	(Hot-humid)	DOE-2	2.77	5.78	2.85	2.29	1.35	0.42				0.09												15.55
			G-M Chart	2.81	6.68				13.89																23.38
High Thermal Mass	Houston	(Hot-humid)	DOE-2	2.43	3.53	1.06	0.94	0.50	0.09			0.03													8.58
			G-M Chart	2.81	6.68																				9.49
	Phoenix	(Hot-dry)	DOE-2	0.34	1.18	0.23	0.13	0.03	0.13	0.01															2.05
			G-M Chart	0.35	4.73																				5.08
Lightweight with an Economizer	Houston	(Hot-humid)	DOE-2	2.66	4.78	1.30	0.79	0.45	0.07																10.05
			G-M Chart	2.81	6.68																				9.49
	San Francisco	(Warm-Marine)	DOE-2	0.15	5.37	12.64	16.04	2.36	0.38			0.02													36.96
			G-M Chart	0.15	5.43																				5.58

Table 5.4 *Comparison of the DOE-2 simulation results and the G-M Chart results during the cooling period, the percentage of the hours-per-year in each region.*

DOE-2 Simulation	City	Climate	Results	Cooling Period (%)																					Total
				0	1	2	3	4	5	6A	6B	7	8	9	10	11	12	13	14A	14B	15A	15B	16	17	(%)
Lightweight (Base-case)	Houston	(Hot-humid)	DOE-2		0.08	0.19	0.46	1.95	11.22	0.11	0.06	9.71	16.68	13.30	0.59	5.87	0.02				8.92	4.86	0.15		**74.17**
			G-M Chart										16.72	13.30	0.59	5.87	0.02	0.00	0.00	0.00	8.92	4.86	0.15	0.00	**50.43**
	San Francisco	(Warm-Marine)	DOE-2			0.08	0.22	0.23	6.14	0.03	0.14	5.71				0.59		0.08		0.01					**13.23**
			G-M Chart													0.59		0.08		0.01					**0.68**
	Phoenix	(Hot-dry)	DOE-2		0.03	0.03	1.53	4.61	12.21	3.85	4.43	11.69	0.21	1.42	0.63	11.18	0.21	6.83	6.78	5.17	0.07	0.27	4.84	1.26	**77.25**
			G-M Chart										0.21	1.42	0.63	11.18	0.21	6.83	6.78	5.17	0.07	0.27	4.84	1.26	**38.87**
	Bangkok	(Very hot-humid)	DOE-2					0.01	0.90			5.09	2.34	34.97	0.70	5.42	0.19	0.37		0.22	26.62	22.49	0.68		**100.00**
			G-M Chart										2.34	34.97	0.70	5.42	0.19	0.37		0.22	26.62	22.49	0.68		**94.00**
	Chicago	(Cool-humid)	DOE-2			0.02	0.08	0.45	6.06	0.07	0.08	10.26	3.15	2.17	0.09	4.94	0.03	0.08	0.01		0.38	0.45	0.15		**28.47**
			G-M Chart										3.31	2.18	0.09	4.95	0.03	0.08	0.01		0.38	0.45	0.15		**11.63**
	Boston	(Cool-humid)	DOE-2			0.03	0.08	0.21	6.06		0.01	10.82	2.48	0.43	0.07	4.62		0.08			0.05				**24.94**
			G-M Chart										2.77	0.43	0.07	4.69		0.08			0.05				**8.09**
	Boise	(Cool-dry)	DOE-2		0.02	0.05	0.22	1.36	6.82	1.75	0.82	8.92				3.24		2.68	1.29	0.22					**27.39**
			G-M Chart													3.24		2.68	1.29	0.22					**7.43**
Lightweight without Internal Loads	Houston	(Hot-humid)	DOE-2		0.01		0.07	0.46	2.72	0.11	0.06	8.22	13.36	13.30	0.59	5.86	0.02				8.90	4.87	0.15		**58.70**
			G-M Chart										16.72	13.30	0.59	5.87	0.02				8.92	4.86	0.15		**50.43**
High Thermal Mass	Houston	(Hot-humid)	DOE-2		0.02	0.27	0.73	2.03	8.31	0.11	0.06	8.57	15.13	13.26	0.59	5.84	0.02				8.90	4.87	0.15		**68.86**
			G-M Chart										16.72	13.30							8.92	4.86	0.15		**43.95**
	Phoenix	(Hot-dry)	DOE-2		0.07	0.18	2.40	5.30	11.40	3.74	4.43	11.69	0.21	1.42	0.63	11.18	0.21	6.83	6.78	5.17	0.07	0.27	4.84	1.26	**78.08**
			G-M Chart										0.21	1.42					6.78	5.17	0.07	0.27	4.84	1.26	**20.02**
Lightweight with an Economizer	Houston	(Hot-humid)	DOE-2						5.22	0.11	0.06	9.63	16.63	13.30	0.59	5.87	0.02				8.92	4.86	0.15		**65.36**
			G-M Chart										16.72	13.30	0.59	5.87	0.02				8.92	4.86	0.15		**50.43**
	San Francisco	(Warm-Marine)	DOE-2						2.97	0.03	0.14	5.41				0.59		0.08		0.01					**9.23**
			G-M Chart													0.59		0.08		0.01					**0.68**

Table 5.5 *Comparison of the DOE-2 simulation results and the G-M Chart results during the non-heating-cooling period, the percentage of the hours-per-year in each region.*

DOE-2 Simulation	City	Climate	Results	Non-Heating-Cooling Period (%)																					Total
				0	1	2	3	4	5	6A	6B	7	8	9	10	11	12	13	14A	14B	15A	15B	16	17	(%)
Lightweight (Base-case)	Houston	(Hot-humid)	DOE-2	0.25	2.42	3.15	4.50	4.22	2.58			0.23	0.05												**17.40**
			G-M Chart			4.20	5.46	6.42	13.89	0.11	0.06	9.94													**40.08**
	San Francisco	(Warm-Marine)	DOE-2		0.08	1.07	14.89	24.32	12.35	0.01	0.02	0.46													**53.20**
			G-M Chart			13.36	28.61	26.37	19.02	0.05	0.16	6.18													**93.75**
	Phoenix	(Hot-dry)	DOE-2		3.34	5.27	5.96	4.18	1.68	0.03															**20.46**
			G-M Chart			5.51	7.58	8.95	14.03	3.88	4.43	11.69													**56.07**
	Bangkok	(Very hot-humid)	DOE-2																						**0.00**
			G-M Chart					0.01	0.90			5.09													**6.00**
	Chicago	(Cool-humid)	DOE-2		0.35	1.19	3.20	5.09	6.66	0.07	0.02	1.45	0.15			0.01									**18.19**
			G-M Chart			6.89	6.86	6.69	13.22	0.14	0.10	11.77													**45.67**
	Boston	(Cool-humid)	DOE-2			0.40	2.12	6.87	8.46	0.01	0.02	1.14	0.30			0.07									**19.39**
			G-M Chart			7.87	7.31	9.32	15.16	0.01	0.03	12.00													**51.70**
	Boise	(Cool-dry)	DOE-2	0.03	1.26	3.44	6.54	5.71	4.22	0.43	0.08	0.31													**22.02**
			G-M Chart			9.61	9.59	7.96	11.26	2.19	0.90	9.25													**50.76**
Lightweight without Internal Loads	Houston	(Hot-humid)	DOE-2	0.03	0.89	1.35	3.09	4.61	10.75			1.72	3.28			0.01					0.01				**25.74**
			G-M Chart			4.20	5.46	6.42		0.11	0.06	9.94													**26.19**
High Thermal Mass	Houston	(Hot-humid)	DOE-2	0.38	3.13	2.87	3.79	3.88	5.49			1.34	1.60	0.03		0.02					0.01				**22.54**
			G-M Chart			4.20	5.46	6.42	13.89	0.11	0.06	9.94			0.59	5.87	0.02								**46.56**
	Phoenix	(Hot-dry)	DOE-2	0.01	3.48	5.10	5.06	3.62	2.50	0.13															**19.90**
			G-M Chart			5.51	7.58	8.95	14.03	3.88	4.43	11.69			0.63	11.18	0.21	6.83							**74.92**
Lightweight with an Economizer	Houston	(Hot-humid)	DOE-2	0.15	1.89	2.90	4.67	5.97	8.61			0.31	0.09												**24.59**
			G-M Chart			4.20	5.46	6.42	13.89	0.11	0.06	9.94													**40.08**
	San Francisco	(Warm-Marine)	DOE-2		0.07	0.72	12.57	24.01	15.67	0.01	0.02	0.74													**53.81**
			G-M Chart			13.36	28.61	26.37	19.02	0.05	0.16	6.18													**93.75**

year in the cool climate representative cities and in the warm-marine representative city (Chicago, 28.47%; Boston, 24.94%; Boise, 27.39%; and San Francisco, 13.23%) than the G-M Chart showed (Chicago, 11.63%; Boston 8.03%, Boise 7.43%, and 0.68%). The significant differences were in the hot-humid climates. DOE-2 showed the percentages of the hours-per-year during the cooling period, which were 74.17% for Houston and 77.25% for Phoenix. These were significantly more than the G-M Chart analysis showed (Houston, 50.43%; Phoenix, 38.87%). In Table 5.4, DOE-2 showed that the results from the DOE-2 simulation in regions 8 through 17 corresponded or very close to the results from the G-M Chart analysis. However, the differences were in regions 1 through 7, where the DOE-2 simulation showed significant portions of the cooling hours in most representative cities fell within regions 5 and 7 (internal gains and the G-M comfort zone). Moreover, DOE-2 also showed that there were many cooling hours in regions 2 to 4 (passive cooling) and 6 (humidification). In the G-M Chart analysis, these regions (0 through 7) were not considered cooling period.

In the non-heating-cooling period, Table 5.2 shows that the DOE-2 simulation results of the lightweight house (base case) for all sites were less than the results from the G-M Chart analysis. The differences were slightly less in the very hot-humid climate (Bangkok, Thailand) where the DOE-2 showed none of the hours-per-year (0.00%) and the G-M Chart analysis showed 6.00%. However, DOE-2 showed significant differences of the hours-per-year in the other representative cities, which the most differences was found in San Francisco. In Table 5.2, DOE-2 showed the percentages of the hours-per-year during the non-heating-cooling periods for Houston (17.40%), Phoenix (20.46%), San Francisco (53.20%), Chicago (18.19%), Boston (19.39%), and Boise (20.02%); which were less than the G-M Chart showed (Houston, 40.08%; Phoenix, 56.07%; San Francisco, 93.75%; Chicago, 45.67%; Boston, 51.70%; and Boise, 50.76%). In Table 5.5, the DOE-2 simulation showed that the majority of the non-heating-cooling hours for all representative cities, except Bangkok which DOE-2 showed no hours in the non-heating-cooling period, falling upon regions 2 through 7 (passive cooling, internal gains, humidification, and the G-M comfort zone) were significantly less than the G-M Chart analysis results. In all representative cities except Bangkok and Boston, DOE-2 showed a small portion of the non-heating-cooling hours in regions 0 and 1 (conventional heating and active solar). Unfortunately, in the G-M Chart analysis, regions 0 and 1 were not usually considered non-heating-cooling period.

5.3.3.2 Lightweight house (base case) versus lightweight house without internal loads in Houston

The DOE-2 simulation results of the lightweight houses with and without internal loads in Houston (Section 5.2.1 to 5.2.2) were compared with the G-M Chart analysis results. Table 5.2 shows that the DOE-2 simulation result (percentages of hour-per-year) of the lightweight house (base case) during the heating period (8.43%) was slightly less than the G-M Chart results (9.49%). However, the differences were more for the lightweight house without internal loads, where the DOE-2 showed only 15.55% of the hours-per-year but the G-M Chart showed as much as 23.38% of the hours-per-year in heating period. In Table 5.3, the DOE-2 simulation results of the lightweight house without internal loads in Houston showed that the heating hours falling upon regions 0 and 1 (conventional heating, active solar) were very close to the G-M Chart analysis results. However, in region 5, which was considered to be a heating period in the G-M Chart analysis; the DOE-2 simulation results were significantly less than the G-M Chart results. Moreover, DOE-2 showed a small portion of the heating hours in regions 2 to 4 (passive cooling), which were not considered to be heating periods in the G-M Chart analysis.

In the cooling period (Table 5.2), the DOE-2 simulation results of the lightweight house (base case) (74.17%) was significantly more than the G-M Chart results (50.43%). However, the differences were less for the lightweight house without internal loads, where the DOE-2 showed 58.70% of the hours-per-year and the G-M Chart showed 50.43% of the hours-per-year in cooling period. In Table 5.4, the DOE-2 simulation results in regions 8 through 17 corresponded or very close to the results from the G-M Chart analysis. However, the differences were in regions 1 through 7. DOE-2 showed significant portions of the cooling hours fell within regions 5 and 7 (internal gains and the G-M comfort zone), which were not considered cooling period in the G-M Chart analysis.

In the non-heating-cooling period (Table 5.2), the DOE-2 simulation results of the lightweight house (base case) (17.40%) was significantly less than the G-M Chart results (40.08%). However, the DOE-2 simulation results of the lightweight house without internal loads (25.74%) were very close to the G-M Chart results (26.19%). In Table 5.5, the DOE-2 simulation showed that the non-heating-cooling hours in regions 2 to 4 and 6 (passive cooling and humidification) and especially in region 7 (the G-M comfort zone) were less than the G-M Chart results. Surprisingly, DOE-2 showed a significant portion of the non-heating-cooling hours in region 5 (internal gains); which was considered to be a heating period in the G-M Chart analysis. DOE-2 also showed a small portion of the non-heating-cooling hours in regions 0, 1, and 8 (conventional heating, active solar, and dehumidification). Unfortunately, in the G-M Chart analysis, these regions were not usually considered non-heating-cooling period.

5.3.3.3 Lightweight house (base case) versus high thermal mass house in Houston and Phoenix

The DOE-2 simulation results (percentage of hours-per-year) of the high thermal mass houses in Houston and Phoenix (Section 5.2.1 and 5.2.3) were compared with the G-M Chart analysis results. Table 5.2 shows that the DOE-2 simulation results during the heating period for all sites were less than the G-M Chart analysis results. In Houston, the DOE-2 simulation results of the lightweight house (base case) (8.43%) and the high thermal mass house (8.58%) were very close to the G-M Chart results (9.49%). In Phoenix, the DOE-2 simulation results of the lightweight house (base case) (2.30%) and the high thermal mass house (2.05%) were slightly less than the G-M Chart results (5.08%). In Table 5.3, DOE-2 showed that the majority of the heating hours in region 0 (conventional heating) for the high thermal mass house in both cities were very close to the G-M Chart results, but in region 1 (active solar) the DOE-2 simulation results were significantly less than the G-M Chart results. DOE-2 also showed a small portion of the heating hours in regions 2 to 4 and 5 (passive cooling and internal gains), which were not usually considered to be heating periods in the G-M Chart analysis.

In cooling period, Table 5.2 shows that the DOE-2 simulation results during the cooling period for all sites were more than the G-M Chart analysis results. In Houston, the DOE-2 simulation results of the lightweight house (base case) (74.17%) and the high thermal mass house (68.86%) were more than the G-M Chart results, which showed 50.43% of the hours-per-year for the lightweight house (base case) and 43.95% of the hours-per-year for the high thermal mass house during the cooling period. Significant differences were in Phoenix; where DOE-2 showed 77.25% of the cooling hours for the lightweight house (base case) and 78.08% of the cooling hours for the high thermal mass house, which were significantly more than the G-M Chart results (38.87%, lightweight and 20.02%, high thermal mass). In the cooling period (Table 5.4), the DOE-2 simulation results in regions 8, 9, and 14 through 17 for the high thermal mass house in both cities corresponded or very close to the results from the G-M Chart analysis. However, the differences were in regions 1 through 7 and 10 through 13. DOE-2 showed a significant portion of the cooling hours for Houston and Phoenix fell within regions 5, 7, and 11 (internal gains, the G-M comfort zone, and high thermal mass). For Phoenix, DOE-2 also showed a significant portion of the cooling hours in region 13 (high thermal mass). Unfortunately, in the G-M Chart analysis, these regions (5, 7, 11 and 13) were not usually considered cooling period.

In non-heating-cooling period, Table 5.2 shows that the DOE-2 simulation results during the non-heating-cooling period for all sites were less than the G-M Chart analysis results. In Houston, DOE-2 showed the results of the lightweight house (base case) (17.40%) and the high thermal mass house (22.54%) while the G-M Chart showed 40.08% for the lightweight house (base case) and 46.56% for the high thermal mass house. Significant differences were in Phoenix, where the DOE-2 showed 20.46% for the lightweight house (base case) and 19.90% for the high thermal mass house. In Phoenix, the G-M Chart showed as much as 56.07% for the lightweight house (base case) and 74.92% for the high thermal mass house. For the non-heating-cooling period of the high thermal mass house in Houston and Phoenix (Table 5.5), the DOE-2 simulation results for regions 2 through 7 and 10 through 13 (passive cooling, internal gains, humidification, the G-M comfort zone, and thermal mass); which were usually considered to be non-heating-cooling periods in the G-M Chart analysis; were significantly less than the G-M Chart results. DOE-2 also showed a portion of the non-heating-cooling hours in regions 0 and 1 (conventional heating and active solar), which were not usually considered to be non-heating-cooling periods in the G-M Chart analysis.

5.3.3.4 Lightweight house (base case) versus lightweight house with an economizer in Houston and San Francisco

The DOE-2 simulation results of the lightweight houses with an economizer in Houston and San Francisco (Section 5.2.1 and 5.2.e4) were compared. Table 5.2 shows that, in Houston, the DOE-2 simulation results of the lightweight house (base case) (8.43%) and the lightweight house with an economizer (10.05%) during the heating period were very close to the G-M Chart results (9.49%). However, in San Francisco, the DOE-2 simulation results of the lightweight house (base case) (33.57%) and the lightweight house with an economizer (36.96%) were significantly more than the G-M Chart results (5.08%). In heating period (Table 5.3), DOE-2 showed that the majority of the heating hours in region 0 and 1 (conventional heating and active solar) for the lightweight house with an economizer in both cities corresponded or were close to the G-M Chart results. However, in Table 5.3 DOE-2 showed a small portion of the heating hours for Houston in regions 2 to 4 and 5 (passive cooling and internal gains). A significant portion of the heating hours in San Francisco were also shown in these regions, which was not usually considered to be a heating period in a G-M Chart analysis.

Table 5.2 shows that the DOE-2 simulation results during the cooling period for all sites were more than the G-M Chart analysis results. In Houston, the DOE-2 simulation results of the lightweight house (base case) (74.17%) and the lightweight house with an economizer (65.36%) were significantly more than the G-M Chart results (50.43%). The differences were also shown in San Francisco; where DOE-2 showed 13.23% of the hours-per-year for the lightweight house (base case) and 9.23% of the hours-per-year for the lightweight house with an economizer, while the G-M Chart results showed only 0.68% of the hour-per-year. For the cooling period of the lightweight house with an economizer in both cities (Table 5.4), the DOE-2 simulation results in regions 8 through 17 corresponded or very close to the G-M Chart results. However, DOE-2 showed a significant portion of the cooling hours in regions 5 through 7, which were not considered to be cooling periods in the G-M Chart analysis.

Table 5.2 shows that the DOE-2 simulation results during the non-heating-cooling period for all sites were less than the G-M Chart analysis results. In Houston, the DOE-2 simulation results of the lightweight house (base case) (17.40%) and the lightweight house with an economizer (24.59%) were less than the G-M Chart results (40.08%). Significant differences were shown in San Francisco; where DOE-2 showed 53.20% of the hours-per-year for the lightweight house (base case) and 53.81% of the hours-per-year for the lightweight house with an economizer, while the G-M Chart results showed as much as 93.75% of the hour-per-year. In the non-heating-cooling period (Table 5.5) of the lightweight house with an economizer in both cities, the DOE-2 simulation showed that the majority of the non-heating-cooling hours fell upon regions 2 through 7 (passive cooling, internal gains, humidification, and the G-M comfort zone), which were considered to be non-heating-cooling periods in the G-M Chart analysis. However, the results from the DOE-2 simulation fell upon these regions were significantly less than the G-M Chart analysis results. DOE-2 also showed a small portion of the non-heating-cooling hours in regions 0, 1, and 8 (conventional heating, active solar, dehumidification), which were not usually considered to be non-heating-cooling periods in the G-M Chart analysis.

5.3.4 The DOE-2 Simulation Results for All Sites

In a similar fashion as Tables 5.3 through 5.5, Table 5.6 shows a comparison of the DOE-2 simulation results for all sites. The table shows percentages of the hours-per-year in each region during the heating period (upper part), cooling period (middle part), and non-heating-cooling periods (bottom part). Totals percentages of hour-per-year during each period for each run are presented at the end of each row (i.e., at the last column). This section focuses on the DOE-2 simulation results of the base-case house in Houston versus the DOE-2 simulation results for all sites. The majority of the hours-per-year of each region for each period are addressed and presented in shades of blue (heating period), orange (cooling period), and green (non-heating-cooling period). Regions with the larger percentages of hours-per-year are presented in the darker colors and regions with smaller percentages of hours-per-year are presented in lighter colors. The boundaries of these regions are then delineated upon the psychrometric charts. For all simulations, the numbers of hours-per-year in each region for each period has been compared in the previous section (Section 5.3.3). Therefore, they will not be discussed in details in this section.

5.3.4.1 Lightweight house (base case) in the seven selected climates

The DOE-2 simulation results of the lightweight house (base case) in the seven selected climates were compared. Table 5.6 shows that during the heating period (upper part), the majority of the heating hours fell into colder areas to the left of the comfort zone (region 7) covering the regions from 0 through 3; which include the G-M conventional heating, active solar, and passive solar design strategies. There were no heating hours in the very hot-humid climate (Bangkok, Thailand). However, in the hot-humid climate, there were heating hours in Houston (8.43%) and Phoenix (2.30%). In all other sites the majority of the hours-per-year are in regions 0 and 1 (conventional heating and active solar). In the warm-marine climate (San Francisco), there was 33.57% of the hours-per-year in this period. In San Francisco, majority of the hours-per-year of regions 0 through 3 (conventional heating, active solar and passive solar) were in heating

Table 5.6 *Comparison of the DOE-2 simulation results for all sites; the percentage of the hours-per- year in each region during the heating, cooling, and non-heating-cooling periods.*

DOE-2 Simulation	City	Climate	Heating Period (%)																					Total (%)
			0	1	2	3	4	5	6A	6B	7	8	9	10	11	12	13	14A	14B	15A	15B	16	17	
Lightweight (Base-case)	Bangkok	(Very hot-humid)																						0.00
	Houston	(Hot-humid)	2.56	4.18	0.86	0.50	0.24	0.09																8.43
	Phoenix	(Hot-dry)	0.35	1.35	0.21	0.09	0.16	0.14																2.30
	San Francisco	(Warm-Marine)	0.15	5.35	12.20	13.50	1.83	0.53			0.01													33.57
	Chicago	(Cool-humid)	26.86	15.48	5.68	3.58	1.15	0.50			0.06	0.01												53.32
	Boston	(Cool-humid)	21.27	18.95	7.43	5.10	2.24	0.64			0.03													55.66
	Boise	(Cool-dry)	21.76	18.74	6.13	2.83	0.89	0.22	0.01		0.02													50.60
Lightweight without Internal Loads	Houston	(Hot-humid)	2.77	5.78	2.85	2.29	1.35	0.42				0.09												15.55
High Thermal Mass	Houston	(Hot-humid)	2.43	3.53	1.06	0.94	0.50	0.09			0.03													8.58
	Phoenix	(Hot-dry)	0.34	1.18	0.23	0.13	0.03	0.13	0.01															2.05
Lightweight with an Economizer	Houston	(Hot-humid)	2.66	4.78	1.30	0.79	0.45	0.07																10.05
	San Francisco	(Warm-Marine)	0.15	5.37	12.64	16.04	2.36	0.38			0.02													36.96

COMFORT ZONE

DOE-2 Simulation	City	Climate	Cooling Period (%)																					Total (%)
			0	1	2	3	4	5	6A	6B	7	8	9	10	11	12	13	14A	14B	15A	15B	16	17	
Lightweight (Base-case)	Bangkok	(Very hot-humid)					0.01	0.90			5.09	2.34	34.97	0.70	5.42	0.19	0.37		0.22	26.62	22.49	0.68		100.00
	Houston	(Hot-humid)		0.08	0.19	0.46	1.95	11.22	0.11	0.06	9.71	16.68	13.30	0.59	5.87	0.02				8.92	4.86	0.15		74.17
	Phoenix	(Hot-dry)		0.03	0.03	1.53	4.61	12.21	3.85	4.43	11.69	0.21	1.42	0.63	11.18	0.21	6.83	6.78	5.17	0.07	0.27	4.84	1.26	77.25
	San Francisco	(Warm-Marine)			0.08	0.22	0.23	6.14	0.03	0.14	5.71				0.59		0.08		0.01					13.23
	Chicago	(Cool-humid)			0.02	0.08	0.45	6.06	0.07	0.08	10.26	3.15	2.17	0.09	4.94	0.03	0.08	0.01		0.38	0.45	0.15		28.47
	Boston	(Cool-humid)			0.03	0.08	0.21	6.06		0.01	10.82	2.48	0.43	0.07	4.62		0.08			0.05				24.94
	Boise	(Cool-dry)		0.02	0.05	0.22	1.36	6.82	1.75	0.82	8.92				3.24		2.68	1.29	0.22					27.39
Lightweight without Internal Loads	Houston	(Hot-humid)		0.01		0.07	0.46	2.72	0.11	0.06	8.22	13.36	13.30	0.59	5.86	0.02				8.90	4.87	0.15		58.70
High Thermal Mass	Houston	(Hot-humid)		0.02	0.27	0.73	2.03	8.31	0.11	0.06	8.57	15.13	13.26	0.59	5.84	0.02				8.90	4.87	0.15		68.86
	Phoenix	(Hot-dry)		0.07	0.18	2.40	5.30	11.40	3.74	4.43	11.69	0.21	1.42	0.63	11.18	0.21	6.83	6.78	5.17	0.07	0.27	4.84	1.26	78.08
Lightweight with an Economizer	Houston	(Hot-humid)						5.22	0.11	0.06	9.63	16.63	13.30	0.59	5.87	0.02				8.92	4.86	0.15		65.36
	San Francisco	(Warm-Marine)						2.97	0.03	0.14	5.41				0.59		0.08		0.01					9.23

DOE-2 Simulation	City	Climate	Non-Heating-Cooling Period (%)																					Total (%)
			0	1	2	3	4	5	6A	6B	7	8	9	10	11	12	13	14A	14B	15A	15B	16	17	
Lightweight (Base-case)	Bangkok	(Very hot-humid)																						0.00
	Houston	(Hot-humid)	0.25	2.42	3.15	4.50	4.22	2.58			0.23	0.05												17.40
	Phoenix	(Hot-dry)		3.34	5.27	5.96	4.18	1.68	0.03															20.46
	San Francisco	(Warm-Marine)		0.08	1.07	14.89	24.32	12.35	0.01	0.02	0.46													53.20
	Chicago	(Cool-humid)		0.35	1.19	3.20	5.09	6.66	0.07	0.02	1.45	0.15			0.01									18.19
	Boston	(Cool-humid)			0.40	2.12	6.87	8.46	0.01	0.02	1.14	0.30			0.07									19.39
	Boise	(Cool-dry)	0.03	1.26	3.44	6.54	5.71	4.22	0.43	0.08	0.31													22.02
Lightweight without Internal Loads	Houston	(Hot-humid)	0.03	0.89	1.35	3.09	4.61	10.75			1.72	3.28			0.01					0.01				25.74
High Thermal Mass	Houston	(Hot-humid)	0.38	3.13	2.87	3.79	3.88	5.49			1.34	1.60	0.03		0.02					0.01				22.54
	Phoenix	(Hot-dry)	0.01	3.48	5.10	5.06	3.62	2.50	0.13															19.90
Lightweight with an Economizer	Houston	(Hot-humid)	0.15	1.89	2.90	4.67	5.97	8.61			0.31	0.09												24.59
	San Francisco	(Warm-Marine)		0.07	0.72	12.57	24.01	15.67	0.01	0.02	0.74													53.81

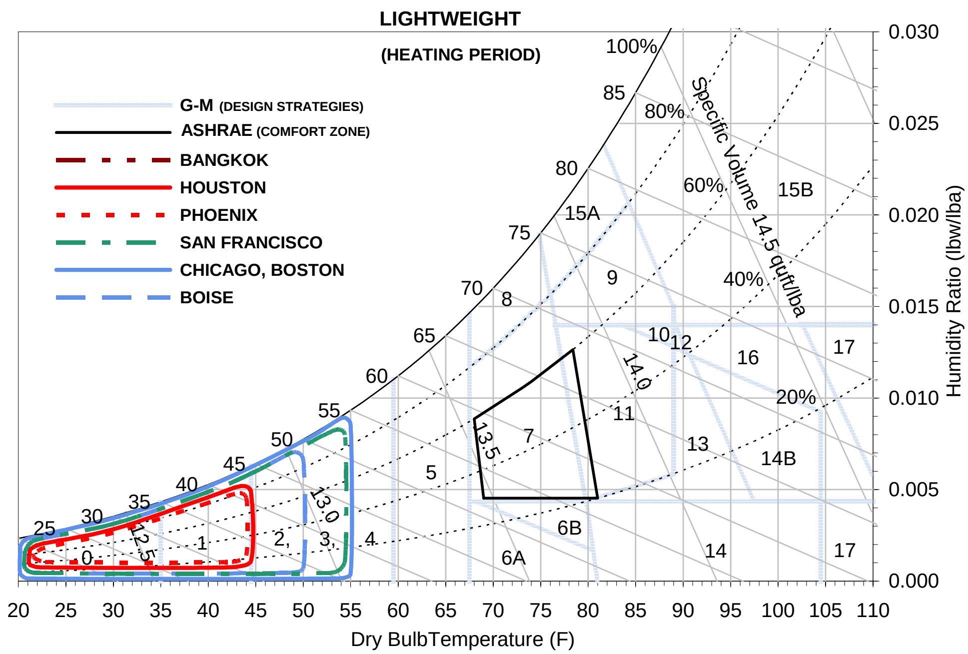


Figure 5.40 *Bioclimatic chart of the lightweight house (base case), during the heating period, in the seven selected climates.*

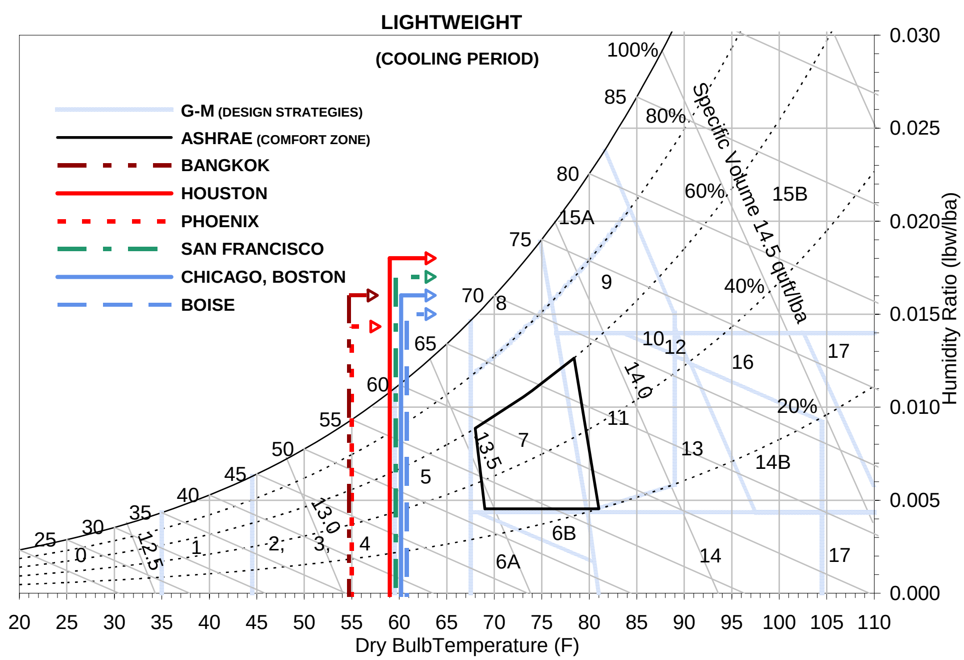


Figure 5.41 *Bioclimatic chart of the lightweight house (base case), during the cooling period, in the seven selected climates.*

period. The numbers of the heating hours-per-year were significantly high in the cool-climate (Chicago, 53.32%; Boston, 55.66%; and Boise, 50.60%). For Chicago, and Boston, the majority of the hours-per-year of regions 0 through 3 were in this period. For Boise, regions 0 through 2 showed that the majority of hours-per-year of each region were in heating period. Figure 5.40 shows boundaries of the heating regions for the lightweight house (base case) in the seven selected climates. The boundary of each location represented the regions which the majority of the hours-per-year were in heating period. These boundaries corresponded to the regions discussed previously in Section 5.3.3.1.

In the cooling period, Table 5.6 (middle part) shows that the majority of the cooling hours covered the comfort zone and were spread-out to the left and the right of the comfort zone covering several regions from 4 through 17; which included the G-M passive solar, internal gains, humidification, ventilation, evaporative cooling, high thermal mass (with and without night ventilation), and air-conditioning (with and without dehumidification) design strategies. In Bangkok, 100% of the hours-per-year were in the cooling period. As expected, in the hot-humid climate, significant portion of the hours in a year were also in this period (Houston, 74.17%; Phoenix, 77.25%). In San Francisco, the cooling hours were only 13.23% of the hours in a year. For the cool-climate; there were 28.47% (Chicago), 24.94% (Boston), and 27.39% (Boise) of the hours-per-year in cooling period. The majority of the hours-per-year for each region; which were shown in cooling period; covered from region 4 (passive solar) for Bangkok and Phoenix or region 5 (Internal gains) for Houston, San Francisco, Chicago, Boston, and Boise; and was spread-out covering all other regions to the right (Figure 5.41).

In non-heating-cooling period, Table 5.6 shows that during the non-heating-cooling period (lower part), the majority of the non-heating-cooling hours fell into the area between the heating and cooling period covering the area to the left of the comfort zone from regions 1 through 5; which included the G-M conventional heating, active solar, passive solar, and internal gains design strategies. There were no non-heating-cooling hours in Bangkok. In the hot-humid climate, there were 17.40% (Houston) and

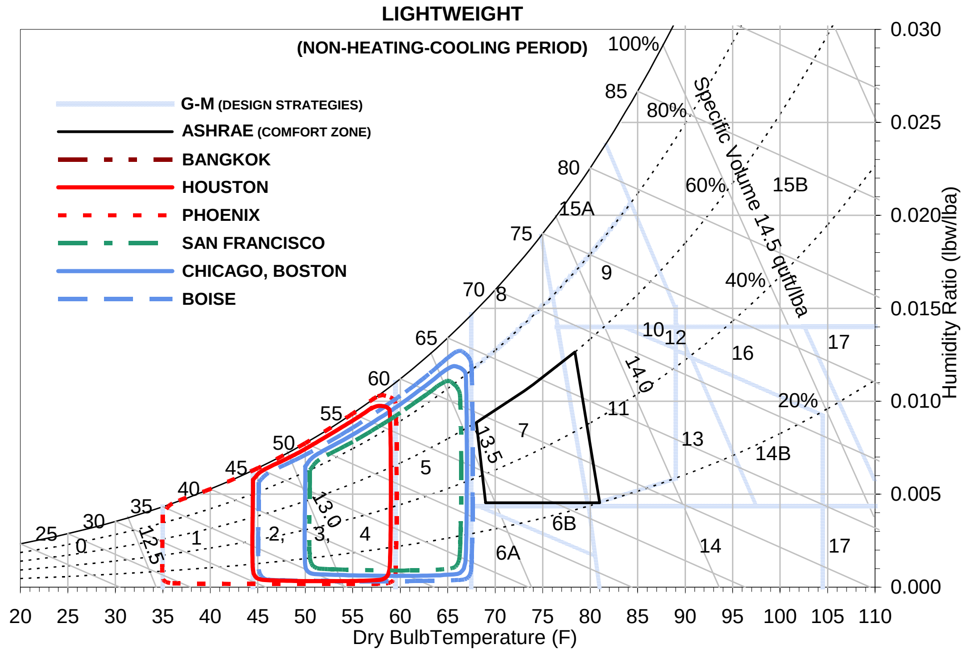


Figure 5.42 *Bioclimatic chart of the lightweight house (base case), during the non-heating-cooling period, in the seven selected climates.*

20.46% (Phoenix) of hours-per-year in non-heating-cooling period. The majority of the hours-per-year of each region showing in the non-heating-cooling period were regions 2 to 4 (passive solar) for Houston and regions 1 to 4 (active solar and passive solar) for Phoenix (Table 5.6 and Figure 5.42). In San Francisco, there were significant hours-per-year in the non-.heating-cooling period (53.20%). The majority of the hours-per-year of each region showing in this period included regions 3 through 5 (passive solar and internal gains) (Table 5.6 and Figure 5.42). In the cool-climate; there were 18.19% (Chicago), 19.39% (Boston), and 22.02% (Boise) of the hours-per-year in the non-heating-cooling period. The majority of the hours-per-year of each region showing in the non-heating-cooling period were regions 3 through 5 for Chicago and Boston, and regions 2 through 5 (passive solar and internal gains) for Boise (Table 5.6 and Figure 5.42).

Finally, Table 5.7 shows a comparison of the G-M bioclimatic analysis and the DOE-2 simulation results of the lightweight house (base case) during the heating, cooling, and non-heating-cooling periods in the seven selected climates. The first column shows the region numbers from 1 to 17 with the design strategy regions at the end of the table. The next three columns shows the G-M bioclimatic analysis for heating ("HTG", in blue), cooling ("CLG", in pink), and non-heating-cooling ("NHC", in green) design strategies of each region (see explanation in Section 5.2.1.1, Figure 5.17d). Then, following with columns for the DOE-2 simulation results during the heating ("HTG", in blue), cooling ("CLG", in pink), and non-heating-cooling ("NHC", in green) periods. Each period consists of eight columns. These columns indicate the majority of hours-per-year that fell in the regions for all locations (see Table 5.6 and Figures 5.40 through 5.41). The location abbreviation codes are explained at the end of the table. The last two rows compare the percentages of hours-per-year of the DOE-2 simulation results (second row from the bottom of the chart) and the G-M chart analysis results (last row at the bottom of the chart) for the lightweight house (base case) during the heating, cooling, and non-heating-cooling periods for all locations.

In Table 5.7, the G-M heating design strategy regions (0, conventional heating; and 1, active solar) corresponded to the heating period regions in Houston and Phoenix. In other location, the heating period was expanded to cover the region 2 (passive solar) in Boise and region 3 (passive solar) in San Francisco, Chicago, and Boston. During the heating period, DOE-2 showed that the percentages of the heating hours-per-year for Houston were very close to the G-M chart analysis results; but for Phoenix, the DOE-2 simulation results were almost half of the G-M Chart analysis results. However, DOE-2 showed larger percentages of heating hours than the G-M Chart showed for Chicago, Boston, and Boise. These are more likely due to the effects of the solar radiation availability during the heating period (see Figure E.1); which is high in Houston and significantly higher in Phoenix, but low in San Francisco and significantly lower in Chicago, Boston, and Boise. In San Francisco, there were many hours-per-year that the outdoor temperatures fell upon passive solar region (2 to 4). Therefore, the percentages

Table 5.7 *Comparison of the G-M bioclimatic analysis and the DOE-2 simulation results; the majority of hours-per-year of each region during the heating, cooling, and non-heating-cooling periods; for the lightweight house (base case) in the seven selected climates.*

Lightweight House (base-case) in the Seven Selected Climates																											
Region Number	G-M Bioclimatic Analysis			DOE-2 Simulation (majority of the hours-per-year)																							
				Heating Period (HTG)								Non-Heating-Cooling Period (NHC)								Cooling Period (CLG)							
	Heating	Non-Heating-Cooling	Cooling	ALL	BKK	HOU	PHO	SAF	CHI	BOS	BOI	ALL	BKK	HOU	PHO	SAF	CHI	BOS	BOI	ALL	BKK	HOU	PHO	SAF	CHI	BOS	BOI
0	**HTG**			**HTG**		HTG	HTG	HTG	HTG	HTG	HTG																
1	**HTG**			**HTG**		HTG	HTG	HTG	HTG	HTG	HTG	**N-H-C**			NHC												
2		**N-H-C**		**HTG**				HTG	HTG	HTG	HTG	**N-H-C**		NHC	NHC				NHC								
3		**N-H-C**		**HTG**				HTG	HTG	HTG		**N-H-C**		NHC	NHC	NHC	NHC	NHC	NHC								
4		**N-H-C**										**N-H-C**		NHC	NHC	NHC	NHC	NHC	NHC	**CLG**	CLG		CLG				
5		**N-H-C**										**N-H-C**				NHC	NHC	NHC	NHC	**CLG**	CLG	CLG	CLG	CLG	CLG	CLG	CLG
16A, 16B		**N-H-C**																		**CLG**	CLG	CLG	CLG	CLG	CLG	CLG	CLG
7		**N-H-C**																		**CLG**	CLG	CLG	CLG	CLG	CLG	CLG	CLG
8			**CLG**																	**CLG**	CLG	CLG	CLG	CLG	CLG	CLG	CLG
9			**CLG**																	**CLG**	CLG	CLG	CLG	CLG	CLG	CLG	CLG
10			**CLG**																	**CLG**	CLG	CLG	CLG	CLG	CLG	CLG	CLG
11			**CLG**																	**CLG**	CLG	CLG	CLG	CLG	CLG	CLG	CLG
12			**CLG**																	**CLG**	CLG	CLG	CLG		CLG		
13			**CLG**																	**CLG**	CLG		CLG	CLG	CLG	CLG	CLG
14A, 14B			**CLG**																	**CLG**	CLG		CLG	CLG	CLG		CLG
15			**CLG**																	**CLG**	CLG	CLG	CLG		CLG	CLG	
16			**CLG**																	**CLG**	CLG	CLG	CLG		CLG		
17			**CLG**																	**CLG**			CLG				
Hours-per-year (%)	**DOE-2 Simulation**			**HTG**	0.00	8.43	2.30	33.57	53.32	55.66	50.60	NHC	0.00	17.40	20.46	53.20	18.19	19.39	22.02	CLG	100.00	74.17	77.25	13.23	28.47	24.94	27.39
of each period	**G-M Bioclimatic Analysis**				0.00	9.49	5.08	5.58	42.69	40.22	41.81		0.00	40.08	56.07	93.75	45.57	51.70	50.76		94.00	50.43	38.87	0.68	11.63	8.09	7.43

***Remark**

Bioclimatic Design Strategy	**Regions**
Conventiona Heating	0
Active Solar	1
Passive Solar	2, 3, 4
Internal Gains	5
Humidification	6A, 6B
G-M Comfort Zone	7
Dehumidification	8
Ventilation	9, 10, 11
Evaporative Cooling	6B, 11, 13, 14A,B
High Thermal Mass	10, 11, 12, 13
High Thermal Mass with Night Ventilation	14B, 16
Air-Conditioning	17
Air-Conditioning with Dehumidification	15

Seven Selected Climates

Bangkok, Thailand (BKK)
Houston, Texas (HOU)
Phoenix, Arizona (PHO)
San Francisco (SAF)
Chicago, Illinois (CHI)
Boston, Massachusetts (BOS)
Boise, Idaho (BOS)

of heating hours-per-year from the DOE-2 simulation, in which the majority heating hours were spread-out covering regions 2 and 3, were significantly higher than the G-M chart analysis result.

In the cooling period, most of the G-M cooling design strategy regions (8 to 17; dehumidification, ventilation, high thermal mass (with and without night ventilation), evaporative cooling, and air-conditioning with and without dehumidification) and the percentages of hours-per-year corresponded to the DOE-2 simulation results for all locations. However, for all sites, DOE-2 showed larger percentages of cooling hours-per-year than the G-M Chart analysis due to the majority of regions 5 through 7 were also in the cooling periods; while these regions were considered non-heating-cooling period in the G-M chart analysis. In addition, DOE-2 showed the majority of the region 4 (passive solar) in the cooling period for Bangkok and Phoenix. These are more likely due to the increased of solar radiation availability for Bangkok and Phoenix during the winter, which was much higher than other locations (see Figure E.1).

In the G-M Chart analysis, regions 2 through 7 (passive solar, internal gains, humidification, were normally considered non-heating-cooling period. However, the DOE-2 simulation results showed that regions 5 through 7 were normally in the cooling period. The G-M passive solar regions (2 to 4) corresponded to the DOE-2 simulation results for Houston location. However, for the location with higher solar radiation availability during the heating period (Phoenix, Arizona), the effective regions were more likely shifted or expanded to left (overlapped with region 1). In contrast, for the locations with lower solar radiation availability during the heating period, the effective regions were shifted or expanded to the right (overlapped with region 5). Therefore, without heating and cooling systems, the house could normally be maintained within the comfort conditions, when the outdoor temperatures were cool (below the comfort zone). These are more likely due to a combination of several effects; which mainly include the mass of the house, the internal loads, and the solar radiation availability of the site.

In summary, for the lightweight house (base case), the G-M heating and cooling design strategy regions (0 to 1 and 8 to 17) corresponded to the results of the DOE-2 simulation. For the non-heating-cooling period, the G-M passive solar regions (2 to 4) corresponded to the DOE-2 simulation results for Houston location. However, for the other locations, with the increased and decreased of solar radiation availability during the heating period, these regions were more likely to be shifted or expanded to the left and to the right; respectively. It is important to note that discrepancies of the G-M chart analysis and the DOE-2 simulation results mostly were in the regions 5 through 7 (internal gains, humidification, and G-M comfort zone); which these regions, in the G-M bioclimatic analysis, were usually considered to be non-heating-cooling-periods for this simulation. However, DOE-2 showed the needs of space cooling in these regions (5 to 7), which were more likely due the internal heat sources (i.e., occupants, equipment, and lights) and the mass and of the house.

5.3.4.2 Lightweight house (base case) versus lightweight house without internal loads in Houston

The DOE-2 simulation results of the lightweight house (base case) and the lightweight house without internal loads in Houston were compared. Table 5.6 shows that during the heating period (upper part), there were 8.43% of the hours-per-year for the lightweight house (base case) and 15.55% of the hours-per-year for the lightweight house without internal loads. For the lightweight house (base case), the regions with the majority of the hours-per-year in the heating period included regions 0 and 1 (see Section 5.3.4.1). For the lightweight house without internal loads, the regions with the majority of the hours-per-year also in the heating period included regions 0 through 3 (conventional heating, active solar, and passive solar).

In the cooling period, Table 5.6 (middle part) shows that there were 74.17% of the hours-per-year for the lightweight house (base case) and 58.70% of the hours-per-year for the lightweight house without internal loads. For the lightweight house (base case), the regions with the majority of the hours-per-year in the cooling period included

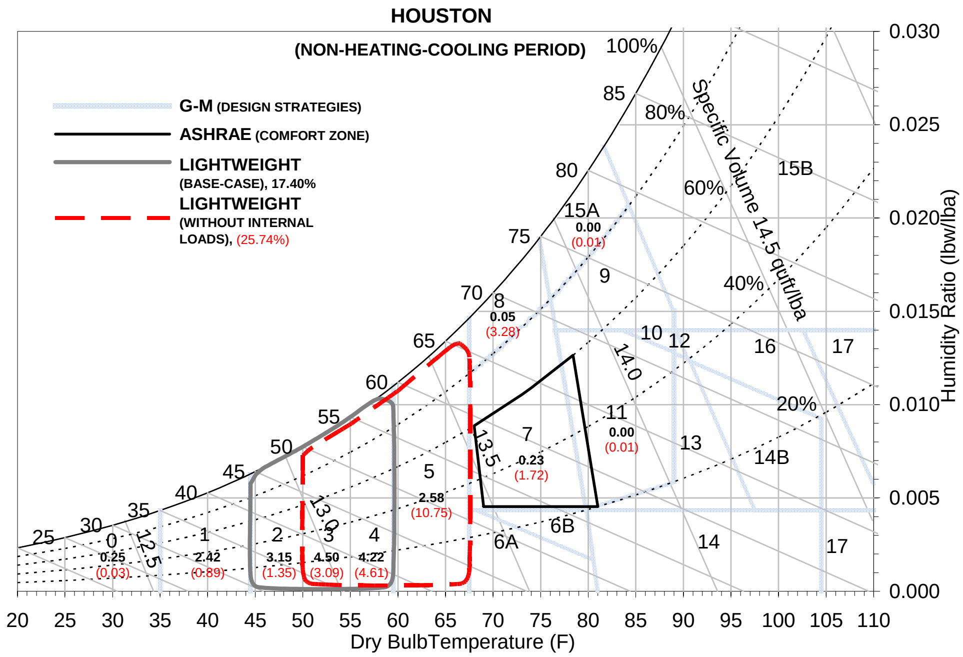


Figure 5.43 *Bioclimatic chart of the lightweight house (base case) and the lightweight house without internal loads, during the non-heating-cooling period, in the hot-humid climate, Houston, Texas.*

region 5, and all other regions to the right of region 5 (see Section 5.3.4.1). For the lightweight house without internal loads, the regions with the majority of the hours-per-year also in the cooling period included region 6, and all other regions above and to the right of region 6.

In the non-heating-cooling period, Table 5.6 (lower part) shows that there were 17.40% of the hours-per-year for the lightweight house (base case) and 25.74% of the hours-per-year for the lightweight house without internal loads. For the lightweight house (base case), the regions with the majority of the hours-per-year in the non-heating-cooling period included regions 2 through 4 (see Section 5.3.4.1). For the lightweight house without internal loads, the regions with the majority of the hours-per-year in the non-heating-cooling period included regions 3 through 5 (passive solar and internal gains). Figure 5.43 shows boundaries of the non-heating-cooling regions for the lightweight house (base case) and the lightweight house without internal loads in

Houston. Each boundary covered the regions with the majority of the hours-per-year were in the non-heating-cooling period.

5.3.4.3 Lightweight house (base case) versus high thermal mass house in Houston and Phoenix

The DOE-2 simulation results of the lightweight house (base case) and the high thermal mass house in Houston and Phoenix were compared. In Houston, Table 5.6 (upper part) shows that the heating hours-per-year of the lightweight house (base case) (8.43%) were very close to the heating hours of the high thermal mass house (8.58%). For the lightweight house (base case) (see Section 5.3.4.1) and the high thermal mass house, the regions with the majority of the hours-per-year in the heating period included regions 0 and 1 (conventional heating and active solar). In the cooling period, Table 5.6 (middle part) shows that the cooling hours in the year of the houses in Houston were 74.17% for the lightweight house (base case) and 68.86% for the high thermal mass house. For both houses, the regions with the majority of the hours-per-year in the cooling period included region 5, and all other regions to the right of region 5 (see Section 5.3.4.1).

In non-heating-cooling period, Table 5.6 (lower part) shows that there were 17.40% of the hours-per-year for the lightweight house (base case) and 22.54% of the hours-per-year for the high thermal mass house in Houston. For the lightweight house (base case), the regions with the majority of the hours-per-year in the non-heating-cooling period included regions 2 through 4 (see Section 5.3.4.1). For the high thermal mass house, the regions with the majority of the hours-per-year in the non-heating-cooling period included regions 1 through 5 (active solar, passive solar, and internal gains). Figure 5.44 shows boundaries of the non-heating-cooling regions for the lightweight house (base case) and the high thermal mass houses in Houston. Each boundary covered the regions with the majority of the hours-per-year were in the non-heating-cooling period.

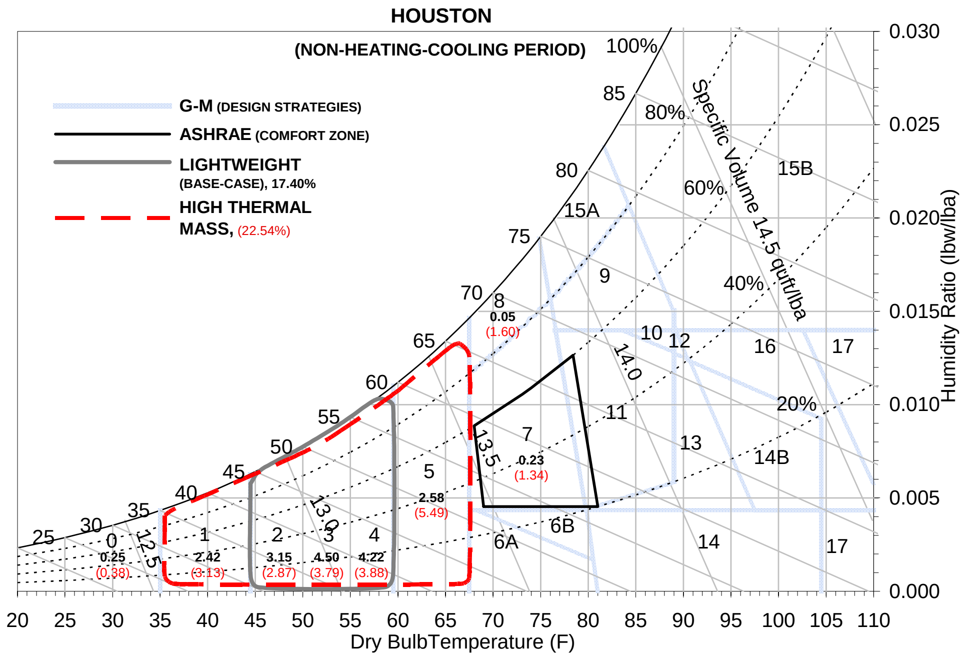


Figure 5.44 *Bioclimatic chart of the lightweight house (base case) and the high thermal mass house, during the non-heating-cooling period, in the hot-humid climate, Houston, Texas.*

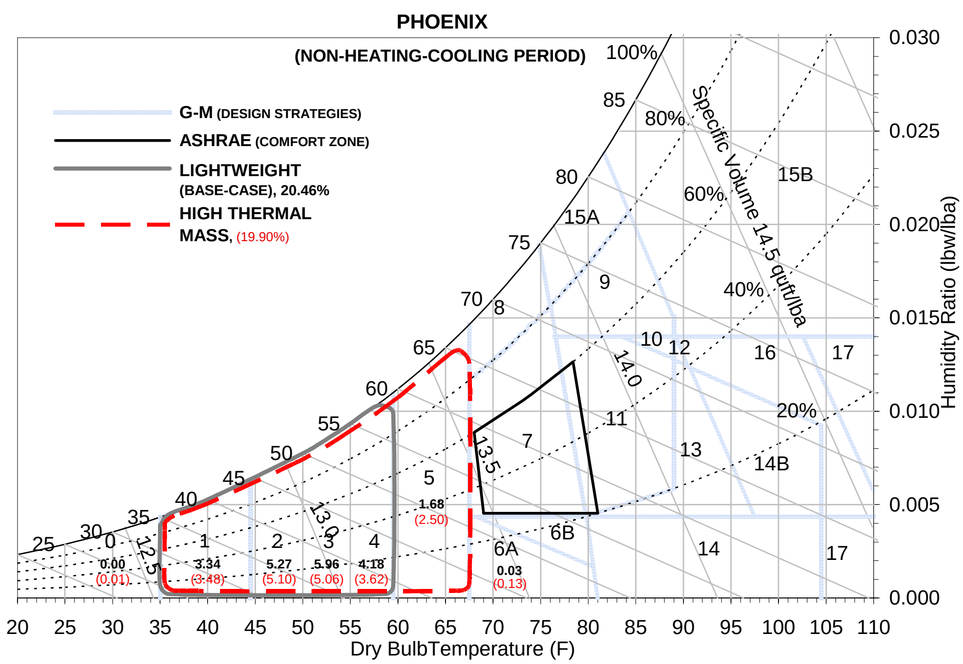


Figure 5.45 *Bioclimatic chart of the lightweight house (base case) and the high thermal mass house, during the non-heating-cooling period, in the hot-dry climate, Phoenix, Arizona.*

In Phoenix, Table 5.6 (upper part) shows that the heating hours-per-year of the lightweight house (base case) (2.30%) were very close to the heating hours of the high thermal mass house (2.05%). For both houses, the heating period regions included regions 0 and 1 (conventional heating and active solar). For region 1, although the percentages of the heating hours-per-year were less in the heating period than in the non-heating-cooling period, they were the majority of data in the heating period (see also Figures 5.28 and 5.34). Therefore, region 1 was included in the heating period for both cases. In cooling period, Table 5.6 (middle part) shows that the cooling hours in the year of the lightweight house (base case) (77.25%) were very close to the high thermal mass house (78.08%). For both houses, the regions with the majority of the hours-per-year in the cooling period included region 4, and all other regions to the right of region 4 (see Section 5.3.4.1).

In the non-heating-cooling period, Table 5.6 (lower part) shows that there were 20.46% of the hours-per-year for the lightweight house (base case) and 19.90% of the hours-per-year for the high thermal mass house in Phoenix. For the lightweight house (base case), the regions with the majority of the hours-per-year in the non-heating-cooling period included regions 1 through 4 (see Section 5.3.4.1). For the high thermal mass house, the regions with the majority of the hours-per-year in the non-heating-cooling period included regions 1 through 5 (active solar, passive solar, and internal gains). Figure 5.45 shows boundaries of the non-heating-cooling regions for the lightweight house (base case) and the high thermal mass houses in Phoenix. Each boundary covered the regions with the majority of the hours-per-year were in the non-heating-cooling period.

5.3.4.4 Lightweight house (base case) versus lightweight house with an economizer in Houston and San Francisco

The DOE-2 simulation results of the lightweight house (base case) and the lightweight house with an economizer in Houston and San Francisco were compared. In Houston, Table 5.6 (upper part) shows that the heating hours in the year of the lightweight house (base case) (8.43%) were less than the heating hours in the year of the lightweight house with an economizer (10.05%). For the lightweight house (base case) (see Section 5.3.4.1) and the lightweight house with an economizer, the regions with the majority of the hours-per-year in the heating period included regions 0 and 1 (conventional heating and active solar). In cooling period, Table 5.6 (middle part) shows that the cooling hours in the year of the houses in Houston were 74.17% for the lightweight house (base case) and 65.36% for the lightweight house with an economizer. For both houses, the regions with the majority of the hours-per-year in the cooling period included region 5, and all other regions to the right of region 5 (see Section 5.3.4.1).

In the non-heating-cooling period, Table 5.6 (lower part) shows that there were 17.40% of the hours-per-year for the lightweight house (base case) and 24.59% of the hours-per-year for the lightweight house with an economizer in Houston. For the lightweight house (base case), the regions with the majority of the hours-per-year in the non-heating-cooling period included regions 2 through 4 (see Section 5.3.4.1). For lightweight house with an economizer, the regions with the majority of the hours-per-year in the non-heating-cooling period included regions 2 through 5 (passive solar and internal gains). Figure 5.46 shows boundaries of the non-heating-cooling regions for the lightweight house (base case) and the lightweight house with an economizer in Houston. Each boundary covered the regions with the majority of the hours-per-year were in the non-heating-cooling period.

In San Francisco, Table 5.6 (upper part) shows that the heating hours in the year of the lightweight house (base case) (33.57%) were less than the heating hours in the year of the lightweight house with an economizer (36.96%). For the lightweight house (base case) (see Section 5.3.4.1) and the lightweight house with an economizer, the regions with the majority of the hours-per-year in the heating period included regions 0 through 3 (conventional heating, active solar, and passive solar). In cooling period, Table 5.6 (middle part) shows that the cooling hours of the lightweight house (base case) (13.23%) were more than the cooling hours in the year of the lightweight house with an economizer (9.23%). For both houses, the regions with the majority of the hours-per-

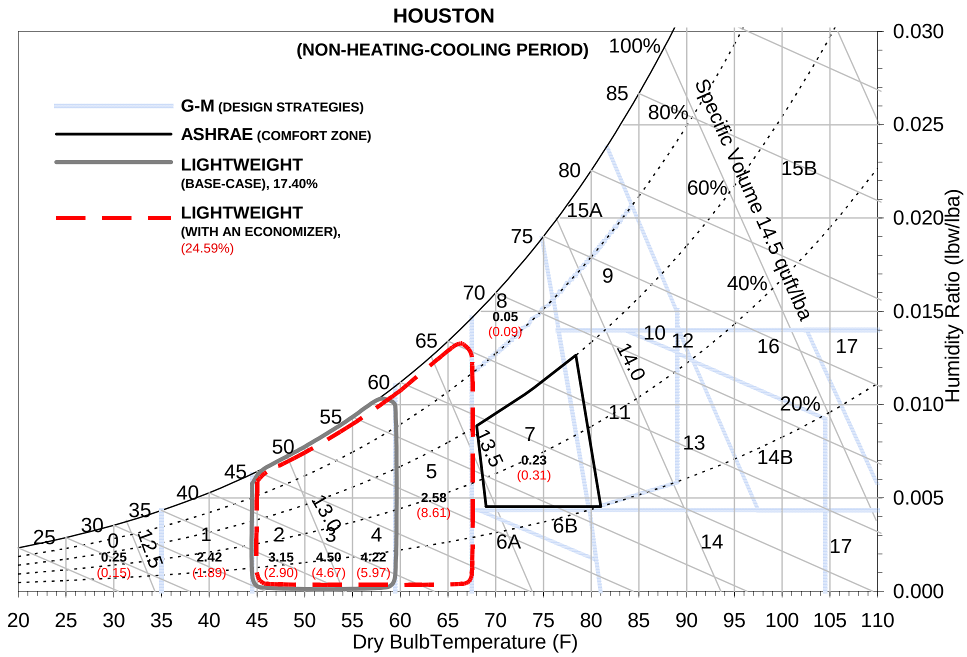


Figure 5.46 *Bioclimatic chart of the lightweight house (base case) and the lightweight house with an economizer, during the non-heating-cooling period, in the hot-humid climate, Houston, Texas.*

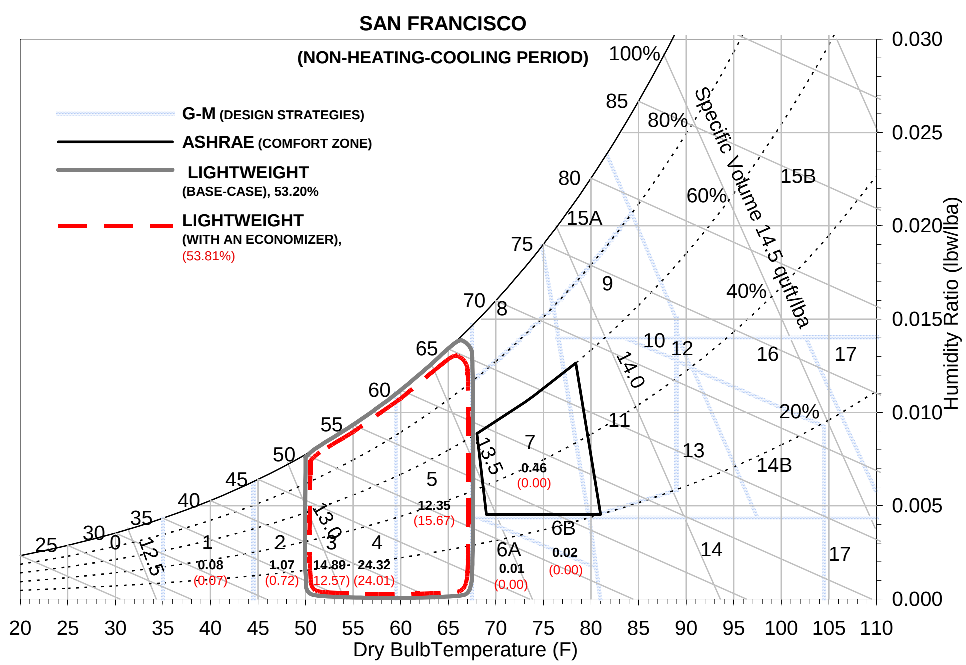


Figure 5.47 *Bioclimatic chart of the lightweight house (base case) and the lightweight house with an economizer, during the non-heating-cooling period, in the warm-marine climate, San Francisco, California.*

-year in the cooling period included region 5, and all other regions to the right of region 5 (see Section 5.3.4.1).

In the non-heating-cooling period, Table 5.6 (lower part) shows that there were 53.20% of the hours-per-year for the lightweight house (base case) and 53.81% of the hours-per-year for the lightweight house with an economizer in San Francisco. For the lightweight house (base case) and the lightweight house with an economizer, the regions with the majority of the hours-per-year in the non-heating-cooling period included regions 3 through 5 (see Section 5.3.4.1). Figure 5.47 shows boundaries of the non-heating-cooling regions for the lightweight house (base case) and the lightweight house with an economizer in San Francisco. Each boundary covered the regions with the majority of the hours-per-year were in the non-heating-cooling period.

5.3.5 Summary of the Comparison of the Results

The comparison of the results from Sections 5.1 to 5.2 and Appendix D, which were discussed and compared, included the indoor and outdoor conditions (Section 5.3.1), the annual energy use (Section 5.3.2), the DOE-2 simulation results versus the G-M Chart analysis results (Section 5.3.3), and the DOE-2 simulations results for all sites (Section 5.3.4).

Section 5.3.1, the comparison of the indoor and outdoor conditions, showed that the ranges of the outdoor temperature and the relative humidity for the whole year were narrow in Bangkok (very hot-humid climate) and San Francisco (warm-marine climate) and were wide in Houston (hot-humid climate), Phoenix (hot-dry climate), Chicago(cool-humid climate), Boston (cool-humid climate), and Boise (cool-dry climate); where the ranges of the outdoor temperature and the relative humidity were widest. In Bangkok, the majority of the outdoor conditions covered the area above and to the right of the comfort zone. In Houston, Boston, and Chicago, the majority of the outdoor conditions covered the comfort zone and were spread-out to left and the right above the 20% relative humidity line. In Phoenix and Boise, the majority of the outdoor conditions covered the comfort zone and were spread-out horizontally to the left and the right covering the area below the humidity ratio lines of 0.010 and 0.015 (lbw/lba) for Phoenix and Boise. In San Francisco, the majority of outdoor conditions covered the comfort zone and the area to the left of the comfort zone above 20% relative line where the frequencies of the occurrences were significantly high. For other sites, the frequencies of the occurrences were high at the area above and to the right of the comfort zone for Bangkok, above the comfort zone for Houston, and along the 0.005 (lbw/lba) humidity ratio lines to the left and the right of the comfort zone for Phoenix. In Chicago, Boston, and Boise, the frequencies of the occurrences were high at the lower temperatures area.

In Section 5.3.1, the indoor temperatures of all sites stayed or fluctuated between the heating and cooling temperature set-points of 68 °F through 78 °F, which corresponded to the activation of the heating or cooling systems. The indoor temperature and relative humidity was very well maintained when the cooling system was continuously activated. The fluctuation of the indoor temperature was less for the high thermal mass house. Although the majority of the indoor relative humidity for all sites stayed in the humidity constraint of the comfort zone (above 60% relative humidity line and under 36 °F dewpoint line), there were many hours-per-year for many sites that the indoor relative humidity was above or below the humidity constraint of the comfort zone.

Section 5.3.2 showed that the total annual energy uses of the lightweight house (base case) in the cool climates (Chicago, 173.8 MBtu; Boston, 174.4 MBtu; and Boise, 148.6 MBtu), which the large portion of the energy use was for space heating, were significantly higher than the total annual energy use in the very hot (Bangkok, 116.0 MBtu) and the hot (Houston, 108.1, MBtu; Phoenix, 100.0 MBtu) climates, where significant portion of the energy use for the house was for space cooling. The total annual energy use of the lightweight house (base case) was lowest in the warm-marine climate (San Francisco, 97.9 MBtu).

For the lightweight house with and without internal loads houses in Houston (Table 5.1), due to the removal of the internal heat sources (people, equipment, and lights), the total annual energy use of the lightweight house (base case) (108.1 MBtu) was higher than the total annual energy use of the lightweight house without internal loads (80.1 MBtu).

For the lightweight house (base case) and the high thermal mass houses in Houston and Phoenix. Table 5.1 showed that, in Houston, the total annual energy use of the high thermal mass house (100.8 MBtu) was less than the total annual energy use of the lightweight house (base case) (108.1 MBtu) in the same location, which the significant portion of the energy reduction was on the cooling energy use. For Phoenix, surprisingly, the total annual energy use for the high thermal mass house (100.2 MBtu) was slightly higher than the total annual energy use of the lightweight house (base case) (100.0 MBtu) (see discussion in the Section 5.3.2.3.).

For the lightweight houses (with and without an economizer) in Houston and San Francisco, although the lightweight house with an economizer could slightly reduce the energy use for cooling, it increased a portion of the energy use for heating (see discussion in the Section 5.3.2.2). Therefore, in Houston and San Francisco, the total annual energy use of the lightweight house with an economizer (109.6 MBtu, Houston; 102.1 MBtu, San Francisco) was more than the total annual energy use of the lightweight house (base case) (108.1 MBtu, Houston; 97.9 MBtu, San Francisco).

Section 5.3.3 showed the DOE-2 simulation results versus the G-M Chart analysis results, which included the results of the lightweight house (base case) in the seven selected climates, the lightweight house without internal loads in Houston, the high thermal mass house in Houston and Phoenix, and the lightweight house with an economizer in Houston and San Francisco.

For the lightweight house (base case) in the seven selected climates (Section 5.3.3.1, Table 5.2), during the heating period, the DOE-2 simulation results for Houston and Phoenix were slightly less than the G-M Chart analysis results. However, DOE-2 showed more heating hours in Chicago, Boston, and Boise than the G-M Chart showed. In San Francisco, the DOE-2 simulation results were significantly more than the G-M Chart analysis results. For all sites, except Bangkok which has no heating period, DOE-2 showed that the heating hours fell upon regions 0 (conventional heating); 1 (active solar); and 2 to 4 (passive solar), which were not usually considered to be heating periods in the G-M Chart analysis. In regions 0 and 1, the results from DOE-2 corresponded or very close to the G-M Chart results, except in Houston and Phoenix where DOE-2 showed less hours in the region 1 than the G-M Chart showed. In regions 2 to 4, DOE-2 showed a small portion of the heating hours in Houston and Phoenix and a significant portion of the heating hours in San Francisco, Chicago, Boston, and Boise.

In cooling period (Table 5.2) the DOE-2 simulation results for all sites were more than the G-M Chart results. The differences were slightly less in Bangkok but much difference in the other sites especially in Houston and Phoenix. DOE-2 showed that the cooling hours covered several regions from 1 through 17. The DOE-2 simulation results in regions 8 through 17 (humidification, ventilation, high thermal mass (with and without night ventilation), evaporative cooling, air-conditioning (with and without dehumidification) corresponded or were very close to the results from the G-M Chart analysis. However, DOE-2 showed significant portions of the cooling hours for several sites in regions 1 through 7 (active solar, passive solar, internal gains, dehumidification, the G-M comfort zone), which were not considered to be cooling periods in the G-M Chart analysis.

In the non-heating-cooling period, the DOE-2 simulation results for all sites were less than the results from the G-M Chart analysis. The differences were slightly less in Bangkok but significant differences in the other sites, where the most differences were in San Francisco. In Table 5.5, DOE-2 showed that the majority of the non-heating-cooling hours for all representative cities, except Bangkok which DOE-2 showed no hours in this period, falling upon regions 2 through 7 (passive solar, internal gains, humidification, and the G-M comfort zone) were significantly less than the G-M Chart analysis results. DOE-2 also showed a small portion of the non-heating-cooling hours of several sites were in regions 0 and 1 (conventional heating and active solar), which were not considered to be non-heating-cooling periods in the G-M Chart analysis.

For the lightweight house (base case) versus the lightweight house without internal loads in Houston (Table 5.2), the DOE-2 simulation results of the lightweight house (base case) during the heating period was slightly different from the G-M Chart results. However, for the lightweight house without internal loads, DOE-2 showed significantly less heating hours than the G-M Chart showed. The differences were in region 5 (internal gains), which the G-M Chart analysis consider to be a heating period. In addition, DOE-2 showed a small portion of the heating hours in regions 2 to 4 (passive solar), which the G-M Chart analysis did not consider to be heating periods. In the cooling period (Table 5.2), the DOE-2 simulation results of the lightweight house (base case) was significantly more than the G-M Chart results. However, for the lightweight house without internal loads, DOE-2 results were slightly more than the G-M Chart results. The differences were in regions 5 and 7 (internal gains and the G-M comfort zone). DOE-2 showed portions of the cooling hours in these regions (5 and 7), which were not considered cooling period in the G-M Chart analysis. In the non-heating-cooling period (Table 5.2), the DOE-2 simulation results of the lightweight house (base case) was significantly less than the G-M Chart results. However, the DOE-2 simulation results of the lightweight house without internal loads were very close to the G-M Chart results. In Table 5.5, DOE-2 showed that the non-heating-cooling hours in regions 2 to 4 (passive solar), 6 (humidification), and especially in region 7 (the G-M comfort zone) were less than the G-M Chart results. Conversely, DOE-2 showed a significant portion of the non-heating-cooling hours in region 5 (internal gains), which was considered to be a heating period in the G-M Chart analysis.

For the lightweight house (base case) versus the high thermal mass house in Houston and Phoenix, Table 5.2 showed that, for both locations, the DOE-2 simulation results of the lightweight house (base case) and the high thermal mass house during the heating period were close to the G-M Chart results for Houston and slightly less than the G-M Chart results for Phoenix. The differences were in regions 1 (active solar), 2 to 4 (passive solar), and 5 (internal gains) (see Table 5.3), where regions 2 through 5 were not usually considered heating periods in the G-M Chart analysis. In the cooling period

(Table 5.2), the DOE-2 simulation results of the lightweight house (base case) and the high thermal mass house in Houston were more than the G-M Chart results. In Phoenix, the DOE-2 simulation results for the both houses were significantly more than the G-M Chart results. Table 5.4 showed that the significant differences were in regions 5, 7, 11, and 13; where DOE-2 showed significant portions of the cooling hours for Houston and Phoenix in regions 5, 7, and 11 (internal gains, the G-M comfort zone, and high thermal mass) and a significant portion of the cooling hours in region 13 (high thermal mass) for the houses in Phoenix. Unfortunately, in the G-M Chart analysis, these regions (5, 7, 11, and 13) were not usually considered to be in the cooling period. In the non-heating-cooling period, Table 5.2 showed that the DOE-2 simulation results during the non-heating-cooling period for all sites were less than the G-M Chart analysis results. Significant differences were seen in the results for the houses in Phoenix. The DOE-2 simulation results of the high thermal mass house in Houston and Phoenix (Table 5.5) during the non-heating-cooling period were significantly less than the G-M Chart results. The significant different were in regions 2 through 7 (passive solar, internal gains, humidification, the G-M comfort zone) and 10 through 13 (high thermal mass) which the G-M Chart analysis were not usually considered to be in the non-heating-cooling period.

For the lightweight house (base case) versus the lightweight house with an economizer in Houston and San Francisco (Tables 5.2 to 5.3), DOE-2 showed that the results of the lightweight house (base case) and the lightweight house with an economizer during the heating period were very close to the G-M Chart results for Houston, but were significantly more than the G-M Chart results for San Francisco. The significant differences were in regions 2 to 4 and 5 (passive heating and internal gains) which the G-M Chart analysis did not consider to be in the heating period. In the cooling period, Table 5.2 showed that the DOE-2 simulation results of the lightweight house (base case) and the lightweight house with an economizer in Houston and San Francisco were more than the G-M Chart analysis results. In Table 5.4, DOE-2 showed a significant portion of the cooling hours in regions 5 through 7 (internal gains, humidification, and the G-M comfort zone), which were not considered to be cooling periods in the G-M Chart analysis. In the non-heating-cooling period, Table 5.2 showed that the DOE-2 simulation results of the lightweight house (base case) versus the lightweight house with an economizer in Houston and San Francisco were less than the G-M Chart analysis results, with the most significant differences in San Francisco. In Table 5.5, the DOE-2 simulation showed that the majority of the non-heating-cooling hours were in regions 2 through 7 (passive solar, internal gains, humidification, and the G-M comfort zone). Whereas, in the G-M Chart analysis, there were considered to be non-heating-cooling periods. Hence, DOE-2 results were significantly less than the G-M Chart analysis.

In Section 5.3.4, the DOE-2 simulation results for all sites (Table 5.6) showed the DOE-2 simulation results of the base-case house in Houston versus the results of other sites. In this table the majority of the hours of each region for each period, especially during the non-heating-cooling period, were addressed and presented upon the psychrometric charts (Figures 5.40 through 5.47).

For the lightweight house (base case) in the seven selected climates (Figures 5.40 through 5.42), DOE-2 showed that in the heating period (Figure 5.40) the majority of the heating hours for representative cities except Bangkok, where there were no hours in heating period, fell upon the area to the left of the comfort zone covering the regions from 0 through 3 (conventional heating, active solar, and passive solar design strategies). The results showed the majority of the hours-per-year of the regions in the heating period included; regions 0 and 1 (Houston and Phoenix), regions 0 through 2 (Boise), and regions 0 through 3 (San Francisco, Chicago, and Boston). In the cooling period (Figure 5.41), the majority of the cooling hours, which in Bangkok were 100% of the hours-per-year, covered the comfort zone and were spread-out to the left and the right of the comfort zone covering several regions from 4 through 17; which were passive solar, internal gains, humidification, ventilation, evaporative cooling, high thermal mass (with and without night ventilation), and air-conditioning (with and without dehumidification design strategies). The majority of the hours-per-year for each region in the cooling period covered region 4 (Bangkok and Phoenix), region 5 (Houston, San Francisco, Chicago, Boston, and Boise), and was spread-out to the right covering the other regions. In the non-heating-cooling period (Figure 5.42), the majority of the non-heating-cooling hours for the representative cities; except Bangkok, which has no non-heating-cooling hours, fell upon the area between heating and cooling period covering the area to the left of the comfort zone from regions 1 through 5 (conventional heating, active solar, passive solar, and internal gains design strategies). Finally, the majority of the hours-per-year of each region were in the non-heating-cooling period included regions 1 through 4 (Phoenix), regions 2 through 4 (Houston), regions 2 through 5 (Boise), and regions 3 through 5 (San Francisco, Chicago, and Boston).

For the lightweight house (base case) versus the lightweight house without internal loads in Houston, DOE-2 showed that the majority of the hours-per-year in the heating period included regions 0 and 1 (conventional heating and active solar) for the lightweight house (base case) and regions 0 through 3 (conventional heating, active solar, and passive solar) for the lightweight house without internal loads. For the lightweight house (base case), the regions with the majority of the hours-per-year in the cooling period included region 5 and all other regions to the right of region 5. For the lightweight house without internal loads, the regions with the majority of the hours-per-year in the cooling period included region 6 and all other regions above and to the right of region 6. In the non-heating-cooling period (Figure 5.43), the regions with the majority of the hours-per-year in this period included regions 2 through 4 (passive solar) for the lightweight house (base case) and regions 3 through 5 (passive solar and internal gains) for the lightweight house without internal loads.

When the lightweight house (base case) was compared to the high thermal mass house in Houston and Phoenix, the DOE-2 simulation results showed that in Houston the regions with the majority of the hours-per-year in the heating period included regions 0 and 1 (conventional heating and active solar). The regions with the majority of the hours-per-year in the cooling period included region 5 (internal gains) and other regions to the right of region 5 for both houses. In the non-heating-cooling period (Figure 5.44), the regions with the majority of the hours-per-year in the non-heating-cooling period included regions 2 to 4 (passive solar) for the lightweight house (base case) and regions 1 to 5 (active solar, passive solar, and internal gains) for the high thermal mass house.

In Phoenix, the regions with the majority of the hours-per-year in the heating period included regions 0 and 1 (conventional heating and active solar) for both houses. Although the majority of the hours-per-year in region 1 was not in the heating period, the percentages of hours-per-year in region 1 were the majority of the hours-per-year in the heating period. For both houses, the regions with the majority of the hours-per-year in the cooling period included region 4 and all other regions to the right of the region 4. In the non-heating-cooling period, (Figure 5.45), the regions with the majority of the hours-per-year in the non-heating-cooling period included regions 1 through 4 (active solar and passive solar) for the lightweight house (base case) and region 1 through region 5 (internal gains) for the high thermal mass house.

For the lightweight house (base case) versus the lightweight house with an economizer in Houston and San Francisco, DOE-2 showed that in Houston, the regions with the majority of the hours-per-year in the heating period included regions 0 and 1 (conventional heating and active solar) and the regions with the majority of the hours-per-year in the cooling period included region 5 (internal gains) and all other regions to the right of region 5 for both houses. In the non-heating-cooling period (Figure 5.46), the regions with the majority of the hours-per-year in the non-heating-cooling period included regions 2 through 4 (passive solar) for the lightweight house (base case) and regions 2 through 5 (passive solar and internal gains for the lightweight house (base case).

In San Francisco, for the lightweight house (base case) and the lightweight house with an economizer, the regions with the majority of the hours-per-year in the heating period included regions 0 through 3 (conventional heating, active solar, and passive solar) and the regions with the majority of the hours-per-year in the cooling period included region 5 (internal gains) and all other regions to the right of the region 5. In non-heating-cooling period, Figure 5.47 showed that the regions with the majority of the hours-per-year in the non-heating-cooling period included regions 3 through 5 (passive solar and internal gains) for both houses.

5.4 SUMMARY OF THE DATA ANALYSIS AND RESULTS

This chapter presented the results of the analysis of the TMY2 weather data for the hot-humid climate (Houston, Texas) (Sections 5.1); which included the data for dry-bulb temperature, relative humidity, solar, and wind. Several existing and new techniques were used for data analysis. The types of graphical display include: time series plots, x-y plots, three dimensional plots, psychrometric plots, bar charts, and tables. The results of the DOE-2 simulation and the G-M Chart analysis for the four prototype houses include the lightweight house (base case), the lightweight house without internal loads, the high thermal mass, and the lightweight house with an economizer in the seven selected climates, were presented in Section 5.2 and Appendix D. These results were discussed and compared in Section 5.3. The comparison of the results included: the indoor and outdoor conditions, the annual energy use, the DOE-2 simulation results versus the G-M Chart analysis results, and the results of the DOE-2 simulations for all sites, which were displayed upon the psychrometric charts and will be used to develop the design guidelines for the new bioclimatic chart for thermostatic-controlled residences in Houston, Texas (see Chapter VI).

An analysis of the hot-humid climate of Houston, Texas, (Section 5.1) showed a wide range of the dry-bulb temperatures and relative humidity, which were narrower in the summer than in the winter. The outdoor conditions covered the comfort zone and were widely spread-out above the 20% relative humidity line to the left and the right of the chart (i.e., from 14 to 97°F). During most of the year, which usually occurred at night, the relative humidity was above 80% relative humidity. As expected, the average global horizontal (GBH) solar radiation and the solar radiation availability were higher in summer than in the winter with the highest hourly average value was 325 Btu/ft^2-hour (i.e., occurred at solar noon in the summer) and 205 Btu/hr-ft^2 (i.e., occurred at solar noon in the winter). The annual global horizontal solar radiation of Houston was 513,026

Btu/ft^2-year (see Appendix E). The hottest hour of the day was usually around 2:00 p.m. The wind speed of Houston stayed below 35 mph, and was usually less than 20 mph. The average wind speed was higher in the daytime (8 to 12 mph) than at night (5 to 7 mph). The lowest average wind speed occurred a few hours before sunrise and the highest average wind speed occurred during a few hours after solar noon. The wind direction usually occurred from the south through the east. The frequency of the occurrence of the wind from the northwest to the southwest directions was low.

The results of the DOE-2 simulation and the G-M Chart analysis (Section 5.2 and Appendix D) were discussed and compared (Section 5.3). These results showed that the ranges of the annual outdoor temperature and the relative humidity were narrow in Bangkok and San Francisco, but were wide in Houston, Phoenix, Chicago, Boston, and Boise; respectively. In the psychromatric chart, the majority of the outdoor conditions of the seven selected climates covered the area from above and to the right of the comfort zone (Bangkok), the comfort zone with the area to the left above the 20% relative humidity line (San Francisco), the comfort zone with the areas to the left and the right above the 20% relative humidity line (Houston, Boston, and Chicago), and the comfort zone with the areas to the left and the right below the humidity ratio lines of 0.010 lbw/lba (Phoenix) and 0.015 lbw/lba (Boise).

For the lightweight house (base case), the total annual energy use of the house was lowest in San Francisco (97.9 MBtu). Due to the large portion of heating energy use of the house in the cool climates; the total annual energy uses of the house in Chicago (173.8 MBtu), Boston (174.4 MBtu), and Boise (148.6 MBtu) were significantly higher than the total annual energy use of the house in Bangkok (116.0 MBtu), Houston (108.1 MBtu), and Phoenix (100.0 MBtu); where the large portion of the energy use was for space cooling.

For the lightweight houses (with and without internal loads) in Houston, due to the removal of the internal heat sources (people, equipment, and lights), the annual energy use of the lightweight house (base case) (108.1 MBtu) was higher than the annual energy use of the lightweight house without internal loads (80.1 MBtu).

For the lightweight house (base case) and the high thermal mass houses in Houston and San Francisco, as expected, the total annual energy use of the high thermal mass house in Houston (100.8 MBtu) was less than the total annual energy use of the lightweight house (base case) in Houston (108.1 MBtu). In Phoenix, surprisingly, the total annual energy use for the high thermal mass house (100.2 MBtu) was slightly higher the total annual energy use of the lightweight house (base case) (100.0 MBtu) (see discussion in the Section 5.3.2.3.).

For the lightweight houses (with and without an economizer) in Houston and San Francisco, the total annual energy use of the lightweight house with an economizer in Houston (109.6 MBtu) and Phoenix (102.1 MBtu) were more than the total annual energy use of the lightweight house without an economizer in the same locations (Houston, 108.1 MBtu and Phoenix, 100.0 MBtu). This is more likely to inappropriate cold air brought in during the heating period (see discussion in the Section 5.3.2.2).

Comparing the G-M bioclimatic analysis to the DOE-2 simulation results, for the lightweight house (base case), the G-M heating and cooling design strategy regions (0 to 1 and 8 to 17) was close to the DOE-2 simulation results. For the non-heating-cooling period, the G-M passive solar regions (2 to 4) corresponded to the DOE-2 simulation results for Houston location. However, these regions were more likely to be shifted or expanded to the left and to the right due to the increased and decreased of solar radiation availability during the heating period. The discrepancies of the G-M chart analysis and the DOE-2 simulation results mostly were in the regions 5 through 7 (internal gains, humidification, and G-M comfort zone); which these regions, in the G-M bioclimatic analysis, were usually considered to be non-heating-cooling-periods. However, DOE-2 showed the needs of space cooling in these regions (5 to 7), which were more likely due the internal heat sources (i.e., occupants, equipment, and lights) and the mass and of the house.

For the lightweight house (with and without internal loads) in Houston, the non-heating-cooling period for the lightweight house (base case), included the G-M passive solar regions (2 through 4). However, these regions were shifted to the right covering the

G-M passive solar and internal gains regions (3 through 5) for the lightweight house without internal loads. In the other periods, the majority of the hours-per-year covered the regions to the left (heating period) and right (cooling period) of the non-heating-cooling period of each house.

When the lightweight house (base case) was compared to the high thermal mass house in Houston and Phoenix, DOE-2 showed that the non-heating-cooling period of the lightweight house (base case) in Houston included regions 2 to 4 (passive solar). However, for the high thermal mass house, the percentages of the hours-per-year in the non-heating-cooling period of these regions (2 to 4) decreased and were expanded to the left and right covering from regions 1 through 5 (active solar, passive solar, and internal gains). In the other periods, the majority of the hours-per-year covered the regions to the left (heating period) and right (cooling period) of the non-heating-cooling period of each house.

In Phoenix, the regions with the majority of the hours-per-year in the non-heating-cooling period included regions 1 through 4 (active solar and passive solar) for the lightweight house (base case). Similarity to the results in Houston, the percentages of the hours-per-year in the non-heating-cooling period were decreased in the regions 2 to 4, increased in region 1 (active solar), and expanded to cover the region 5 (internal gains). In the other periods, the majority of the hours-per-year covered the regions to the left (heating period) and right (cooling period) of the non-heating-cooling period of each house.

For the lightweight house (with and without an economizer) in Houston and San Francisco, DOE-2 showed that, for the lightweight house (base case) in Houston, the regions with the majority of the hours-per-year in the non-heating-cooling period included the regions 2 through 4 (passive solar). As expected, for the lightweight house with an economizer house in Houston, the percentages of the non-heating-cooling hours were reduced in region 2, but increased in regions 3 and 4, and expanded to cover regions 5 with the significant portion of the hours-per-year. During the other periods, the majority of the hours-per-year covered the regions to the left (heating period) and right (cooling period) of the non-heating-cooling period of each house.

For the lightweight house (with and without an economizer) in San Francisco, the DOE-2 simulation showed the regions with the majority of the non-heating-cooling hours in the regions 3 through 5 (passive solar and internal gains) for both houses. However, in regions 2 and 3, the percentages of the hours-per-year for the lightweight house (with an economizer) were slightly less than for the base-case house (without an economizer). In the region 5 (internal gains), the non-heating-cooling hours for the lightweight house (with an economizer) were slightly more than the base-case house. For each house, the majority of the heating hours-per-year covered the regions to the left of the non-heating-cooling period of the house and the majority of the cooling hours-per-year covered the regions to the left of the non-heating-cooling period of each house.

CHAPTER VI

DESIGN GUIDELINES FOR THE NEW BIOCLIMATIC CHART

The DOE-2 simulation results of the passive and active design strategies for the prototype house in the hot-humid climate (Houston, Texas) in Section 5.3.4 were analyzed and superimposed on the psychrometric chart. The potential design strategies in this study included: a lightweight house (base case), a lightweight house without internal loads, a high thermal mass house, and a lightweight house with an economizer. These houses were presented to show periods where the DOE-2 simulation required heating, cooling, or periods with non-heating-cooling. The results of these simulations also showed the need for humidification and dehumidification design strategies (see Appendix F), which will also be added in the new bioclimatic chart. Design guidelines for the new bioclimatic chart will be explained in Sections 6.1 through 6.9.

In Section 5.3.4, the design strategy boundaries were delineated according to the design strategy boundary lines of the G-M bioclimatic chart, which were described in the "*Climatic Design*" (Watson and Labs, 1983, p. 206) (see Figure 2.10). These design strategy boundaries were carefully modified and then combined with new design strategy boundaries in order to develop the new bioclimatic chart for the prototype thermostatically-controlled house in Houston, Texas. It is important to note that the design boundaries represent the majority of the data; therefore, they are not exact lines. Hence, these boundaries spread out or overlap with other design strategy regions.

6.1 LIGHTWEIGHT HOUSE (BASE CASE)

The lightweight house (base case) in this study was a traditional one-story, single-family house for two occupants with an area of 2,500 ft^2. The house consists of a conditioned living space, an unconditioned garage and a crawl space under the conditioned space. The roof, walls, and floor of the house are a wood stud structure. Each wall has an aluminum double pane low-e glazing window with 15% of external wall area (U-value = 0.75, SHGC = 0.4). The heating, ventilating, and air-conditioning

(HVAC) system is a single zone reheat system with a gas furnace and an electric reciprocating chiller. Although this type of system is more common in commercial buildings, it was necessary to use it for the residence, because the DOE-2 program would not display the interior humidity when using the RESYS system. The heating temperature setpoint was 68 °F (20.0 °C) and the cooling temperature setpoint was 78 °F (25.6 °C). Additional information of the lightweight base-case house can be found in Section 4.2.1.1.

In Figure 6.1, the boundary of Houston's outdoor conditions for the whole year is presented as three different periods (i.e., heating, cooling, and non-heating-cooling periods). The blue, red, and green lines indicate the boundaries of the outdoor conditions for the lightweight house (base case) during the heating, cooling, and non-heating-cooling periods; respectively. The ASHRAE comfort zone (ASHRAE, 1992) is presented in black lines. The boundary of the non-heating-cooling period, where the DOE-2 simulation showed comfort conditions could be maintained without heating or cooling, covers the area above the 20% relative humidity line from 45 °F (7.2 °C) through 60 °F (15.6 °C) dry-bulb temperatures. The boundary of the outdoor conditions during the heating period covers the area to the left of this non-heating-cooling period and the boundary of the outdoor conditions during the cooling period covers the area to the right of this non-heating-cooling period.

6.2 LIGHTWEIGHT HOUSE WITHOUT INTERNAL LOADS

The lightweight house without internal loads is similar to the base-case house except there are no internal loads (i.e., occupants, lights, and equipment). Additional information of the lightweight house without internal gains can be found in Section 4.2.1.2. In a similar fashion as Figure 6.1, Figure 6.2 presented the boundaries of the outdoor conditions for the lightweight house without internal gains during the heating (blue lines), cooling (red lines), and non-heating-cooling periods (green lines). The boundary of the non-heating-cooling period, where the DOE-2 simulation showed comfort conditions could be maintained without heating or cooling, covers the area

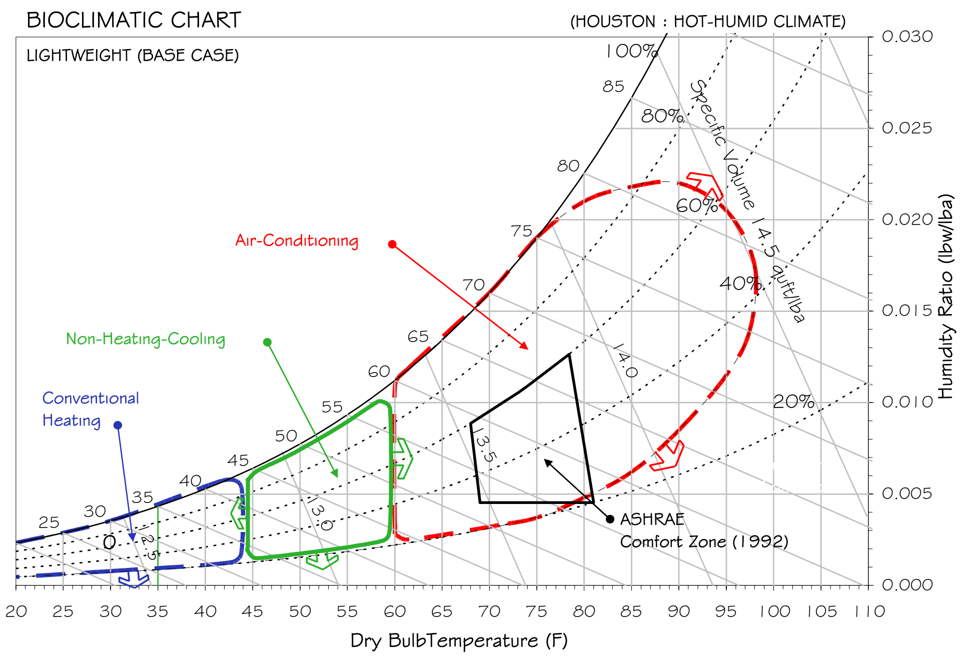


Figure 6.1 *Lightweight (base case) design strategy boundaries for the prototype house in the hot-humid climate, Houston, Texas.*

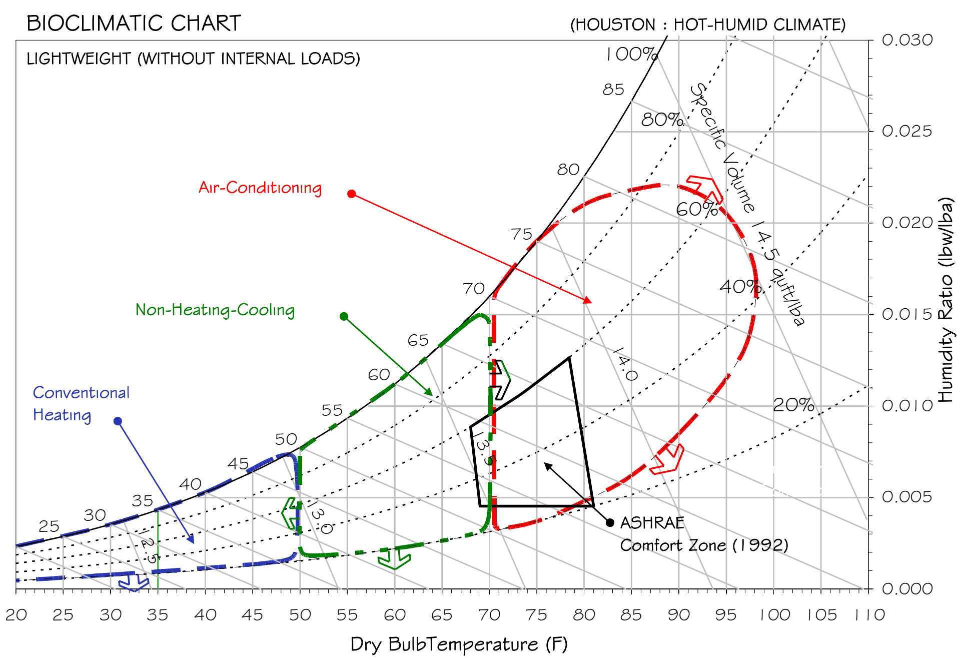


Figure 6.2 *Lightweight (without internal loads) design strategy boundaries for the prototype house in the hot-humid climate, Houston, Texas.*

above the 20% relative humidity line from 50 °F (10 °C) through 70 °F (21.1 °C) dry-bulb temperatures. The boundary of the outdoor conditions during the heating period covers the area to the left of this non-heating-cooling period and the boundary of the outdoor conditions during the cooling period covers the area to the right of this non-heating-cooling period.

Comparing Figure 6.1 to Figure 6.2, it is important to note that with the presence of the internal loads, the non-heating-cooling period of the lightweight house is shifted to the colder region, and reduces the percentages of the hours-per-year that occurs in this period from 25.7% to 17.4% (see details in Table 5.6). Therefore, the house without internal loads required heating during warmer outdoor periods and there is a delay in air conditioning until warmer periods.

6.3 HIGH THERMAL MASS HOUSE

The high thermal mass house is similar to the base-case house except the walls and floor of the house have been replaced with high mass materials. Additional information about the high thermal mass house can be found in Section 4.2.1.3. Similar to Figure 6.1, Figure 6.3 shows boundaries of the heating, cooling, and non-heating-cooling periods of the high thermal mass house in Houston, Texas. The boundary of the non-heating-cooling period, where the DOE-2 simulation showed comfort conditions could be maintained without heating or cooling, covers the area above the 20% relative humidity line from 40 °F (4.4 °C) through 67.5 °F (19.7 °C) dry-bulb temperatures. The boundary of the outdoor conditions during the heating period covers the area to the left of this non-heating-cooling period and the boundary of the outdoor conditions during the cooling period covers the area to the right of this non-heating-cooling period.

Comparing Figure 6.1 to Figure 6.3, it can be seen that with the high thermal mass, the frequency of the occurrences in the non-heating-cooling regions for the High thermal mass house is slightly increased. However, this non-heating-cooling boundary is expanded to the left and right covers the colder and warmer regions, which increases the

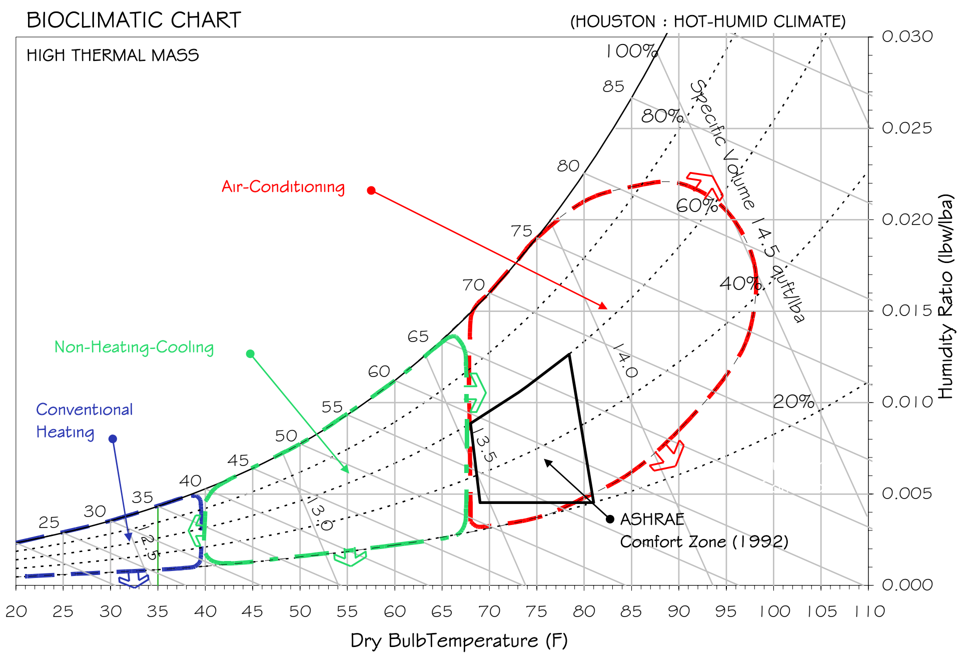


Figure 6.3 *High thermal mass design strategy boundaries for the prototype house in the hot-humid climate, Houston, Texas.*

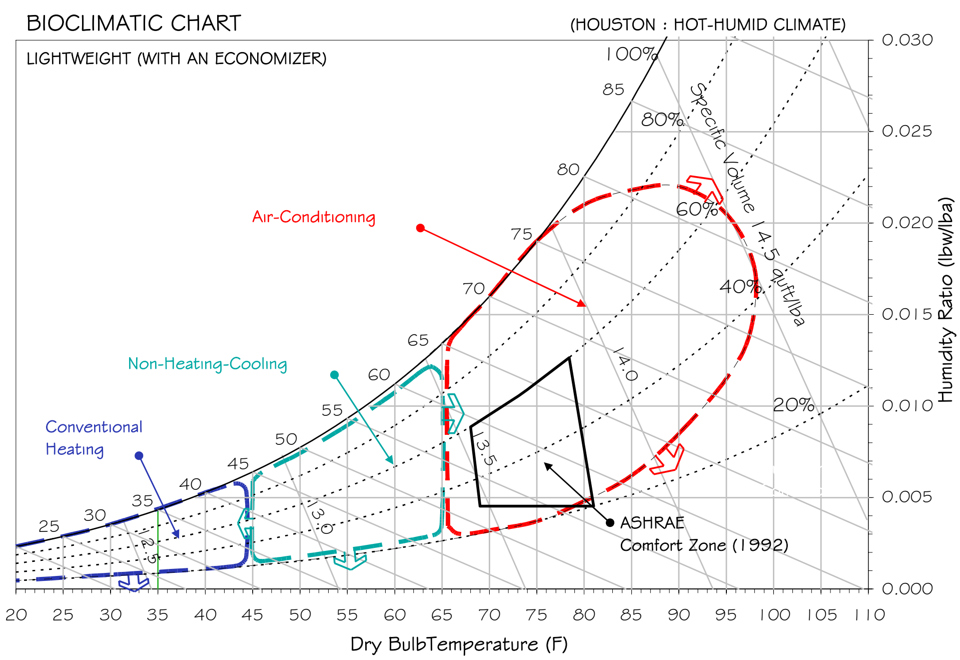


Figure 6.4 *Lightweight with an economizer design strategy boundaries for the prototype house in the hot-humid climate, Houston, Texas.*

percentages of the hours-per-year that occurs in this period from 17.4% to 22.5% (see details in Table 5.6).

6.4 LIGHTWEIGHT HOUSE WITH AN ECONOMIZER

The lightweight house with an economizer is similar to the base-case house except an economizer system was added. Additional information of the lightweight house with an economizer can be found in Section 4.2.1.4. Figure 6.4 showed boundaries of the heating, cooling, and non-heating-cooling periods of the lightweight house with an economizer in Houston, Texas. The boundary of the non-heating-cooling period, where the DOE-2 simulation showed comfort conditions could be maintained without heating or cooling, covers the area above the 20% relative humidity line from 45 °F (7.2 °C) through 65 °F (18.3 °C) dry-bulb temperatures. The boundary of the outdoor conditions during the heating period cover the area to the left of this non-heating-cooling period and the boundary of the outdoor conditions during the cooling period cover the area to the right of this non-heating-cooling period.

When Figure 6.1 is compared to Figure 6.4, as expected, the non-heating-cooling period of the lightweight house is expanded to the right (warmer region) covering the area where the outdoor conditions is cool enough to substitute for air-conditioning (i.e., slightly colder than the comfort conditions). The outdoor air brought in from this region can satisfy the cooling loads, which results in increased of the percentages of the non-heating-cooling hours-per-year from 17.4% to 24.6% (see details in Table 5.6).

6.5 HUMIDIFICATION

Appendix F showed the area of the outdoor conditions during the period that the indoor relative humidity was below the comfort zone (i.e., under 36 °F dewpoint line), which was when a humidification system should be active. In Figure 6.5, the outdoor conditions of the Houston location is presented in grey lines. The light blue lines in shows the boundary of the humidification design strategy for Houston, which covers the area under the 36 °F (2.2 °C) dewpoint line. Table F.1 shows that the need for

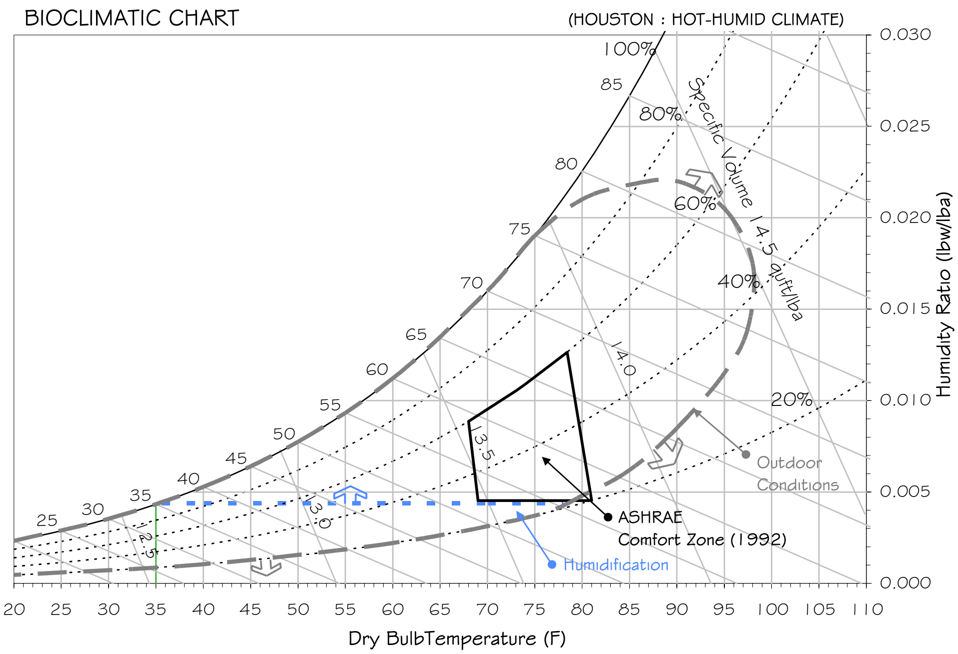


Figure 6.5 *Humidification design strategy boundaries for the prototype house in the hot-humid climate, Houston, Texas.*

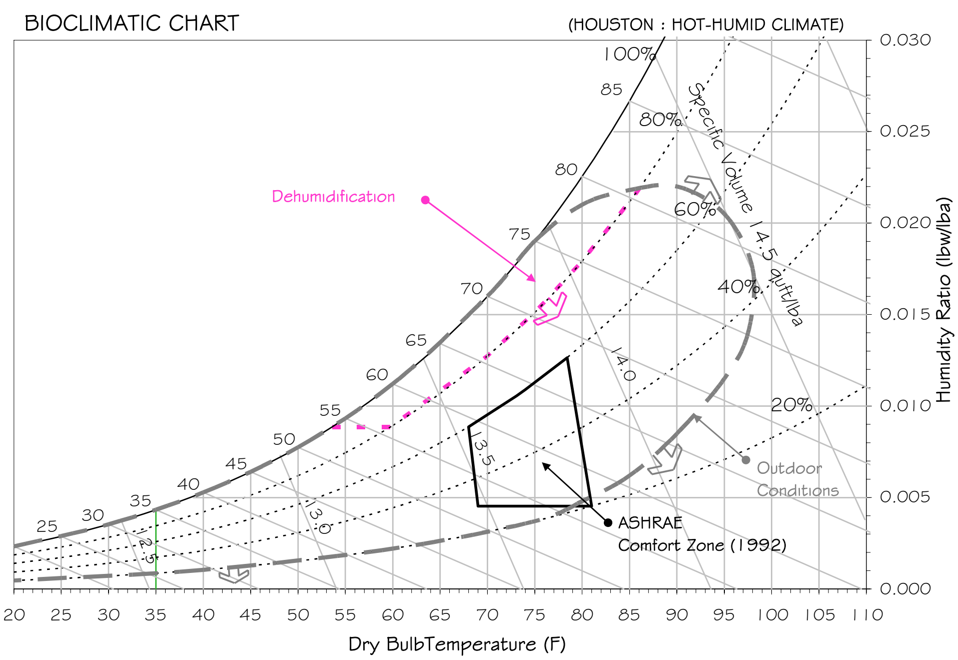


Figure 6.6 *Dehumidification design strategy boundaries for the prototype house in the hot-humid climate, Houston, Texas.*

humidification of the lightweight house (base case), the lightweight house without internal loads, the high thermal mass house, and the lightweight house with an economizer; were 7.1, 12.0, 7.0, and 7.4% of the hours-per-year; respectively.

The percentages of the hours-per-year when the humidification system is needed for each house is very similar except for the house without an internal loads where the percentages of the hours-per-year of this design strategy are slightly higher than the others. This is due to the removal of the humidity from the occupants.

6.6 DEHUMIDIFICATION

Appendix F showed the area of the outdoor conditions during the period that the indoor relative humidity was above the constraint of the comfort zone (above 60% RH), which was when a dehumidification system should be active. The pink line in Figure 6.6 shows the boundary the dehumidification design strategy for Houston, which covers the area above the 80% relative humidity line and the 54 °F (12.2 °C) dewpoint line. Table F.1 shows that the needs for dehumidification for the lightweight house (base case), the lightweight without internal loads house, the high thermal mass house, and the lightweight house with an economizer; were 8.8, 23.7, 12.6, and 14.8% of the hours-per-year, respectively.

The percentages of the hours-per-year, which show the need for dehumidification is lowest for the lightweight house (base case) and highest for the lightweight house without internal loads. This is most likely due to the activations of the air-conditioning system, which helps to remove moisture in the air. This also corresponds to DOE-2 simulation results of the percentages of the cooling hours-per-year, which is high for lightweight house without internal loads, but higher for the lightweight house with an economizer and the high thermal mass house, and highest for lightweight house (base case) (see Table 5.6).

6.7 CONVENTIONAL HEATING

For the lightweight house (base case) and the lightweight house with an economizer, conventional heating is needed when the outdoor conditions are below 45 °F (7.2 °C) dry-bulb temperature. This area of the conventional heating design strategy region is spread out to the left (colder region) to 40 °F (4.4 °C) dry-bulb temperature for the high thermal mass house and to the right (warmer region) to 50 °F (10 °C) dry-bulb temperature for the lightweight house without internal loads. The activations of the conventional heating system for the lightweight house (base case), the lightweight house without internal loads, the high thermal mass house, and the lightweight house with an economizer; were 8.4, 15.6, 8.6, and 10.0% of the hours-per-year; respectively (see Table 5.6).

Although the heating region of the high thermal mass house is colder than the lightweight house (base case), the heating hours-per-year of the high thermal mass house are slightly less than the heating hours-per-year of the lightweight house (base case). These percentages of the hours-per-year in the heating period increase for the lightweight house with an economizer. This is due to inappropriate cool air brought in during the heating period. For the lightweight house without internal loads, the percentages of the hours-per-year in this period increased significantly. This is due to the removal of internal heat sources (i.e., occupants, equipment, and lights).

6.8 AIR-CONDITIONING (WITH AND WITHOUT DEHUMIDIFICATION)

For the lightweight house (base case), the lightweight house with an economizer, the high thermal mass house, and the lightweight house without internal loads; air-conditioning (with and without dehumidification) are needed when the outdoor conditions are above 60, 65, 67.5, and 70 °F (15.6, 18.3, 19.7, and 21.1 °C) dry-bulb temperatures; respectively. The activations of the air-conditioning system for the lightweight (base case), the lightweight without internal loads, the high thermal mass, and the lightweight with an economizer; were 74.2, 58.7, 68.9, and 65.4% of the hours-per-year; respectively (see Table 5.6).

Comparing all cases, the percentages of the cooling hours-per-year of the lightweight house (base case) are the highest. Without internal heat loads, the percentages of the hours-per-year in this cooling period reduce dramatically. The high thermal mass as well as an economizer system helps to reduce the cooling hours substantially. The annual energy use for space cooling for the high thermal mass house (20.5 MBtu) is significantly less than the energy use for space cooling for the lightweight base-case house (25.3 MBtu) (see Table 5.1). However, when compare the annual energy use for space cooling of the lightweight base-case house to annual energy use for space cooling of the lightweight house with an economizer system (25.2 MBtu), the reduction is insignificant (see Table 5.1). This is due to the reduction of the cooling hours for the lightweight house with an economizer is mostly in region 5 (see Table 5.4), where the outdoor temperature is cool and the cooling loads are very small.

6.9 DESIGN GUIDELINES FOR THE NEW BIOCLIMATIC CHART FOR THE HOT-HUMID CLIMATE OF HOUSTON, TEXAS

The bioclimatic design guidelines suggested in Section 6.1 through 6.8 were summarized and graphically presented in Tables 6.1 and 6.2. The design strategy boundaries presented in the Figures 6.1 through 6.6 are combined and presented onto a psychrometric chart in Figure 6.7. This new bioclimatic chart (Figure 6.7) represents a traditional, thermostatically-controlled one-story, single-family house in the hot-humid climate of Houston, Texas. The new chart demonstrates boundaries of specific passive and active climate-controlled design strategies, which were tested in this study using simulation.

Table 6.1 shows identifications of each design strategy region corresponding to the regions presented in Table 6.2 and Figure 6.7. The first column is the region numbers with the definitions of each region, which described the outdoor conditions of each specific region, in the last column. Columns 2 through 5 show the effective design strategy regions for the four prototype houses in this study; which include the lightweight house (base case), the lightweight house without internal loads, the high

Table 6.1 *Identification of the regions in the building bioclimatic design strategies for residences in the hot-humid climate, Houston, Texas.*

<table>
<tr><th>Regions</th><th colspan="4">BIOCLIMATIC DESIGN STRATEGIES FOR RESIDENCES: HOT-HUMID CLIMATE (HOUSTON, TEXAS)</th><th>Definitions</th></tr>
<tr><td>0</td><td colspan="4">Conventional Heating</td><td>Tdb <40 °F</td></tr>
<tr><td>1</td><td>Conventional Heating</td><td rowspan="2">Conventional Heating</td><td rowspan="5">High Thermal Mass</td><td>Conventional Heating</td><td>40 °F ≤ Tdb <45 °F</td></tr>
<tr><td>2</td><td rowspan="2">Lightweight (base case)</td><td rowspan="3">Lightweight (with an economizer)</td><td>45 °F ≤ Tdb <50 °F</td></tr>
<tr><td>3</td><td rowspan="4">Lightweight
(without internal loads)</td><td>50 °F ≤ Tdb < 60 °F</td></tr>
<tr><td>4</td><td rowspan="3">Air-Conditioning</td><td>60 °F ≤ Tdb < 65 °F</td></tr>
<tr><td>5</td><td rowspan="2">Air-Conditioning</td><td>65 °F ≤ Tdb < 67.5 °F</td></tr>
<tr><td>6</td><td>Air-Conditioning</td><td>67.5 °F ≤ Tdb < 70 °F</td></tr>
<tr><td>7</td><td colspan="4">ASHRAE Comfort Zone (1992)</td><td>ET* = 68-79 °F, Tdp ≥36 °F, RH ≤60%</td></tr>
<tr><td>8</td><td colspan="4">Humidification</td><td>Tdp < 36 °F</td></tr>
<tr><td>9</td><td colspan="4">Dehumidification</td><td>RH >80%, Tdp > 54 °F</td></tr>
<tr><td>10</td><td colspan="4">Air-Conditioning</td><td>Tdb ≥ 70 °F</td></tr>
</table>

NOTE Tdb = Dry bulb temperature
Tdp = Dew point temperature
ET* = Effective Temperature Index
RH = Relative Humidity

Table 6.2 *Effectiveness of the building bioclimatic design strategies analysis for residences in the hot-humid climate, Houston, Texas.*

<table>
<tr><th rowspan="2">Regions</th><th colspan="2">Design Strategies
Effectiveness : hours-per-year (%)</th><th colspan="2">Conventional Heating</th><th colspan="2">Air-Conditioning</th><th colspan="2">Humidification</th><th colspan="2">Dehumidification</th></tr>
<tr><th>Regions</th><th>(hrs-per-year)</th><th>Regions</th><th>(hrs-per-year)</th><th>Regions</th><th>(hrs-per-year)</th><th>Regions</th><th>(hrs-per-year)</th></tr>
<tr><td>2-3</td><td>Lightweight (Base Case)</td><td>(17.4%)</td><td>0-1</td><td>8.4%</td><td>4-6, 10</td><td>74.2%</td><td>8</td><td>7.1%</td><td>9</td><td>8.8%</td></tr>
<tr><td>3-6</td><td>Lightweight without Internal Loads</td><td>(25.7%)</td><td>0-2</td><td>15.6%</td><td>10</td><td>58.7%</td><td>8</td><td>12.0%</td><td>9</td><td>23.7%</td></tr>
<tr><td>1-5</td><td>High Thermal Mass</td><td>(22.5%)</td><td>0</td><td>8.6%</td><td>6, 10</td><td>68.9%</td><td>8</td><td>7.0%</td><td>9</td><td>12.6%</td></tr>
<tr><td>2-4</td><td>Lightweight with an Economizer</td><td>(24.6%)</td><td>0-1</td><td>10.0%</td><td>5-6, 10</td><td>65.4%</td><td>8</td><td>7.4%</td><td>9</td><td>14.8%</td></tr>
</table>

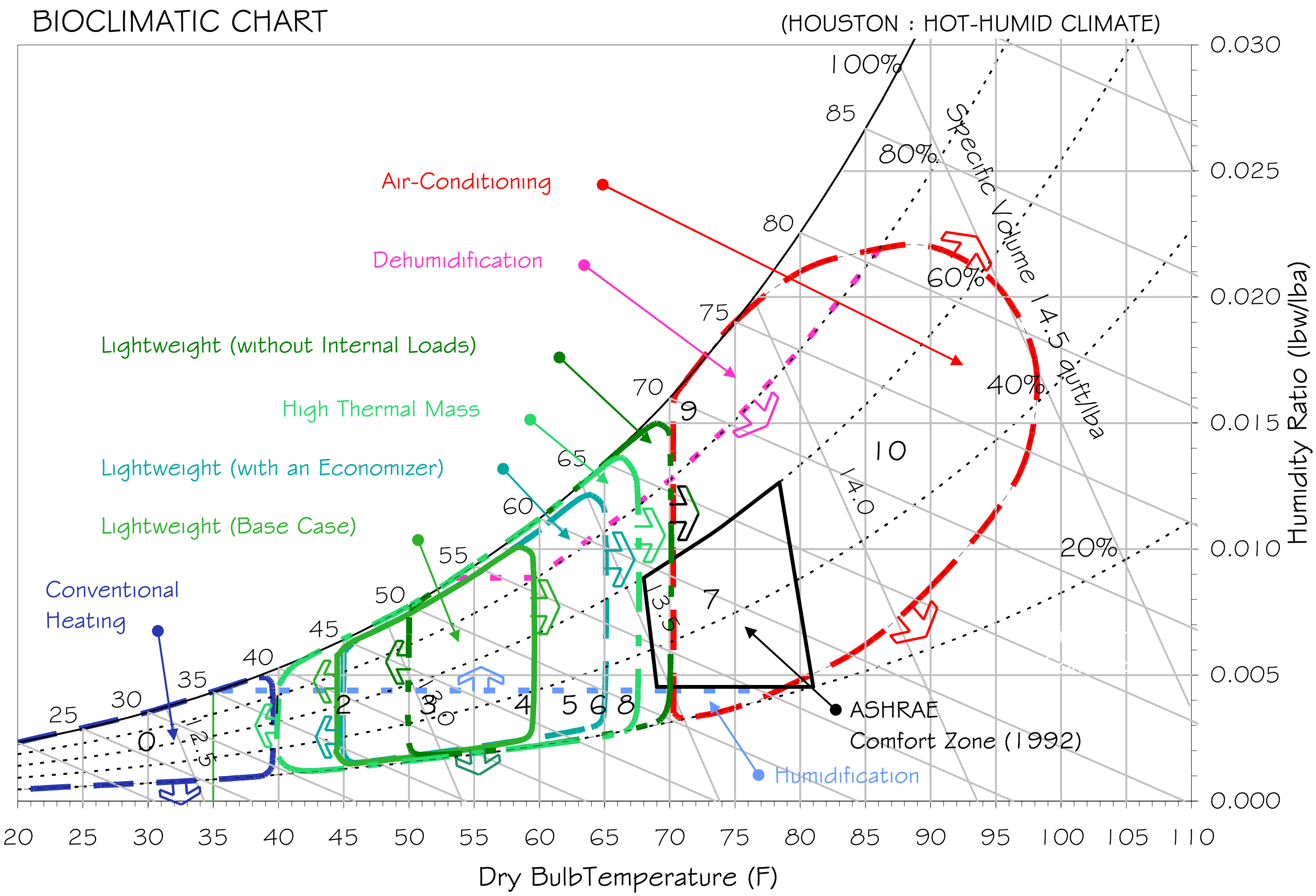


Figure 6.7 *The bioclimatic chart for thermostatically controlled residences in the hot-humid climate, Houston, Texas.*

thermal mass house, and the lightweight with an economizer house. The conventional heating design strategy, which covers regions from 0 to 2, is presented in dark blue. The green color in the regions 1 through 6 represents the non-heating-cooling regions, where the DOE-2 simulation showed that the indoor temperatures were maintained in the comfort conditions without using heating or cooling systems. Therefore, they are the effective regions of the design strategies used for each house. The orange color represents the air-conditioning design strategy, which covers from the regions 4 through 6 and 10. Regions 7 (grey), 8 (light blue), and 9 (pink) represent the regions of the ASHRAE comfort zone (1992), humidification, and dehumidification design strategies; respectively. It is important to note that parts of these three regions overlap with other regions. Descriptions of each region are as follows.

- Region 0 (conventional heating) covers the area when the outdoor dry-bulb temperatures (Tdb) are below 40 ºF (4.4 ºC). - Region 1 (conventional heating and high thermal mass) covers the area when the outdoor dry-bulb temperatures (Tdb) are above or equal to 40 ºF (4.4 ºC) and below 45 ºF (7.2 ºC).

- Region 2 (conventional heating, lightweight, high thermal mass, and lightweight with an economizer) covers the area when the outdoor dry-bulb temperatures (Tdb) are above or equal to 45 ºF (7.2 ºC) and below 50 ºF (10.0 ºC).

- Region 3 (lightweight with and without internal loads, high thermal mass, and lightweight with an economizer) covers the area when the outdoor dry-bulb temperatures (Tdb) are above or equal to 50 ºF (10.0 ºC) and below 60 ºF (15.6 ºC).

- Region 4 (lightweight without internal loads, high thermal mass, lightweight with an economizer, and air-conditioning) covers the area when the outdoor dry-bulb temperatures (Tdb) are above or equal to 60 ºF (15.6 ºC) and below 65 ºF (18.3 ºC).

- Region 5 (lightweight without internal loads, high thermal mass, and air-conditioning) covers the area when the outdoor dry-bulb temperatures (Tdb) are above or equal to 65 ºF (18.3 ºC) and below 67.5 ºF (19.7 ºC).

- Region 6 (lightweight without internal loads and air-conditioning) covers the area when the outdoor dry-bulb temperatures (Tdb) are above or equal to 67.5 ºF (19.7 ºC) and below 70 ºF (21.1 ºC).

- Region 7 (ASHRAE comfort zone, 1992) covers the area when the outdoor dry-bulb temperatures (Tdb) are in the range of 68 through 79 ºF (20.0 to 26.1 ºC) of the Effective Temperature Index (ET*), the outdoor dewpoint temperatures (Tdp) are above or equal to 36 ºF, and the outdoor relative humidity (RH) is above or equals to 60%.

- Region 8 (humidification) covers the area when the outdoor dewpoint temperatures (Tdp) are below 36 ºF (2.2 ºC).

- Region 9 (dehumidification) covers the area when the outdoor relative humidity (RH) is above 80% and the dewpoint temperatures (Tdp) are above 54 ºF (12.2 ºC).

- Region 10 (air-conditioning) covers the area when the outdoor temperatures are above or equal to 70 ºF (21.1 ºC).

Table 6.2 shows percentages of the effective hours-per-year of each bioclimatic design strategy corresponding to regions in Table 6.1 and the boundaries presented in the new bioclimatic chart (Figure 6.7). Tables 6.2 shows that, for the lightweight house (base case), the effective design strategy regions (non-heating-cooling period) of this house covers the regions from 2 to 3 with 17% of the hour-per-year. The conventional heating design strategy, with 8.4% of the hours-per-year, covers the region from 0 to 1; and the air-conditioning design strategy, with 74.2 % of the hour-per-year, covers the regions from 4 to 6 and 10. Humidification and dehumidification design strategies cover the regions 8 and 9, with 7.1 and 8.8% of the hours-per-year; respectively. As mentioned in the previous paragraph, the humidification and dehumidification design strategy regions are parts of the other regions. Therefore, the total percentages of the hours-per-year will be more than 100% if these design strategies are included.

For the lightweight house without internal loads, the effective design strategy regions (non-heating-cooling period) of this house covers the regions from 3 through 6 with 27.7% of the hour-per-year. The conventional heating design strategy, with 15.6% of the hours-per-year, covers the regions from 0 to 2. The air-conditioning design strategy, with 58.7% of the hour-per-year, covers the region 10. The humidification and dehumidification design strategies cover the regions 8 and 9, with 12.0 and 23.7% of the hours-per-year; respectively.

Table 6.2 shows that, for the high thermal mass house, the effective design strategy regions (non-heating-cooling period) of this house covers the regions from 1 through 5 with 22.5% of the hour-per-year. The conventional heating design strategy, with 8.6% of the hours-per-year, covers region 0. The air-conditioning design strategy, with 68.9% of the hour-per-year, covers regions 6 and 10. The humidification and dehumidification design strategies cover regions 8 and 9, with 7.0 and 12.6% of the hours per year; respectively.

In Table 6.2, the effective design strategy regions (i.e., non-heating-cooling period) of the lightweight house with an economizer covers regions from 2 through 4 with 24.6% of the hour-per-year. The conventional heating design strategy, with 10.0% of the hours-per-year, covers regions 0 to 1. The air-conditioning design strategy, with 65.4% of the hour-per-year, covers regions from 5 to 6 and 10. The humidification and dehumidification design strategies cover regions 8 and 9, with 7.4 and 14.8% of the hour-per-year; respectively.

Finally, Figures 6.1 through 6.6 were combined and presented in Figures 6.7 to create a new bioclimatic chart for thermostatically controlled residences in the hot-humid climate of Houston, Texas. Design guidelines of each design strategy; which include lightweight with and without internal loads, high thermal mass, lightweight with an economizer, humidification, dehumidification, conventional heating, and air-conditioning; are explained in Sections 6.1 to 6.8. Descriptions and identifications of each design strategy region (Tables 6.1 and 6.2) were described previously.

Figure 6.1 shows that, the outdoor conditions for the hot-humid climate of Houston, Texas, covers the area above the 20% relative humidity (RH) line and is spread-out widely from the colder temperature at 20 °F (-6.7 ºC) or lower to the warmer temperature, and reach the highest temperature at 97 °F (36.1 ºC).

The non-heating-cooling design strategy boundary of each house is presented in green lines. For the lightweight house without internal loads, the indoor thermal comfort is maintained within the 1992 ASHRAE comfort zone (region 7, black lines); when the outdoor conditions stay within regions 3 through 6. However, with the internal loads added to the lightweight house (base case), these regions (regions 3 to 6) are shifted to the left (colder temperature) covering regions 2 to 3. An economizer system helps this non-heating-cooling regions expand from regions 2 and 3 to the right (warmer temperature), which includes region 4. A high thermal mass design strategy, which has the ability to temper and delay both heating and cooling loads, affects the non-heating-cooling regions to be spread-out from the originate location to the left (colder temperature) and right (warmer temperature). Therefore, with the high thermal mass, the non-heating-cooling regions of the base-case house (regions 2 to 3) are expanded covering the regions from 1 through 5.

The conventional heating design strategy (in dark blue lines) is needed when the outdoor temperatures falls within the colder temperatures (i.e., the right of the non-heating-cooling regions of each house). This conventional heating region is expanded from region 0 (for the high thermal mass house) to region 1 (for the lightweight house with and without an economizer) and region 2 (for the lightweight house without internal loads).

The air-conditioning design strategy (in red lines) is needed when the outdoor temperatures fall within the warmer temperatures of the non-heating-cooling regions of each house. This air-conditioning region is expanded from region 10 (for the lightweight house without internal loads) to region 6 (for the high thermal mass house), region 5 (for the lightweight house with an economizer) and region 2 (for the lightweight house, base case).

For all cases, the humidification design strategy is needed when the humidity ratio of the outdoor conditions is very low (i.e., region 8, below the light blue line). In contrast, dehumidification is required, when the relative humidity of the outdoor conditions are high (i.e., region 9, above the pink lines).

6.10 COMPARISON OF THE NEW BIOCLIMATIC CHART AND THE G-M BIOCLIMATIC CHART

Comparing the new bioclimatic chart for the thermostatically-controlled houses to the traditional Givoni-Milne bioclimatic chart (1979) (Figure 1.2), each design strategy boundary of both charts is compared and discussed as follows. For this analysis, the detailed description and delineations of the G-M design strategy boundaries, presented in the “Climatic Design” by Watson and Labs (1983, p. 206) (see Figure 2.10, Table 2.1, and Figure 4.12) were used.

a) The G-M conventional heating region and active solar regions cover the area from 20 ºF (-6.7 ºC) or lower to 44.5 ºF (6.9 ºC) dry-bulb temperatures (see Figure 6.8). This is very close to the conventional heating region of the new bioclimatic chart, which covers the area from 20 ºF (-6.7 ºC) or lower to 40 ºF (4.4 ºC) dry-bulb temperatures for the high thermal mass house and is expanded to 50 ºF (10 ºC) dry-bulb temperatures for the lightweight house without internal loads.

b) For the passive solar region, In the G-M passive solar region (see Figure 6.9), the outdoor dry-bulb temperatures fall within the area from 44.5 ºF to 59.5 ºF (6.9 ºC to 15.3 ºC). The passive solar design strategy is considered as using south-facing glass with appropriate floor area and thermal mass to collect and distribute solar heating energy. Although the passive solar design strategy was not simulated in this study; in the new bioclimatic chart, this region is noticed to be slightly different from the non-heating-cooling period region of the lightweight house (base case), which covers the area from 45 ºF to 60 ºF (7.2 ºC to 15.6 ºC) dry-bulb temperatures. It appears that the non-heating-cooling period of the lightweight house (base case) in this study was a result from a combination of the internal heat loads, the solar radiation availability, and the mass of the house, which was well-insulated and has a larger floor area and a smaller percentages of south-facing glass than that of the G-M passive solar house (see Section 2.3.2).

c) For the internal loads design strategy region, the G-M chart shows that this region covers the area from 59.5 ºF to 67.5 ºF (15.3 ºC to 19.7 ºC) dry-bulb temperatures (see Figure 6.10); which means, when the outdoor temperatures fall within this region, a

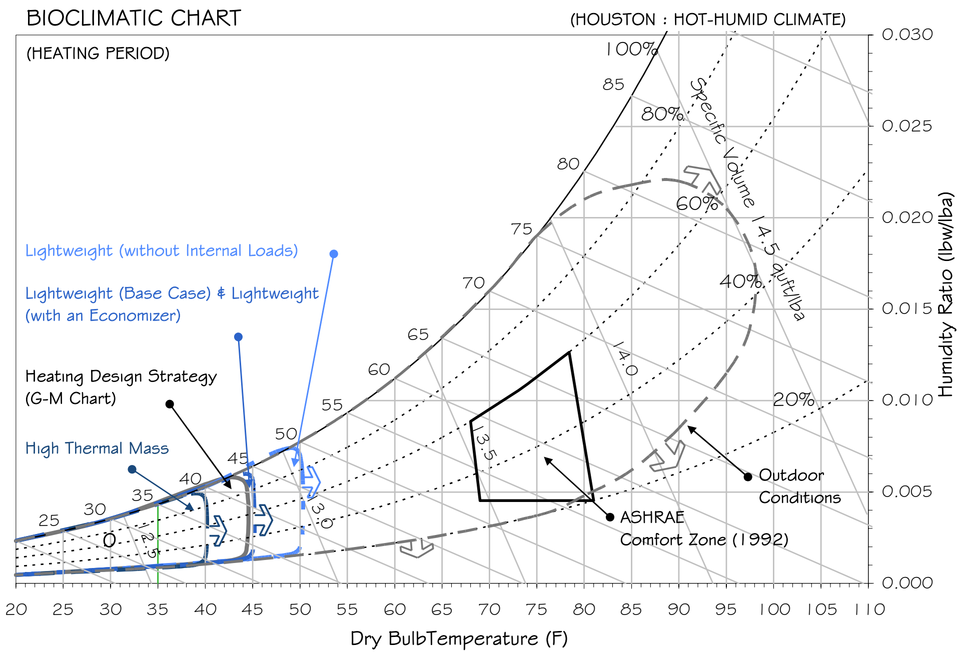


Figure 6.8 *Comparison of the G-M heating design strategy boundary and the prototype houses in the hot-humid climate, Houston, Texas, during the heating period.*

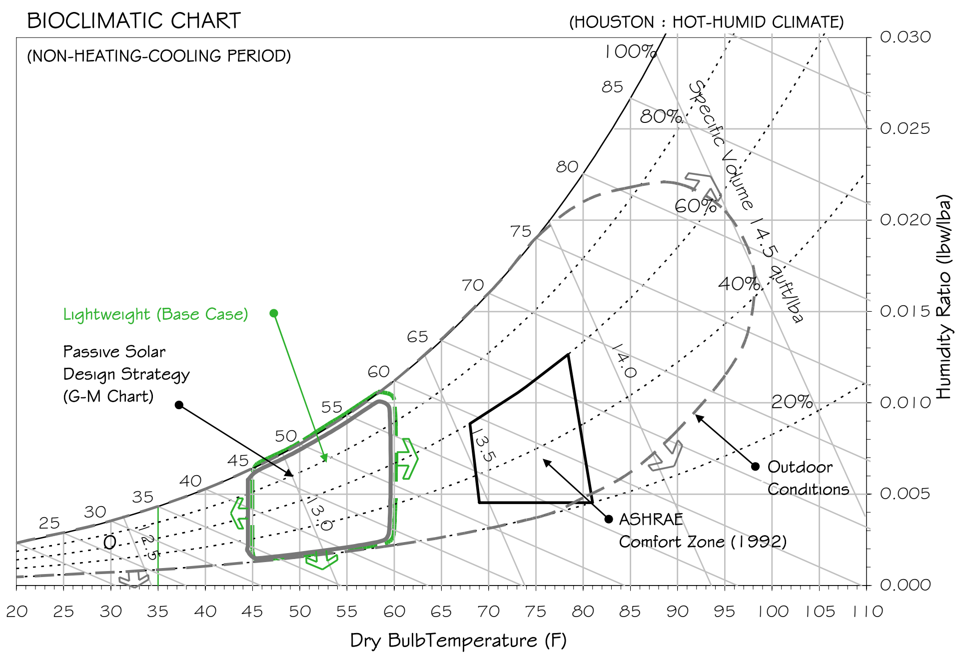


Figure 6.9 *Comparison of the G-M passive solar design strategy boundary and the prototype house (lightweight, base case) in the hot-humid climate, Houston, Texas, during the non-heating-cooling period.*

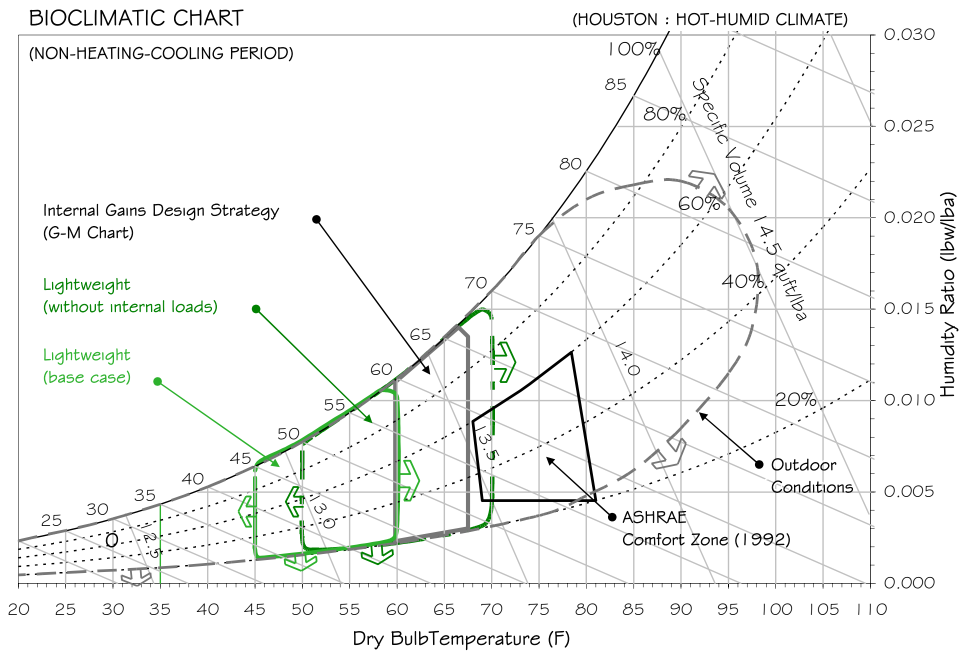


Figure 6.10 *Comparison of the G-M internal gains design strategy boundary and the prototype houses (lightweight, base case, and lightweight without internal loads) in the hot-humid climate, Houston, Texas, during the non-heating-cooling period.*

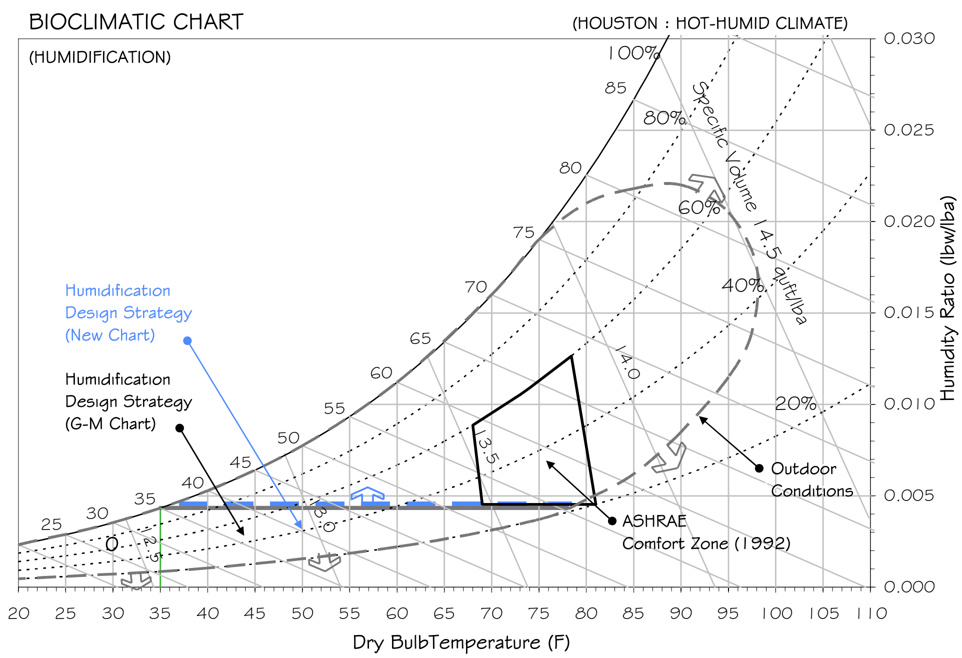


Figure 6.11 *Comparison of the G-M humidification design strategy boundary and the new bioclimatic chart humidification design strategy boundary for the prototype houses in the hot-humid climate, Houston, Texas.*

heating design strategy is needed. The indoor comfort condition can be achieved with internal heat loads (i.e., heat sources from occupants, lights, and equipments). However, in the new bioclimatic chart, this region is considered as a cooling period, where air-conditioning is needed for the lightweight house (base case). In addition, in order to achieve thermal comfort when the outdoor conditions are in this region, an economizer or high thermal mass design strategies are recommended in the new bioclimatic chart. The new bioclimatic chart also shows that, with the internal loads, the non-heating-cooling region of the lightweight house is shifted to the colder regions, which is from the 50 ºF through 70 ºF (10 ºC through 21.1 ºC) dry-bulb temperatures to 45 ºF through 60 ºF (7.2 ºC through 15.6 ºC) dry-bulb temperatures.

d) In the G-M Chart, humidification is needed when the outdoor conditions fall below 34 ºF (1.1 ºC) dewpoint temperature (i.e., 5 mmHg or 0.004 lbw/lba humidity ratio) (see Figure 6.11). This corresponds approximately to the new bioclimatic chart, which shows the needs of humidification in the region with the outdoor conditions are below 36 ºF (2.2 ºC) dewpoint temperature (5.4 mmHg, 0.0045 lbw/lba humidity ratio).

e) In the G-M Chart, dehumidification is needed when the outdoor conditions are above 67.5 ºF (19.4 ºC) dry-bulb temperature and 80% relative humidity (RH) or above 67 ºF (19.4 ºC) dewpoint temperature (17 mmHg, 0.014 lbw/lba humidity ratio) (see Figure 6.12). This is similar to the new bioclimatic chart, except the lower limit of the G-M dehumidification region is higher than the lower limit of the dehumidification region in the new bioclimatic chart, which shows the need for dehumidification in the region where the outdoor conditions are above 54 ºF (12.2 ºC) dewpoint temperature (10.6 mmHg, 0.009 lbw/lba humidity ratio) and the relative humidity (RH) is above 80%. In the new bioclimatic chart, dehumidification is not included in the area with humidity ratio above 54 ºF (12.2 ºC) dewpoint temperature and the relative humidity below 80%, due to the indoor comfort conditions can be maintained within the humidity constraint of the comfort zone using air-conditioning recommended in this region.

f) The ASHRAE comfort zone, 1992, was used to evaluate indoor comfort conditions in this study (see Figure 6.13). The region of the G-M comfort zone is very

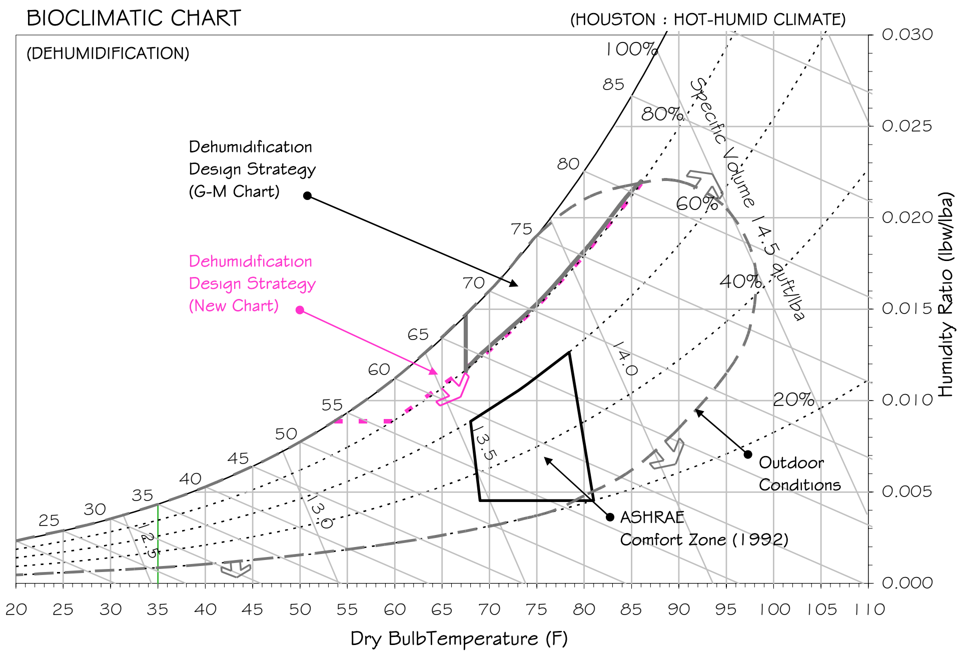


Figure 6.12 *Comparison of the G-M dehumidification design strategy boundary and the new bioclimatic chart dehumidification design strategy boundary for the prototype houses in the hot-humid climate, Houston, Texas.*

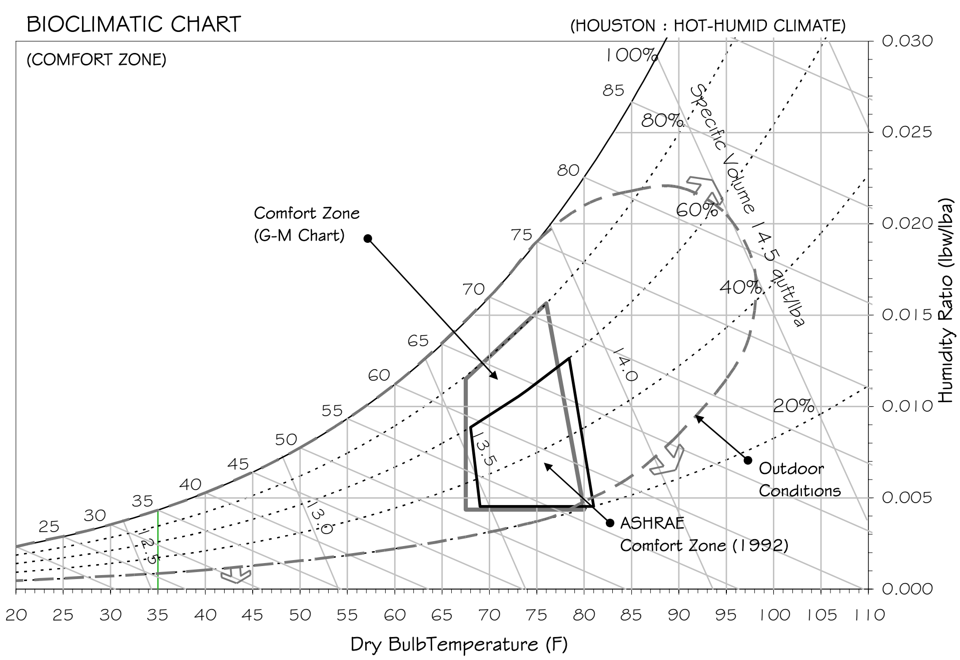


Figure 6.13 *Comparison of the G-M comfort zone and the ASHRAE comfort zone (1992).*

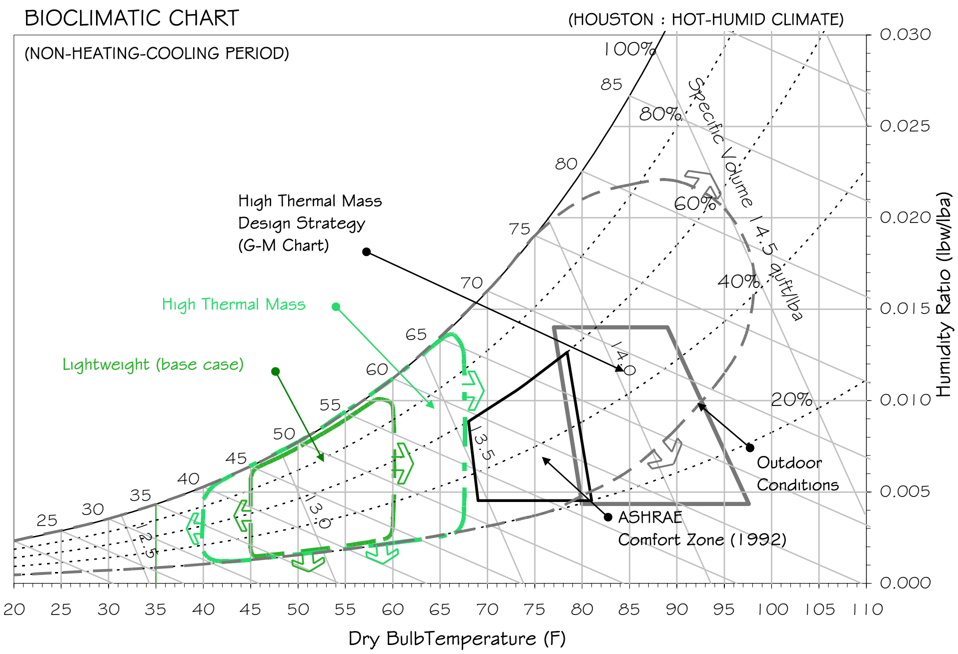


Figure 6.14 *Comparison of the G-M high thermal mass design strategy boundary and the prototype houses (lightweight, base case, and high thermal mass) in the hot-humid climate, Houston, Texas, during the non-heating-cooling period.*

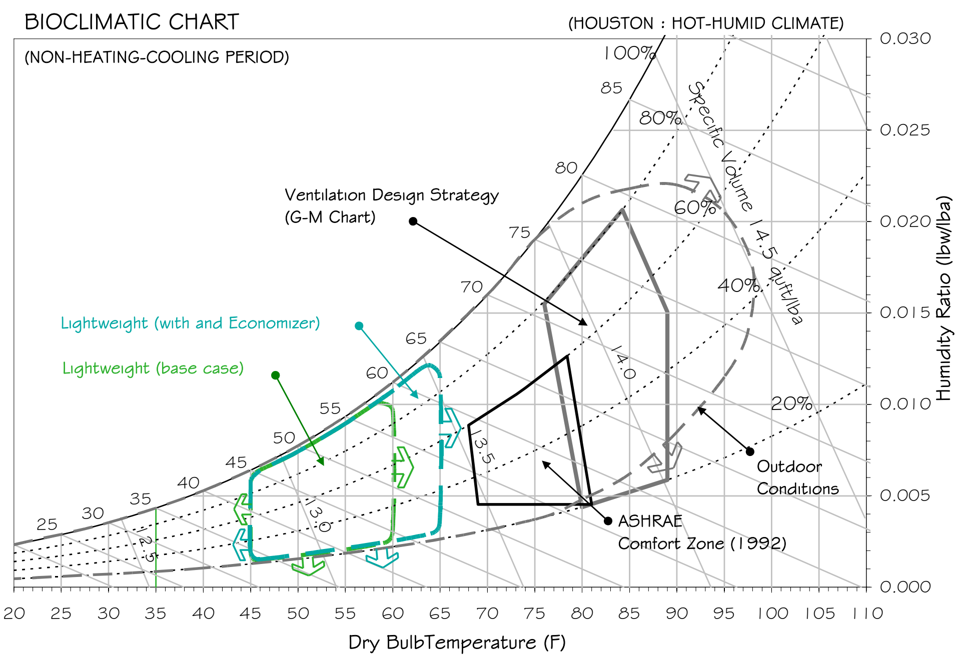


Figure 6.15 *Comparison of the G-M ventilation design strategy boundary and the prototype houses (lightweight, base case, and lightweight with an economizer) in the hot-humid climate, Houston, Texas, during the non-heating-cooling period.*

close to the region of the ASHRAE comfort zone, except the upper humidity constraints of the G-M comfort zone is at 80% relative humidity (RH), while the upper humidity limits of the ASHRAE comfort zone (1992) is at 60% relative humidity (RH). In the G-M chart, the comfort zone is the non-heating-cooling period (see bioclimatic needs analysis, region 7, Table 2.1). However, the new bioclimatic chart shows that the houses need cooling (air-conditioning design strategy), when the outdoor conditions are within the ASHRAE comfort zone.

g) For the high thermal mass design strategy, in the G-M Chart, the region covers the area to the right of the G-M comfort zone, which is the area below 67 ºF (19.4 ºC) dewpoint temperature (17 mmHg or 0.014 lbw/lba) and above 34 ºF (1.1 ºC) dewpoint temperature (5 mmHg or 0.004 lbw/lb humidity ratio) from 78 °F effective temperature index (ET*) to the right to 14.15 ft^3/lb specific volume line (see Figure 6.14). This region, in the G-M Chart, is expanded to the right with night ventilation design strategy, which was not included in this study. In the new bioclimatic chart, the G-M high thermal mass region is in the cooling period where air-condition design strategy is required. The new bioclimatic chart shows that with the high thermal mass, the non-heating-cooling region of the base-case house is tempered and extended to the colder region at the left (i.e., from 45 ºF to 40 ºF, 7.2 ºC to 4.4 ºC) as well as to the warmer region at the right (i.e., from 60 ºF to 67.5 ºF, 15.6 ºC to 19.7 ºC).

h) For the ventilation design strategy, the basic idea is to exchange warm indoor air (i.e., mainly from the internal heat loads of occupants, lights, and equipments) for cooler outdoor air as well as to increase the rate of evaporation and heat loss of the body. In the G-M Chart, this ventilation region covers the region between the 20% to 80% relative humidity, from 78 ºF (25.6 ºC) Effective Temperature Index (ET*) to 89.5 ºF (31.9 ºC) dry-bulb temperatures, and below the 14.15 ft^3/lb specific volume line (see Figure 6.15). However, this area, in the new bioclimatic chart, is in the cooling period, where air-conditioning design strategy is recommended. The new bioclimatic chart shows the ventilative cooling region, where an economizer helps to extend the non-heating-cooling region of the lightweight house (base case) to the warmer region at the right (from 60 ºF to 65 ºF, 15.6 ºC to 18.3 ºC), which is the internal gains region in the G-M Chart analysis. Due to the effects of increased air movement, which extend the upper limit of the comfort zone to higher temperatures, the comfort zone may be adjusted. An investigation on the ventilation region due to the air movement is recommended for future study. In addition, with economizer operation settings, further investigation on the high thermal mass with night ventilation is also recommended.

i) In the G-M Chart, the evaporative cooling region covers the area below 20% relative humidity (RH) from the 78 ºF (25.6 ºC) Effective Temperature Index (ET*) to 89.5 ºF (31.9 ºC) dry-bulb temperature and the area below the 71.5 ºF (21.9 ºC) wet-bulb temperature from 89.5 ºF (31.9 ºC) to 104.5 ºF (40.3 ºC) dry-bulb temperatures. Unfortunately, the evaporative cooling design strategy was not included in this study. Therefore, for the future study recommendations, an evaporative cooling system should be analyzed for the appropriate climate regions.

j) Finally, an air-conditioning design strategy was compared. In the G-M Chart, this region stays to the right of the G-M comfort zone within the cooling regions, where the dry-bulb temperatures are above the 78 ºF (25.6 ºC) Effective Temperature Index (ET*) (see Figure 6.16). However, the passive cooling design strategies (i.e., ventilation, high thermal mass with and without night ventilation, evaporative cooling design strategies) were first recommended in the G-M Chart. An additional air-conditioning design strategy was recommended for the regions beyond the limitations of the passive cooling design strategy. The cooling region in the G-M Chart (i.e., above the 78 ºF Effective Temperature Index), was also part of the cooling region in the new bioclimatic chart. In the new bioclimatic chart, this air-conditioning region covers the area to the right (warmer region) of the non-heating-cooling region of each house. The new bioclimatic chart shows the lower limit of this air-conditioning region is at the 70 ºF (21.1 ºC) dry-bulb temperature (for the lightweight house without internal loads) and expanded to the 67.5 ºF (19.7 ºC) dry-bulb temperature for the high thermal mass house, 65 ºF (18.3 ºC) dry-bulb temperature for the lightweight house with an economizer, and 60 ºF (15.6 ºC) dry-bulb temperature for the lightweight house, base case.

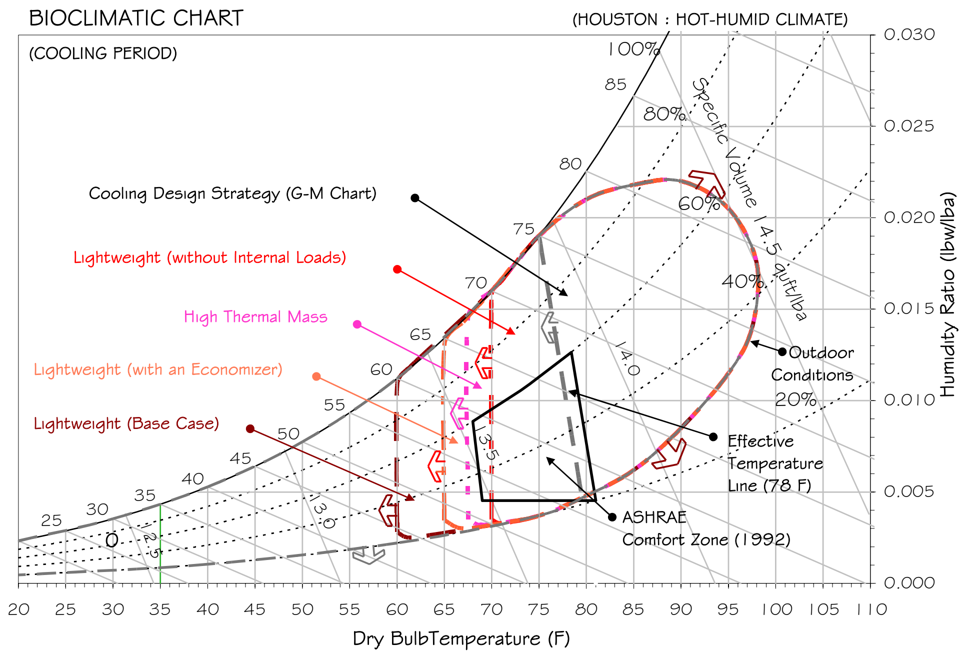


Figure 6.16 *Comparison of the G-M cooling design strategy boundary and the prototype houses in the hot-humid climate, Houston, Texas, during the cooling period.*

6.11 SUMMARY OF THE DESIGN GUIDELINES FOR THE HOT-HUMID CLIMATE OF HOUSTON, TEXAS

In summary, a new bioclimatic chart (Figure 6.7) for a thermostatically-controlled one-story, single-family residence in the hot-humid climate of Houston, Texas, was developed. This new chart demonstrated boundaries of specific passive and active climate-controlled design strategies, which were tested in this study using the DOE-2 simulation program. The new design strategy boundaries of the new bioclimatic chart were compared to the traditional Givoni-Milne (G-M) bioclimatic chart (1979).

In Figure 6.7, the new bioclimatic chart showed the boundary of the outdoor conditions for the hot-humid climate of Houston, Texas, consisted of several regions from regions 1 to 10. The heating (region 1, dark blue lines), cooling (region 10, red lines), and non-heating cooling (regions 2 to 6, green lines) design strategy regions, as well as regions where humidification (region 8, light blue lines) or dehumidification (region 9, pink lines) is required. The ASHRAE comfort zone (1992) (region 7, black line) was used to evaluate the simulated indoor comfort conditions in this study. Conventional heating and air-conditioning design strategies were used to maintain the indoor comfort conditions when the outdoor conditions fell outside the non-heating-cooling effective region.

In this study, a lightweight house (base case), the lightweight house without internal loads, the high thermal mass house, and the lightweight house with an economizer were tested using the DOE-2 simulation program. For each house, the boundary of the effective region during each period represented the majority of the outdoor conditions (i.e., determined by percentages of the hours-per-year) during that period. These boundaries were then superimposed onto the psychrometric chart.

This new bioclimatic chart (Figure 6.7) showed that with the lightweight house without internal loads, indoor comfort conditions can be maintained within the ASHRAE comfort zone (1992), when the outdoor conditions fell in the 50 °F (10 °C) to 70 °F (21.1 °C) dry-bulb temperatures (regions 3 through 6). However, in the house with internal loads (lightweight, base case), these regions were shifted to the left covering the regions from 45 °F (7.2 °C) to 60 °F (15.6 °C) dry-bulb temperatures (regions 2 to 3). In one of the houses, an economizer system moved the upper limit of the non-heating-cooling period of the lightweight house (base case) from 60 °F (15.6 °C) dry-bulb temperature to 65 °F (18.3 °C) dry-bulb temperature (i.e., from regions 3 to 4). It was also shown that the high thermal mass house tempered and delayed both heating and cooling loads, which changed the non-heating-cooling regions of the base-case house to be spread-out to the left from 45 °F (7.2 °C) to 40 °F (4.4 °C) dry-bulb temperatures (i.e., from regions 2 to 1), and to the right from 60 °F (15.6 °C) to 67.5 °F (19.7 °C) dry-bulb temperatures (i.e., from regions 3 to 5).

For each house, a conventional heating design strategy covered the region(s) to the left of the non-heating-cooling effective regions of that house. In contrast, the air-conditioning design strategy covered the region(s) to the right of the non-heating-cooling regions of each house. A humidification design strategy (region 8) was recommended when the outdoor conditions were below 36 ºF (2.2 ºC) dewpoint temperature (i.e., 5.4 mmHg or 0.0045 lbw/lba humidity ratio). Similarly, a dehumidification design strategy (region 9) was recommended, when the outdoor conditions were above 54 ºF (12.2 ºC) dewpoint temperature (i.e., 10.6 mmHg or 0.009 lbw/lba humidity ratio) and the 80% relative humidity (RH). Finally, each design strategy boundary of the new bioclimatic chart (Figure 6.7) and the traditional Givoni-Milne bioclimatic chart (1979) (Figure 1.2) was compared.

The G-M conventional heating region and active solar region corresponded approximately to the conventional heating region of the new bioclimatic chart (Figure 6.7). The G-M passive solar region (see Section 2.3.2) was noticed to be slightly different from the non-heating-cooling period region of the lightweight house (base case), which resulted from a combination of the internal heat loads, the solar radiation availability, and the mass of the house.

For the G-M internal loads design strategy region, indoor comfort conditions were achieved with internal heat loads (i.e., heat sources from occupants, lights, and equipment). However, in the new bioclimatic chart (Figure 6.7), this region was considered to be in the cooling region, where air-conditioning was required for the lightweight house (base case). In addition, in order to achieve thermal comfort when the outdoor conditions were in this region, a house with an economizer or high thermal mass design strategies were recommended in the new bioclimatic chart. The new bioclimatic chart also showed that, with the internal loads, the non-heating-cooling region of the lightweight house was shifted toward the colder region.

In the G-M Chart, the humidification design strategy region corresponded approximately with the new bioclimatic chart (Figure 6.7), which showed the need for humidification in the region where the outdoor conditions were below 36 ºF (2.2 ºC) dewpoint temperature (i.e., 5.4 mmHg or 0.0045 lbw/lba humidity ratio).

In the G-M chart, the comfort zone was to be considered as a non-heating-cooling period (see bioclimatic needs analysis, region 7, Table 2.1). However, the new bioclimatic chart (Figure 6.7) showed the need for cooling (i.e., an air-conditioning design strategy), when the outdoor conditions were within the ASHRAE comfort zone (1992).

In the G-M Chart, dehumidification was needed when the outdoor conditions was above 67 ºF (19.4 ºC) dewpoint temperature (17 mmHg, 0.014 lbw/lba humidity ratio) or 80% relative humidity (RH), which was similar to the new bioclimatic chart. The differences were in the lower limit of the G-M dehumidification region, which were higher than in the new bioclimatic chart (Figure 6.7), which showed the need of dehumidification when the outdoor conditions were above 54 ºF (12.2 ºC) dewpoint temperature (10.6 mmHg, 0.009 lbw/lba humidity ratio) and the relative humidity (RH) was above 80%.

For the high thermal mass design strategy in the G-M Chart, the region covered the area to the right of the G-M comfort zone. However, in the new bioclimatic chart (Figure 6.7), this region was considered as a cooling region (i.e., an air-conditioning design strategy). The new bioclimatic chart showed that in a house with the high thermal mass, the non-heating-cooling region of the base-case house was extended to the left and the right (colder and warmer regions).

For the G-M ventilation design strategy region, the new bioclimatic chart showed the need for air-conditioning in this region. The new bioclimatic chart (Figure 6.7) also showed the ventilative cooling region, which used an economizer to help extend the non-heating-cooling region of the lightweight house (base case) to the warmer regions, which included the internal gains region in the G-M Chart analysis.

The air-conditioning design strategy in the G-M Chart stayed to the right of the comfort zone, and was a part of the cooling region in the new bioclimatic chart (Figure 6.7). However, in the new bioclimatic chart, this air-conditioning design strategy region also covered the area to the right of the non-heating-cooling region of each house.

CHAPTER VII

SUMMARY AND RECOMMENDATIONS FOR FUTURE STUDY

This chapter summarizes the current research work (Section 7.1) and includes recommendations for future study (Section 7.2).

7.1 SUMMARY

This summary reviews the current work four sections, including: 1) the purpose and objective, 2) the literature review, 3) the methodology, 4) the data analysis and the results, and 5) the design guidelines for the new bioclimatic chart.

7.1.1 Summary of the Objective

The purpose of this research is to promote comfortable and energy efficient residences by developing tools that identify appropriate building design strategies for different climate region. The objective of this study was to develop a new bioclimatic chart for thermostatically-controlled residences by verifying and testing the original Givoni-Milne (G-M) bioclimatic chart (1979) using an energy simulation program and appropriate weather data from several representative cities in various climates. To achieve this objective, the following four tasks were conducted: 1) investigating the G-M bioclimatic chart using representative weather data from several climates, 2) analyzing and developing new design strategy boundaries using an energy simulation program and appropriate representative weather data to simulate a thermostatically-controlled prototype residence under varying conditions in selected climates, 3) comparing these new design strategy boundaries to the original G-M design strategy boundaries, and 4) developing general design guidelines for the new bioclimatic chart for thermostatically-controlled residence.

7.1.2 Summary of the Literature Review

From the literature review, the following reports and papers were found to be the most relevant to this study. The ASHRAE Standard 55-1992 comfort chart (ASHRAE, 1992), which contains an upper limit for relative humidity level of 60% in order to prevent mold and mildew growth (Olesen, 2000), was used to evaluate comfort conditions for this research. To simulate the residence, the DOE-2 program (LBNL, 2000a; 2000b; 2001), the most extensively used and wildly accepted public-domain simulation program in the U.S., was used in this research. The DrawBDL program (Huang, 1994) was used to generate architectural renderings of the prototype house. TMY2 weather data (Marion and Urban, 1995), which has the appropriate long-term weather data (Huang and Crawley, 1996, p.4.188; and Crawley, 1998), was used in this study. The new climate classification; which was developed by Briggs et al. (2003a; 2003b) based on the widely accepted classification systems of world climates (Köppen and Geiger, 1930) and was meant to improve the implementation of building energy codes and standards, played a role in the site selection in this research. Finally, the design strategies recommended in the Givoni-Milne chart (1979) were considered in this research.

7.1.3 Summary of the Methodology

The methodology used in this study included: 1) a procedure for selecting and preparing representative weather data; 2) a procedure for simulating selected design strategies; 3) a procedure for mapping weather data onto the psychrometric chart; and 4) a procedure for analyzing and projecting the simulation outcomes onto the psychrometric chart.

For the process of selecting representative climates in this research, seven representative climates of the U.S and Thailand were selected using four criteria (Section 4.1.1). The seven selected climates and their representative cities in this research were: 1) a very hot-humid climate (Bangkok, Thailand), 2) a hot-humid climate (Houston, Texas), 3) a hot-dry climate (Phoenix, Arizona), 4) a warm-marine climate (San Francisco, California), 5) a cool-humid climate (Chicago, Illinois), 6) a cool-humid climate (Boston, Massachusetts), and 7) the cool-dry climate (Boise, Idaho). For the process of preparing representative weather data, the TMY2 weather data of the selected climates in the U.S. locations was obtained from the National Renewable Energy Laboratory (NREL) web site and weather data for selected climates in Thailand was obtained from the International Weather for Energy Calculations (IWEC) CD-ROM (ASHRAE, 2002). The "Weather Converter Program" from the EnergyPlus program (Crawley et al., 2000) was used to convert the Thailand weather data in IWEC format (ASHRAE, 2002) into TMY2 format. Finally, to prepare the TMY2 files for use with the DOE-2 simulation, the TMY2 files (ASCII) were converted to the binary files using the DOE-2 weather processor (Buhl, 1999).

To simulate selected design strategies; a traditional one-story, single-family house input file (Haberl et al., 2003c; 2004) that is compliant with the 2000 International Energy Conservation Code with 2001 Supplement (ICC, 1999; 2006) was used to represent a simple prototype model for each design strategy. The four specific design strategies that were investigated in this research included: 1) a lightweight house (base case, Section 4.2.1.1), 2) a lightweight house without internal loads (Section 4.2.1.2), 3) a high thermal mass house (Section 4.2.1.3), and 4) a lightweight house with an economizer (Section 4.2.1.4). To accomplish this, the DOE-2.1e program (Winkelmann, 1993a; 1993b) was used to simulate a conventional heating and cooling system (SZRH) for the prototype residences together with the TMY2 weather files prepared from the previous step. The outcomes of the simulations, which can be divided into two main areas were the outcomes from the selected weather data analysis and the outcomes from the DOE-2 simulation of the residence.

The weather data used for the analysis were obtained from the DOE-2 hourly reports. The process of mapping the TMY2 weather data onto the psychrometric chart included: 1) developing a psychrometric model for plotting the ASHRAE comfort chart (1992) and the G-M bioclimatic chart (1979) for each climate, 2) identifying and extracting appropriate weather data, and 3) analyzing and projecting the weather data onto the psychrometric chart. To perform the analysis, new bioclimatic analysis strategies were also mapped onto the psychrometric chart. The ASHRAE comfort chart (1992) and the traditional G-M design strategy boundaries were then overlaid onto the psychrometric chart to facilitate the comparison. Using a number of tools and techniques developed for the specific tasks, the weather data (thermal, solar, and wind) were extracted from the DOE-2 hourly reports and rearranged into the appropriate format. The rearranged data were then separated into whole-year datasets, daytime, and nighttime datasets, which were then analyzed and displayed on the psychrometric chart. The types of displays include; density plots, cumulative plots, average plots, and hourly average data plots. Most of the data analysis tools and graphical displays in this research were developed using Microsoft Excel (Microsoft Office, 2003). New animated techniques for using the psychrometric chart to present solar and wind data were also demonstrated.

The process to analyze and display the simulation outcomes included two main tasks, which were: 1) extracting the appropriate data from the simulation outcomes, 2) analyzing and projecting the simulation outcomes on the combined chart using tools developed with Microsoft Excel (MS Office, 2003). To accomplish this, the simulation outcomes from the DOE-2 hourly reports and BEPS report were extracted and rearranged in an appropriate format. The thermal and systems data for the whole year (all periods), heating period, cooling period, and non-heating-cooling period were transferred to the appropriate design strategy regions. The number of hours and the percentage of occurrence for each period that fell into each design strategy region were counted and displayed. These results were displayed and compared using comparison tables. The results from the G-M Chart design strategy regions and the DOE-2 simulations for each period were then compared and analyzed in the tables for further analysis.

7.1.4 Summary of the Data Analysis and Results

The outdoor conditions from the TMY2 weather data, the simulated indoor comfort conditions, the energy usage from the DOE-2 hourly reports, and the Building Energy Performance Summary (BEPS) data were used to analyze and develop graphical display results, which included: time series plots, x-y plots, three dimensional plots, psychrometric plots, bar charts, and tables**.** The results consist of three main areas, which include: 1) weather analysis for selected climates, 2) results of the DOE-2 simulation and the G-M chart analysis, and 3) comparison of the results.

7.1.4.1 Weather analysis for the selected climates

The weather analysis focused on the thermal, solar, and wind data for the hot-humid climate of Houston, Texas. The thermal data showed a wide range of the ambient dry-bulb temperatures and relative humidity. In addition, the ambient conditions for the whole year covered the comfort zone and were widely spread-out above the 20% relative humidity line to the left and the right of the comfort chart. The results showed the range of the temperature and relative humidity was narrower in the summer than in the winter. In the winter, the minimum hourly temperature was 14 °F (-10 °C) and the minimum average daily temperature was 25 °F (-3.9 °C). In the summer, the maximum hourly temperature is 97 °F (36.1 °C) and the maximum average daily temperature was 86 °F (30 °C). The minimum relative humidity was 14% and the maximum relative humidity was 100%. During most of the year, the relative humidity was above 80%, which usually occurred at night.

The analysis of the solar data showed that the average global horizontal solar radiation (GBH) of Houston was higher in summer than in the winter, as expected. The highest hourly average value in the summer was 325 Btu/ft^2-hour and the highest hourly average value in the winter was 205 Btu/ft^2-hour. The lowest solar radiation was at temperatures below 30 °F (-1.1 °C). The cumulative global horizontal solar radiation was very high at temperatures above 70 °F (21.1 °C) when the relative humidity was between 40 to 60%. On the psychrometric chart, the ambient conditions moved back and forth from the left (nighttime) to the right (daytime). The maximum average hourly global horizontal solar radiation occurred at solar noon, as expected. The hottest hour of the day was usually around 2:00 p.m.

The wind data for Houston showed that the hourly wind speed stayed below 35 mph, and was usually less than 20 mph. Furthermore, there were seldom any times when there was no wind or the wind speed exceeded 20 mph. The average wind speed was higher in the daytime (8 to 12 mph) than at night (5 to 7 mph). The lowest average wind speed occurred a few hours before sunrise. The highest average wind speed occurred during a few hours after solar noon. The wind direction usually occurred from the south through the east directions. The frequency of the occurrence of the wind from the northwest to the southwest directions was low.

7.1.4.2 Results of the DOE-2 simulation and the G-M Chart analysis

The second part of the analysis presented the results of the DOE-2 simulation and the G-M chart analysis for four prototype houses in the representative climates, which included: 1) a lightweight house (base case) for all sites, 2) a lightweight house without internal loads for Houston, 3) a high thermal mass house for Houston and Phoenix, and 4) a lightweight house with an economizer for Houston and San Francisco. In this analysis, the indoor and outdoor thermal conditions of each representative city were graphically reported as well as the annual energy use of each category. The indoor and outdoor thermal data during the heating, cooling, and non-heating-cooling periods were superimposed onto the G-M Chart and the number of the hours-per-year that fell upon the G-M Chart design strategy regions were calculated. These results were then compared with the results from the G-M bioclimatic chart analysis. The analysis showed that there were some differences in the results from the DOE-2 simulation and the results from the G-M Chart analysis, which will be described in the following section.

7.1.4.3 Comparison of the results

The third part of the analysis compared the results from the second part against a traditional G-M Chart analysis, which included: 1) the indoor and outdoor conditions, 2) the annual energy use, 3) the DOE-2 simulation results versus the G-M Chart results, and 4) the DOE-2 simulation results for all sites.

7.1.4.3.1 Indoor and Outdoor Conditions

For the comparison of the outdoor conditions, DOE-2 showed that the range of the outdoor temperatures and relative humidity for the whole year were narrow in Bangkok and San Francisco and wide in Houston, Phoenix, Chicago, Boston. In Boise (cool-dry climate), the ranges of the outdoor temperature and the relative humidity were the widest. When superimposed on the psychrometric chart, the outdoor conditions for the whole year for all sites corresponded to their climate categories. In Bangkok the data covered the area above and to the right of the comfort zone. In Houston, Boston, and Chicago, the outdoor conditions covered the comfort zone and were spread out to the left and the right above the 20% relative humidity line. In Phoenix and Boise, the outdoor conditions covered the comfort zone and were spread out horizontally to the left and the right covering the area below the humidity ratio lines of 0.010 and 0.015 (lbw/lba) for Phoenix and Boise, respectively. In San Francisco, the majority of outdoor conditions covered the comfort zone and the area to the left of the comfort zone above the 20% relative humidity line.

For the comparison of the indoor conditions, DOE-2 showed that the indoor temperatures for all sites stayed or fluctuated between the heating and cooling temperature set-points of 68 °F (20 °C) and 78 °F (25.6 °C), which corresponded to the activation of the heating or cooling systems. The indoor temperature and relative humidity were very well maintained when the cooling system was continuously activated. The fluctuation of the indoor temperature was less for the high thermal mass house, as expected. Although the majority of the indoor relative humidity for all sites stayed within the humidity constraint of the comfort zone (above 60% relative humidity line and under 36 °F dewpoint line). Surprisingly, there were a significant number of hours in the year when the indoor relative humidity was above or below the humidity constraint of the comfort zone.

7.1.4.3.2 Annual Energy Use

The analysis of the annual energy use showed that, the total annual energy use of the lightweight house (base case) in the cool climates (Chicago, 173.8 MBtu; Boston, 174.4 MBtu; and Boise, 148.6 MBtu), where the large portion of the use was for space heating, were significantly higher than the total annual energy use in the very hot climates (Bangkok, 116.0 MBtu; Houston, 108.1 MBtu; Phoenix, 100.0 MBtu), where a significant portion of the use was for space cooling. The total annual energy use of the lightweight house (base case) was lowest in the warm-marine climate (San Francisco, 97.9 MBtu).

For the lightweight house (base case) with and without internal loads in Houston, the annual energy use was higher for the lightweight house (base case) (108.1 MBtu) than for the lightweight house without internal loads (80.1 MBtu) due to the removal of the internal heat sources and the energy use for equipment and lights.

For the lightweight house (base case) versus the high thermal mass house in Houston and San Francisco, the annual energy use in Houston was less for the high thermal mass house (100.8 MBtu) than for the lightweight house (base case) (108.1 MBtu). A significant portion of the reduction was in the cooling energy use. For Phoenix, surprisingly, the annual energy use for the high thermal mass house (100.2 MBtu) was slightly higher the annual energy use of the lightweight house (base case) (100.0 MBtu), which was for the cooling energy use. Although the reason for this was unknown, it may be a result of fact that the high thermal mass used in this study might not be sufficient to delay the heat transfer to the house in Phoenix, where the intensity and the availability of the solar radiation were significantly higher. To reduce the cooling loads, higher thermal mass and night ventilation might be considered.

For the lightweight house with and without an economizer in Houston and San Francisco, it was focused that the economizer increased the energy use for heating. This was most likely due to the need for more heating energy use during the winter to compensate the inappropriate cool air brought in by the economizer, which was set to activate when the outdoor temperature was below 65 ºF (18.3 ºC). Therefore, the annual energy use was more for the lightweight house with an economizer (109.6 MBtu, Houston; 102.1 MBtu, San Francisco) than for the lightweight house (base case) (108.1 MBtu, Houston; 97.9 MBtu, San Francisco). To reduce the heating loads, perhaps an economizer seasonal activation switch should be considered, or additional economizer setpoint was investigating.

7.1.4.3.3 The DOE-2 Simulation Results versus the G-M Chart Results

Comparing the DOE-2 simulation results versus the G-M Chart analysis results, for the lightweight house (base case) in the seven selected climates during the heating period, the DOE-2 simulation results for all sites were close the G-M Chart analysis results except for San Francisco, where the DOE-2 simulation results were significantly more than the G-M Chart analysis results. For all sites, except Bangkok, which has no heating requirements, DOE-2 showed the heating hours in regions 0 (conventional heating) and 1 (active solar) were very close to the G-M Chart results. In regions 2 to 4 (passive solar) DOE-2 showed a small portion of the heating hours in Houston and Phoenix and a significant portion of the heating hours in San Francisco, Chicago, Boston, and Boise. However, in a G-M Chart analysis regions 2 to 4 were not usually considered heating periods. In the cooling period, the DOE-2 simulation results for all sites were more than the G-M Chart results especially in Houston and Phoenix. DOE-2 showed that the cooling hours covered several regions from 1 through 17.

The DOE-2 simulation results in regions 8 through 17 (humidification, ventilation, high thermal mass with and without night ventilation, evaporative cooling, air-conditioning with/ without dehumidification) corresponded or were very close to the results from the G-M Chart analysis. However, DOE-2 showed significant portions of the cooling hours in several sites from regions 1 through 7 (active solar, passive solar, internal gains, dehumidification, the G-M comfort zone), whereas in the G-M Chart analysis these regions were not usually considered cooling periods. In the non-heating-cooling period, the DOE-2 simulation results for all sites were less than the results from the G-M Chart analysis especially in San Francisco. DOE-2 showed that the majority of the non-heating-cooling hours for all representative cities, except Bangkok, which showed no hours in this period, fell upon regions 2 through 7 (passive solar, internal gains, humidification, and the G-M comfort zone). These were significantly less than the G-M Chart analysis results. DOE-2 also showed a small portion of the non-heating-cooling hours of several sites in regions 0 and 1 (conventional heating and active solar), where in the G-M Chart analysis were not considered non-heating-cooling period.

For the lightweight house (base case) versus the lightweight house without internal loads in Houston, the DOE-2 simulation results of the lightweight house (base case) during the heating period were close to the G-M Chart results. However, for the lightweight house without internal loads, DOE-2 showed significantly less heating in region 5 (internal gains) and a small portion of the heating hours in regions 2 to 4 (passive solar), which were not considered a heating period in the G-M Chart. In the cooling period, the DOE-2 simulation results of the lightweight house (base case) were significantly more than the G-M Chart results. However, for the lightweight house without internal loads, DOE-2 showed slightly more cooling hours than the G-M Chart showed. The differences were in regions 5 and 7 (internal gains and the G-M comfort zone), where DOE-2 showed portions of the cooling hours. Unfortunately, these regions were not considered cooling period in the G-M Chart analysis.

In the non-heating-cooling period, the DOE-2 simulation results of the lightweight house (base case) were significantly less than the G-M Chart results. The DOE-2 simulation results of the lightweight house without internal loads were very close to the G-M Chart results. However, the DOE-2 simulation results of the non-heating-cooling hours in regions 2 to 4 (passive solar), 6 (humidification), and especially in region 7 (the G-M comfort zone) were less than the G-M Chart results. Moreover, DOE-2 showed a significant portion of the non-heating-cooling hours in region 5 (internal gains), which were considered heating period in the G-M Chart analysis.

For the lightweight house (base case) versus the high thermal mass house in Houston and Phoenix, the DOE-2 simulation results of the lightweight house (base case) and the high thermal mass house during the heating period were close to the G-M Chart results for Houston and slightly less than the G-M Chart results for Phoenix. The heating hours covered regions 1 (active solar), 2 to 4 (passive solar), and 5 (internal gains). It should be noted that regions 2 through 5 were not usually considered heating periods in the G-M Chart analysis. In the cooling period, the DOE-2 simulation results of the lightweight house (base case) and the high thermal mass house for both locations were more than the G-M Chart results, where the significant portions of the cooling hours for Houston and Phoenix were in regions 5, 7, and 11 (internal gains, the G-M comfort zone, and high thermal mass). A significant difference was also shown in region 13 (high thermal mass) for the houses in Phoenix. Unfortunately, in the G-M Chart analysis, these regions (5, 7, 11, and 13) were not usually considered to be a cooling period.

In the non-heating-cooling period, the DOE-2 simulation results of the high thermal mass house in Houston and Phoenix during the non-heating-cooling period were significantly less than the G-M Chart results. The significant differences were in regions 2 through 7 (passive solar, internal gains, humidification, the G-M comfort zone) and 10 through 13 (high thermal mass) which were not considered non-heating-cooling periods in the G-M Chart.

For the lightweight house (base case) versus the lightweight house with an economizer in Houston and San Francisco, the DOE-2 simulation results of both prototype houses were very close to the G-M Chart results for Houston, but were significantly more than the G-M Chart results for San Francisco. The significant differences were in regions 2 to 4 and 5 (passive heating and internal gains). In contrast, in the G-M Chart analysis these regions were not considered to be in the heating period. In the cooling period, the DOE-2 simulation results of the lightweight house (base case) and the lightweight house with an economizer in Houston and San Francisco were more than the G-M Chart analysis results. Significant portions of the cooling hours were in regions 5 through 7 (internal gains, humidification, and the G-M comfort zone), which were not considered to be in the cooling period on the G-M Chart.

In the non-heating-cooling period, the DOE-2 simulation results of both prototype houses in both locations were less than the G-M Chart analysis results, where differences were more significant in San Francisco. The majority of the non-heating-cooling hours were in regions 2 through 7 (passive solar, internal gains, humidification, and the G-M comfort zone), which were considered non-heating-cooling period on the G-M Chart, were significantly less than the G-M Chart analysis results.

7.1.4.3.4 The DOE-2 Simulation Results across All Sites

Next, comparing the DOE-2 simulation results across all the sites, DOE-2 showed that the majority of the heating hours for the lightweight house (base case) in the seven selected climates, except Bangkok, fell upon the area to the left of the comfort zone covering the regions from 0 through 3 (conventional heating, active solar, and passive solar design strategies). The majority of each region in the heating period included; regions 0 and 1 (Houston and Phoenix), regions 0 through 2 (Boise), and regions 0 through 3 (San Francisco, Chicago, and Boston). In the cooling period, the majority of the cooling hours, which in Bangkok were 100% of the hours-per-year, covered the comfort zone and were spread out to the left and the right covering several regions from 4 through 17. The majority of the hours-per-year for each region in the cooling period covered region 4 (Bangkok and Phoenix) and region 5 (Houston, San Francisco, Chicago, Boston, and Boise), and was spread out to the right covering other regions.

In the non-heating-cooling period, the majority of the non-heating-cooling hours for the representative cities except Bangkok, fell upon the area between heating and cooling period covering the area to the left of the comfort zone from regions 1 through 5 (conventional heating, active solar, passive solar, and internal gains design strategies). The majorities of the hours-per-year for each region in the non-heating-cooling period included regions 1 through 4 (Phoenix), regions 2 through 4 (Houston), regions 2 through 5 (Boise), and regions 3 through 5 (San Francisco, Chicago, and Boston). Although the exact cause of this is not known, it is possible that the shift of the non-heating-cooling regions to the cooler regions were due to the effects of the solar radiation, since the availabilities were higher in the hotter climates than in the cooler climates.

Comparing the DOE-2 simulation results of the lightweight house (base case) versus the lightweight house without internal loads in Houston, DOE-2 showed that the majority of the hours-per-year for each region in the heating period included regions 0 and 1 (conventional heating and active solar) for the lightweight house (base case) and regions 0 through 3 (conventional heating, active solar, and passive solar) for the lightweight house without internal loads. In the cooling period, for the lightweight house (base case), the majorities of the hours-per-year for each region in the cooling period included region 5 and all other regions to the right of region 5. For the lightweight house without internal loads, the regions with the majority of the hours-per-year for each region in the cooling period included region 6 and all other regions above and to the right of region 6.

For the lightweight house (base case), the majority of the hours-per-year in the non-heating-cooling period for each region included regions 2 through 4 (passive solar). For the lightweight house without internal loads, the majority of the hours-per-year for each region in the non-heating-cooling period included regions 3 through 5 (passive solar and internal gains). This could result from the effects of the internal gains, which made the non-heating-cooling regions shift to the left side (cooler regions).

Comparing the results of the lightweight house (base case) versus the high thermal mass house in Houston, the majority of the hours-per-year for each region in the heating period included regions 0 and 1 (conventional heating and active solar) for both houses. The majority of the hours-per-year for each region in the cooling period included region 5 (internal gains) and other regions to the right of region 5 also for both prototype houses. The majority of the hours-per-year for each region in the non-heating-cooling period included regions 2 through 4 (passive solar) for the lightweight house (base case) and regions 1 through 5 (active solar, passive solar, and internal gains) for the high thermal mass house. The expansion of the non-heating-cooling period to the left and right sides (colder and warmer temperatures) were most likely due to the high thermal mass effects.

In Phoenix, for the high thermal mass house, the majority of the hours-per-year for each region in the heating period included only region 0 (conventional heating). For the lightweight house (base case), the majority of each region in the heating period included regions 0 and 1 (conventional heating and active solar). For both houses, the majority of the hours-per-year for each region in the cooling period included region 4 and all other regions to the right of the region 4. In the non-heating-cooling period, the majority of the hours-per-year for each region in the non-heating-cooling period covered regions 1 through 4 (active solar and passive solar) for the lightweight house (base case) and region 1 through region 5 (internal gains) for the high thermal mass house. The results in Phoenix, in a similar fashion to the results in Houston, also showed the expansion of the non-heating-cooling period to the left and right sides (colder and warmer temperatures), which was most likely due to the high thermal mass effects.

Comparing the lightweight house (base case) versus the lightweight house with an economizer in Houston and San Francisco, for both houses in Houston, the majority of the hours-per-year of each region included regions 0 and 1 (conventional heating and active solar) for the heating period and the regions from region 5 (internal gain) to the right for the cooling period. In the non-heating-cooling period, the majority of the hours-per-year of each region in the non-heating-cooling period included regions 2 through 4 (passive solar) for the lightweight house (base case) and regions 2 through 5 (passive solar and internal gains) for the lightweight house with an economizer. For the both prototype houses in San Francisco, the majorities of the hours-per-year of each period included regions 0 through 3 (conventional heating, active solar, and passive solar) for the heating period, the regions from region 5 (internal gain) to the right for the cooling period, and regions 3 through 5 (passive solar and internal gains) for the non-heating-cooling period. DOE-2 also showed an expansion of the non-heating-cooling period to region 5 in Houston, and an even large expansion of the non-heating-cooling hours in region 5 in San Francisco. These were most likely due to the effects of using economizer system.

7.1.5 Summary of the Design Guidelines for the New Bioclimatic Chart

A new bioclimatic chart for choosing design strategies for a thermostatically-controlled residence in the hot-humid climate (Houston, Texas) was developed using the TMY2 representative weather data and the DOE-2 energy simulation program of a code-complaint residence. The DOE-2 simulation results of the passive and active design strategies were analyzed and combined onto the psychrometric chart. These design strategies included: a lightweight house (base case), a lightweight house without internal loads, a high thermal mass house, a lightweight with an economizer, humidification strategy, dehumidification strategy, conventional heating strategy, and air conditioning strategy.

New design strategy boundaries were drawn to represent the majority of the data. Therefore, these new strategy boundaries are not the exact lines and can be spread-out or overlapped with other design strategy regions. The new bioclimatic chart was presented in detail for the outdoor conditions of Houston with the specific design strategy boundaries delineated on the chart. New design strategy regions were also identified and presented. A summary of the results is as follows:

a) The lightweight house (base case) in this study was a traditional one-story, single-family house (Haberl et al., 2003c; 2004) for two occupants with an area of 2,500 ft^2. The house consisted of a conditioned living space, an unconditioned garage, and a crawlspace. The roof, walls, and floor of the house are a wood-stud structure. The windows were double-pane low-e glazing window (15% of external wall area) with aluminum frames without a thermal break. The heating, ventilating, and air-conditioning (HVAC) system was a single zone reheat system with a gas furnace and an electric hermetically-sealed reciprocating chiller with the heating temperature set point at 68 °F

(20.0 °C) and the cooling temperature set point at 78 °F (25.6 °C). The effective region of the lightweight house (base case) to maintain comfort conditions, which is 17.4% of the hours-per-year, covers the area above the 20% relative humidity line from 45 °F (7.2 °C) to 60 °F (15.6 °C) dry-bulb temperatures.

b) For the lightweight house without internal loads, the results showed the effective region to maintain comfort condition (25.7% of the hours-per-year) covers the area above the 20% relative humidity line from 50 °F (10 °C) through 70 °F (21.1 °C) dry-bulb temperatures.

c) For the high thermal mass house, the walls and floor of the base case house were replaced with high mass materials. The results showed the effective region to maintain comfort condition of the high thermal mass house (22.5% of the hours-per-year) covers the area above the 20% relative humidity line from 40 °F (4.4 °C) through 67.5 °F (19.7 °C) dry-bulb temperatures.

d) For the lightweight house with an economizer, an economizer system was added to the base case house HVAC simulation. The results showed the effective region to maintain comfort condition of the lightweight house with an economizer (24.6% of the hours-per-year) covers the area above the 20% relative humidity line from 45 °F (7.2 °C) through 65 °F (18.3 °C) dry-bulb temperatures.

e) The results showed a need for an additional humidification strategy that should be applied when the outdoor conditions are under the 36 °F (2.2 °C) dewpoint line. The need for humidification for the lightweight house (base case), the lightweight house without internal loads, the high thermal mass house, and the lightweight house with an economizer are 7.1, 12.0, 7.0, and 7.4% of the hours-per-year; respectively.

f) The results showed a need for an additional dehumidification strategy that should be applied when the outdoor conditions are above the 80% relative humidity line and the 54 °F (12.2 °C) dewpoint line. The need for dehumidification for the lightweight house (base case), the lightweight house without internal loads, the high thermal mass house, and the lightweight house with an economizer are 8.8, 23.7, 12.6, and 14.8% of the hours-per-year; respectively.

g) The results showed that a conventional heating design strategy is needed for the lightweight house (base case), the high thermal mass house, and the lightweight house with an economizer design strategies, when the outdoor conditions are below 45 °F (7.2 °C) dry-bulb temperature. This area of conventional heating design strategy region is spread out to the left (colder region) to 40 °F (4.4 °C) dry-bulb temperature for the high thermal mass house and to the right (warmer region) to 50 °F (10 °C) dry-bulb temperature for the lightweight house without internal loads. The activations of the conventional heating system for the lightweight house (base case), the lightweight house without internal loads, the high thermal mass house, and the lightweight house with an economizer; are 8.4, 15.6, 8.6, and 10.0% of the hours-per-year; respectively.

h) The results showed that an air-conditioning (with and without dehumidification) design strategy is needed for the lightweight house (base case), the lightweight house with an economizer, the high thermal mass house, and the lightweight house without internal loads design strategies, when the outdoor conditions are above 60, 65, 67.5, and 70 °F (15.6, 18.3, 19.7, and 21.1 °C) dry-bulb temperatures; respectively. The activations of the air-conditioning system for the lightweight house (base case), the lightweight house without internal loads, the high thermal mass house, and the lightweight house with an economizer; are 74.2, 58.7, 68.9, and 65.4% of the hours-per-year; respectively.

i) Each design strategy boundary of the new bioclimatic chart and the traditional Givoni-Milne bioclimatic chart (1979) was compared. The G-M conventional heating region and active solar region corresponded to the conventional heating region of the new bioclimatic chart. Although the lightweight house (base case) in this study had a larger floor area and less percentages of the south-facing glass than the G-M passive solar house (see Section 2.3.2), the passive solar regions of both charts were different.

j) The discrepancies were in the G-M internal loads design strategy region, which this region in the new bioclimatic chart was considered to be the cooling period (i.e., an air-conditioning design strategy) for the lightweight house (base case). However, in order to achieve thermal comfort when the outdoor conditions were in this region, an economizer or high thermal mass design strategies were recommended in the new bioclimatic chart. The new bioclimatic chart also showed that, with the internal loads, the non-heating-cooling region of the lightweight house was shifted to the colder region.

k) In the G-M Chart, the humidification design strategy region corresponded to the new bioclimatic chart. For the dehumidification strategy region, this region was very similar in both charts. However, the differences were in the lower limit of the G-M dehumidification region, which was higher than in the new bioclimatic chart, which showed the needs of dehumidification when the outdoor conditions were above 54 ºF (12.2 ºC) dewpoint temperature (10.6 mmHg, 0.009 lbw/lba humidity ratio) and the relative humidity (RH) was above 80%.

l) In the G-M chart, it is possible that the G-M comfort zone could be considered as a non-heating-cooling period if the G-M chart's authors have considered the house to be totally shaded (thus, no solar), extremely well ventilated with very low internal loads. However, the house in this research was neither totally shaded nor well ventilated with very low internal loads. Therefore, the new bioclimatic chart showed the needs of cooling (i.e., air-conditioning, in this study) in this zone due to heat gains from solar radiation and internal loads, as well as other effects of house mass.

m) For the high thermal mass design strategy, in the G-M Chart, this region covered the area to the right of the G-M comfort zone, while this area was to be considered as a cooling period (air-conditioning design strategy) in the new bioclimatic chart. The new bioclimatic chart showed that with the high thermal mass, the non-heating-cooling region of the base case house was extended to the left and the right (colder and warmer regions).

n) For the G-M ventilation design strategy region, the new bioclimatic chart showed the needs of air-conditioning in this region. The new bioclimatic chart showed that an economizer helped to extend the non-heating-cooling region of the lightweight house (base case) to the warmer region, which was the internal gains region in the G-M Chart analysis.

o) The air-conditioning design strategy in the G-M Chart stayed to the right of the G-M comfort zone and was a part of the cooling region in the new bioclimatic chart. However, in the new bioclimatic chart, this air-conditioning design strategy region also covered the area to the right of the non-heating-cooling region of each house.

In summary the DOE-2 results showed that, without internal loads, the non-heating-cooling period of the lightweight house (base-case) was in the region next to the left (colder region) of the ASHRAE comfort zone (1992). This implied that mostly when the outdoor conditions were in this region, the indoor conditions of a lightweight without internal loads house remained comfortable. With internal heat loads, this region was shifted further to the left (colder region), which is noted to be very close to the passive solar region of the G-M Chart. Comparing the non-heating-cooling period of the high thermal mass house to the lightweight house (base case), the non-heating-cooling period region of the high thermal mass was expanded to the left (colder region) and the right (warmer region) of the non-heating-cooling period region of the lightweight house (base case). This confirmed that high thermal mass helps to extend the non-heating-cooling period to the colder and warmer regions, which implies that it was an effective design strategy for both heating and cooling. For the lightweight house with an economizer, the non-heating-cooling period region was expanded to the right (warmer region, left of comfort zone) of the non-heating-cooling period region of the lightweight house (base case). This showed that bringing in appropriate outdoor air helps to reduce cooling loads.

According to the results in this research, the G-M chart was largely confirmed by DOE-2 with respect to conditions below the comfort zone as well as humidification and dehumidification needs. However, the G-M “Internal Gains” region is misleading as when outside air is in this region the heat must be removed rather than used. Therefore, this region should be renamed “Outside Air Cooling”. In addition, in order to emphasize the “Conventional Heating” (combustion) on its damaging effect on greenhouse gas accumulations, this region should be renamed “Combustion”. For the comfort zone and the regions to the right of the comfort zone, DOE-2 showed the needs of cooling design strategy, which should be noted that it was not limited to the air-conditioning (compression cycle cooling) only.

Without further modification, it was difficult to verify the Givoni-Milne bioclimatic chart (1979), which leads to the conclusion that the G-M Chart may not be appropriate for a thermostatically-controlled residence. Therefore, the new methodology developed in this research was used to verify the use of the bioclimatic chart for a thermostatically-controlled house. To improve the usefulness of the bioclimatic chart, a new bio-climatic chart that contains design strategies for a thermostatically-controlled residence in the hot-humid climate (Houston, Texas) was developed using the TMY2 representative weather data and the DOE-2 energy simulation program. The new bioclimatic chart will be a complimentary to the original G-M bioclimatic chart. The new design strategy recommendations will enhance the indoor comfort conditions and improve the building energy performance of a thermostatically-controlled residence.

7.2 RECOMMENDATIONS FOR FUTURE RESEARCH

This research is limited to the design strategies for a typical single-family residence with a HVAC system in the selected climates. This study has focused on the hot-humid climate for Houston, Texas. In order to improve the usefulness of the bioclimatic chart for Houston, future research is recommended for:

a) The solar radiation and wind influence on building performance and indoor comfort conditions can be easily seen when the corresponding outdoor conditions for each design strategy region in Houston or other representative cities are compared using the chart.

b) Additional building design strategies such as: passive solar, active solar, evaporative cooling, high thermal mass with night ventilation, air motion, shading devices, super-insulation materials, etc., which will need to be simulated.

c) Other building forms, orientations, and openings.

d) Other prototype models (2-story and multi-family residences with and without basement)

e) Other building operations for building equipment, seasonal schedules, nighttime setback temperature, and economizer activation schedules, etc.

For Thailand locations, where the comfort zone exist over a broad range of effective temperatures, it has been recommended that the summer comfort zone be adjusted approximately 7 °F (4 °C) to the right side (Busch, 1992). Therefore, an appropriate indoor comfort zone for the prototype residence in Bangkok, Thailand, would be in the range of 73 °F (22.8 °C) to 86 °F (30 °C) Effective Temperature (ET*) with the RH below 60% and the dewpoint temperature above 36 °F (2.2 °C).

In addition, due to the effects of increased air movement, which extend the upper limit of the comfort zone to higher temperatures, the comfort zone may be adjusted for a prototype house during the period with natural or mechanical ventilation strategies.

For low-income or remote residences, where the HVAC system may be restricted or unavailable, appropriate design strategies to maintain optimum indoor comfort conditions with minimal energy use may be investigated.

Investigations are also recommended for the design strategies that are beyond DOE-2's capability. For example: 1) a real natural ventilation with Computational Fluid Dynamics (CFD) (Andrews and Prithiviraj, 1997), 2) use of passive solar with movable insulation (at night), 3) nighttime cooling, using sky ponds, 4) evaporative cooling, and 5) alternative thermostat settings to allow for large temperature swings.

Finally, new bioclimatic charts for other climate zones with appropriate building design strategies and comfort zones and are recommended for future research. Development of an interactive computerized program for various bioclimatic charts and effective design strategies in various climate zones is also recommended.

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APPENDIX A

CLIMATE CHARACTERISTICS AND WEATHER DATA FORMATS

A.1 CLIMATE CHARACTERISTIC OF THE SELECTED CLIMATES

In this study the seven climates were selected using criteria in Section 4.1.1. Table A.1.1 presents general information of the seven representative cities in the selected climates, which are: 1) very hot-humid (Bangkok, Thailand), 2) hot-humid (Houston, Texas), 3) hot-dry (Phoenix, Arizona), 4) warm-marine (San Francisco, California), 5) cool-humid (Chicago, Illinois), 6) cool-humid (Boston, Massachusetts), 7) cool-dry (Boise, Idaho). The first and the second columns are the zone number and climate type as defined in the "*Climate Classification for Building Energy Codes and Standards*" (Briggs et al., 2003). Column 3 shows the state name (for U.S. city) or country name (for Bangkok) and column 4 shows the representative city name. Column 5 contains the station Weather Bureau Army Navy Number (WBAN) (Marion and Urban, 1995) for U.S. city or the World Meteorological Organization (WMO) identifier (ASHRAE, 2002) for Bangkok, Thailand. The latitude and the longitude of the city, expressed in degrees and minutes, are shown in the columns 6 to 9. Column 10 contains the elevation (ft) of the city above sea level and Column 11 shows the time zone in which the city is located from Greenwich, England (i.e., Longitude = 0), which is expressed in hours and minutes ahead (+) or behind (-) Universal Time (UT). Normal annual mean dry-bulb temperature (Tdb, °F) and normal annual precipitations (inches) are presented in columns 12 and 13. Finally, the last two columns show the average annual heating and cooling degree days (HHD65 and CCD65) of each representative city. The characteristics and definitions of the selected climates based on the publications by Briggs et al. (2003) and Koppen-Geiger system (Köppen and Geiger, 1930) as represented in the *"Physical Geography"* (Strahler, 1969) are defined.

Table A.1 *Comparative climate data of the seven representative cities in the selected climates*

Representative Cities for Several Climates (1961-1990)																	
Classification	Type	State/	City	WBAN / WMO	Latitude		Longitude		Elevation	Time	Normal Annual*		HDD50**	HDD65**	CDD50**	CDD65**
Zone Number		Country		Number	Degrees	Minutes	Degrees	Minutes	(ft.)	Zone	Mean Tdb (°F)	Precip. (inches)				
1A	Very Hot-Humid	Thailand	Bangkok	484560	13N	0	107E	0	10	7	83.3 (a)	59.98 (b)	-	-	12163 (a)	6907 (a)
2A	Hot-Humid	Texas	Houston	12960	29N	59	95W	22	108	-6	67.9	46.07	195	1346	7215	2891
2B	Hot-Dry	Arizona	Phoenix	23183	33N	26	112W	1	1112	-7	72.6	7.66	90	1382	7830	3647
3C	Warm-Marine	California	San Francisco	23234	37N	37	122W	23	16	-8	57.1	19.7	138	3041	2663	92
5A	Cool-Humid	Illinios	Chicago	94846	41N	47	87W	45	623	-6	49	35.82	3000	6151	3339	1015
5A	Cool-Humid	Massachusetts	Boston	14739	42N	22	71W	2	16	-5	51.3	41.51	2416	5775	2810	695
5B	Cool-Dry	Idaho	Boise	24131	43N	34	116W	13	2867	-7	50.9	12.11	2276	5667	2828	744

NOTE

***** Data from The Northeast Regional Climate Center (NRCC)

****** Data from Mechanical and Electric Equipment for Buildings (Stein and Reynolds, 1992)

(a) Data from The International Weather for Energy Calculation (IWEC)

(b) Data from The World Meteorological Organization (WMO)

HDD50 = Average annual heating degree days (base 50 °F)

HDD65 = Average annual heating degree days (base 65 °F)

CDD50 = Average annual cooling degree days (base 50 °F)

CDD65 = Average annual cooling degree days (base 65 °F)

A.1.1 Very Hot-Humid (Bangkok, Thailand)

In this climate (cooling-dominated), the mean monthly temperature is above 64.4 °F (18 °C) for the whole year. The rainy season begins in March, reaching the peak in July and August, and then declines until November. There is no rain during December through February. The temperature cycle is related with the precipitation. The air temperature rises quickly in February and March, which is the beginning of hot season. The air temperature then declines from the effect of the rain and stays at an even level from July through January. The annual precipitation is:

$$P_{in} \geq 0.44\ (T_F\ -\ 19.5)\ \text{or} \quad \text{(A.1)}$$

$$P_{cm} \geq 2\ (T_C + 7). \quad \text{(A.2)}$$

Where P_{in} is annual precipitation in inches, P_{cm} is annual precipitation in cm, T_F is annual mean temperature in degrees Fahrenheit, and T_C is annual mean temperature in degrees Celsius. The cooling degree-days (CDD) base-50 °F or base-10 °C is:

$$9{,}000 < CDD_{50\ °F}\ \text{or} \quad \text{(A.3)}$$

$$5{,}000 < CDD_{10\ °C}. \quad \text{(A.4)}$$

For Bangkok, Thailand, Table A1 shows that the annual precipitation is 59.98 inches (152.35 cm), the annual mean temperature is 83.3 ºF (28.5 °C), and the cooling degree-days base-50°F is 12,163 (6,907 cooling degree-days, base-10°C). Therefore:

$$59.98 \geq 28.07\ \text{or} \quad \text{(for A.1)}$$

$$152.35 \geq 71\ \text{and} \quad \text{(for A.2)}$$

$$9{,}000 < 12{,}163\ \text{or} \quad \text{(for A.3)}$$

$$5{,}000 < 6{,}907. \quad \text{(for A.4)}$$

A.1.2 Hot-Humid (Houston, Texas)

This climate (cooling-dominated) has a mild winter and a warm summer with high humidity. The range of the annual temperature cycle is wide. The mean temperature of the coldest month is above 32 °F (0 °C) and the warmest monthly mean is over 71.6 °F (22 °C). There is sufficient precipitation in all months and total annual rainfall is copious. Heavy rainfall is from an occasional tropical storm from the nearby Gulf of Mexico. The annual precipitation is similar to a very hot-humid climate (see Equations A.1 and A.2). The cooling degree-days (CDD) base-50 °F or base-10 °C is:

$$6{,}300 < CDD_{50\ °F} \leq 9{,}000 \text{ or} \tag{A.5}$$

$$3{,}500 < CDD_{10\ °C} \leq 5{,}000. \tag{A.6}$$

For Houston, Texas, Table A1 shows that the annual precipitation is 46.07 inches (117.02 cm), the annual mean temperature is 67.9 ºF (19.9 °C). The heating and cooling degree-days (base-50 °F) are 195 and 7,215 (i.e., 108 heating degree-days and 4,008 cooling degree-days; base-10 °C). The heating and cooling degree-days (base-65 °F) are 1,346 and 2,891 (i.e., 748 heating degree-days and 1,606 cooling degree-days; base-18 °C). Therefore:

$$6{,}300 < 7{,}215 \leq 9{,}000 \text{ or} \qquad \text{(for A.5)}$$

$$3{,}500 < 4{,}008 \leq 5{,}000. \qquad \text{(for A.6)}$$

A.1.3 Hot-Dry (Phoenix, Arizona)

A hot-dry climate (cooling-dominated) has a strong seasonal cycle. The annual range of temperature is around 36 °F (20 °C). The mean annual temperature is above 64.4 °F (18 °C). The monthly mean temperature in the summer is as high as 91.4 °F (33 °C), and the monthly mean temperature in the winter is as low as 55 °F (13 °C). Precipitation is light for the whole year. There is nearly rainless in May and June are nearly rainless. The annual precipitation of this climate is defined as:

$$P_{in} < 0.44\ (T_F\ \text{-}\ 19.5)\ \text{or} \tag{A.7}$$

$$P_{cm} < 2\ (T_C + 7). \tag{A.8}$$

The cooling degree-days (CDD) of a hot-dry climate is similar to a hot-humid climate (see Equations A.5 and A.6).

For Phoenix, Arizona, Table A1 shows that the annual precipitation is 7.66 inches (19.46 cm), the annual mean temperature is 72.6 ºF (22.6 °C). The heating and cooling degree-days (base-50 °F) are 90 and 7,830 (i.e., 50 heating degree-days and 4,350 cooling degree-days; base-10 °C). The heating and cooling degree-days (base-65 °F) are 1,382 and 3,647 (i.e., 768 heating degree-days and 2,026 cooling degree-days; base-18 °C). Therefore:

$7.66 < 23.36$ or (for A.7)

$19.46 < 59.11$ and (for A.8)

$6{,}300 < 7{,}830 \leq 9{,}000$ or (for A.5)

$3{,}500 < 4{,}350 \leq 5{,}000$. (for A.6)

A.1.4 Warm-Marine (San Francisco, California)

In this climate (heating-dominated), the annual range of temperature is narrow. The winter temperatures are very mild. The mean temperature of the coldest month is between 26.6 °F (-3 °C) and 64.4 °F (18 °C). The warmest month mean is less than 71.6 °F (22 °C). At least four months have mean temperature above 50 °F (10°C). Precipitation is significant for the whole year, which the heaviest rainfall is in the winter (October through March) is at least three times of the smallest rainfall in the summer (April through September). The heating degree-days (HDD) base-65 °F or base-18 °C of this climate is defined:

$$HDD_{65\,°F} \leq 3{,}600 \text{ or} \tag{A.9}$$

$$HDD_{18\,°C} \leq 2{,}000. \tag{A.10}$$

For San Francisco, California, Table A1 shows that the annual precipitation is 19.7 inches (50.04 cm), the annual mean temperature is 57.1 ºF (13.9 °C). The heating and cooling degree-days (base-50 °F) are 138 and 2,663 (i.e., 77 heating degree-days and 1,479 cooling degree-days; base-10 °C). The heating and cooling degree-days (base-65 °F) are 3,041 and 92 (i.e., 1,689 heating degree-days and 51 cooling degree-days; base-18 °C). Therefore:

$$2{,}663 \leq 3600 \text{ or} \qquad \text{(for A.9)}$$

$$1{,}479 \leq 2000. \qquad \text{(for A.10)}$$

A.1.5 Cool-Humid (Chicago, Illinois)

A cool-humid (heating-dominated) climate has warm summers and cold winters which causes a wide range of annual temperature. The warmest monthly mean is over 50 °F (10 °C) and the coldest monthly mean is under 26.6 °F (-3 °C). The monthly means from December through February are below the freezing temperature. Precipitation is significant in all months. The maximum precipitation (rainfall) occurs in the summer and the minimum precipitation (snow) occurs in the winter. The annual precipitation of the cool-humid climate is defined similar to a very hot-humid climate (see Equations A.1 and A.2). The heating degree-days (HDD) base-65 °F or base-18 °C of a cool-humid climate is:

$$5{,}400 < HDD_{65\,°F} \leq 7{,}200 \text{ or} \tag{A.11}$$

$$3{,}000 < HDD_{18\,°C} \leq 4{,}000. \tag{A.12}$$

For Chicago, Illinois, Table A1 shows that the annual precipitation is 35.82 inches (90.98 cm), the annual mean temperature is 49 ºF (9.4 °C). The heating and cooling degree-days (base-50 °F) are 3,000 and 3,339 (i.e., 1,667 heating degree-days and 1,855 cooling degree-days; base-10 °C). The heating and cooling degree-days (base-65 °F) are 6,151 and 1,015 (i.e., 3,417 heating degree-days and 564 cooling degree-days; base-18 °C). Therefore:

$35.82 \geq 12.98$ or (for A.1)

$90.98 \geq 32.80$ and (for A.2)

$5{,}400 < 6{,}151 \leq 7{,}200$ or (for A.11)

$3{,}000 < 3{,}417 \leq 4{,}000$. (for A.12)

A.1.6 Cool-Humid (Boston, Massachusetts)

In general, Boston climate is similar to Chicago climate. However, the solar radiation availability in Boston is less than in Chicago. Therefore, in this study, both cities were selected to compare the effect of the sunlight. For Boston, Massachusetts, Table A1 shows that the annual precipitation is 41.51 inches (105.44 cm), the annual mean temperature is 51.3 ºF (10.7 °C). The heating and cooling degree-days (base-50 °F) are 2,416 and 2,810 (i.e., 1,342 heating degree-days and 1,561 cooling degree-days; base-10 °C). The heating and cooling degree-days (base-65 °F) are 5,775 and 695 (i.e., 3,208 heating degree-days and 386 cooling degree-days; base-18 °C). Therefore:

$41.51 \geq 13.99$ or (for A.1)

$105.44 \geq 35.4$ and (for A.2)

$5{,}400 < 5{,}775 \leq 7{,}200$ or (for A.11)

$3{,}000 < 3{,}208 \leq 4{,}000$. (for A.12)

A.1.7 Cold-Dry (Boise, Idaho)

This cold-dry climate (heating-dominated) has a wide annual range of temperature. The temperature is warm to hot in the summer and cold in the winter. The mean annual temperature is under 64.4 °F (18 °C). The mean temperature of the coldest month is below the freezing temperature. Precipitation is light for the whole year. Precipitation (rainfall) in the summer is more than the precipitation (snowfall) in the winter. The annual precipitation is similar to a hot-dry climate (see Equations A.7 and A.8) and the heating degree-days is similar to a cool-humid climate (see Equations A.11 and A.12).

For Boise, Idaho, Table A1 shows that the annual precipitation is 12.11 inches (30.76 cm), the annual mean temperature is 50.9 ºF (10.5 °C). The heating and cooling degree-days (base-50 °F) are 2,276 and 2,828 (i.e., 1,264 heating degree-days and 1,571 cooling degree-days; base-10 °C). The heating and cooling degree-days (base-65 °F) are 5,667 and 744 (i.e., 3,148 heating degree-days and 413 cooling degree-days; base-18 °C). Therefore:

$$12.11 < 13.82 \text{ or} \qquad \text{(for A.7)}$$

$$30.76 < 35 \text{ and} \qquad \text{(for A.8)}$$

$$5{,}400 < 5{,}667 \le 7{,}200 \text{ or} \qquad \text{(for A.11)}$$

$$3{,}000 < 3{,}148 \le 4{,}000. \qquad \text{(for A.12)}$$

A.2 TMY2 WEATHER DATA FORMAT

The Typical Meteorological Year (TMY2) weather files (Marion and Urban, 1995) derived from the 1961-1990 National Solar Radiation Data Base (NSRDB; 1992, 1995) contain computer readable ASCII characters. A TMY2 file consists of a file header and 8,760 hourly weather data records. The format of file header and data are shown in Figure A.1. The header shows the station, which was defined as the station Weather Bureau Army Navy (WBAN) identification number, city, state, time zone, latitude, longitude, and elevation (see Table A.1). The 8760 hourly data records following the file header contain one year of solar radiation, illuminance, and meteorological data along with their source flags and uncertainty flags. Each record line starts with the year, month, day, and hour, consecutively. The filed positions, definition of the elements, as well as sample FORTRAN and C formats for reading the data are provided in Table A.2 (Marion and Urban, 1995).

A.3 IWEC Weather Data Format

The International Weather Year for Energy Calculation (IWEC) weather files were derived from up to 18 years (1982-1999) of DATSAV3 weather data developed by National Climatic Data Center (ASHRAE, 2002). The IWEC weather data contains Typical Meteorological Year (TMY2) hourly weather data for 227 locations outside the U.S. and Canada. The IWEC format was developed using TMY2 format as a basis. Similar to the TMY2 weather file, the IWEC file consists of the file header and the 8760 hourly records (see Figure A.2). Table A.2 describes the positions, elements, and definitions of the file header. Table A.3 contains the positions, elements, values, and definitions of the data records (ASHRAE, 2002).

```
14944 SIOUX_FALLS          SD  -6 N 43 34 W  96 44   435
85010101000000000000?00000?00000?00000?00000?00000?00000?010A710A7-150A7-211A7060A70975A7360A7052A70161A700945A70999099999004E7050F8000A700E7
85010102000000000000?00000?00000?00000?00000?00000?00000?010A710A7-144A7-206A7060A70975A7350A7077A70161A700914A70999099999004E7050F8000A700E7
85010103000000000000?00000?00000?00000?00000?00000?00000?010A710A7-144A7-200A7063A70975A7340A7062A70161A700732A70999099999004E7050F8000A700E7
85010104000000000000?00000?00000?00000?00000?00000?00000?010A710A7-150A7-206A7063A70976A7330A7072A70161A700640A70999099999004E7050F8000A700E7
85010105000000000000?00000?00000?00000?00000?00000?00000?010A710A7-156A7-217A7060A70976A7330A7067A70161A700640A70999099999003E7050F8000A700E7
85010106000000000000?00000?00000?00000?00000?00000?00000?010A710A7-167A7-222A7062A70976A7340A7067A70161A700640A70999099999003E7050F8000A700E7
85010107000000000000?00000?00000?00000?00000?00000?00000?004A704A7-183A7-233A7065A70977A7300A7052A70193A777777A70999999999003E7050F8000A700E7
85010108000000000000?00000?00000?00000?00000?00000?00000?002A702A7-194A7-244A7065A70978A7310A7036A70193A777777A70999999999003E7050F8000A700E7
85010109010212970037G50173G40024G50038I50071I40033I50043I604A700A7-200A7-256A7062A70978A7330A7046A70193A777777A70999999999003E7050F8000A700E7
85010110028714150157G50560G40043G50159I50444I40069I50079I600A700A7-189A7-256A7056A70979A7310A7067A70193A777777A70999999999003E7050F8000A700E7
85010111043614150276G40714G40056G50286I40642I40088I50111I500A700A7-172A7-250A7051A70979A7310A7062A70161A777777A70999999999003E7050F8000A700E7
85010112053014150357G40782G40064G50374I40735I40098I50131I500A700A7-167A7-244A7051A70978A7300A7062A70161A777777A70999999999003E7050F8000A700E7
85010113056214150387G40806G40067G50407I40767I40101I50139I500A700A7-156A7-244A7047A70978A7320A7067A70193A777777A70999999999003E7050F8000A700E7
85010114053014150359G40788G40064G50377I40742I40098I50131I500A700A7-144A7-239A7045A70978A7310A7062A70193A777777A70999999999003E7050F8000A700E7
85010115043614150277G40716G40056G50289I40645I40088I50111I500A700A7-139A7-239A7043A70978A7330A7052A70193A777777A70999999999003E7050F8000A700E7
85010116028614150157G50564G40043G50162I50450I40069I50080I600A700A7-139A7-233A7045A70978A7300A7052A70161A777777A70999999999003E7050F8000A700E7
85010117010412730038G50209G40021G50038I50104I40030I50038I600A700A7-150A7-233A7049A70978A7290A7041A70241A777777A70999999999003E7050F8000A700E7
85010118000000000000?00000?00000?00000?00000?00000?00000?000A700A7-167A7-233A7057A70978A7000A7000A70241A777777A70999999999003E7050F8000A700E7
85010119000000000000?00000?00000?00000?00000?00000?00000?000A700A7-172A7-233A7059A70978A7000A7000A70241A777777A70999999999003E7050F8000A700E7
85010120000000000000?00000?00000?00000?00000?00000?00000?000A700A7-178A7-233A7062A70978A7000A7000A70241A777777A70999999999003E7050F8000A700E7
85010121000000000000?00000?00000?00000?00000?00000?00000?000A700A7-183A7-239A7062A70978A7260A7015A70241A777777A70999999999003E7050F8000A700E7
85010122000000000000?00000?00000?00000?00000?00000?00000?000A700A7-183A7-239A7062A70977A7220A7021A70241A777777A70999999999003E7050F8000A700E7
85010123000000000000?00000?00000?00000?00000?00000?00000?000A700A7-178A7-239A7059A70977A7220A7015A70241A777777A70999999999003E7050F8000A700E7
85010124000000000000?00000?00000?00000?00000?00000?00000?000A700A7-178A7-239A7059A70977A7240A7010A70241A777777A70999999999003E7050F8000A700E7

                                                                                                 1         1         1         1         1
         1         2         3         4         5         6         7         8         9         0         1         2         3         4
1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012
                                                        (for field position identification only)
```

Figure A.1 *Sample file header and data in the TMY2 format for January 1 (Marion and Urban 1995, p. 18). Copyright © 1995 by NREL (Reprinted with permission).*

Table A.2 *Header elements in the TMY2 format (Marion and Urban 1995, p. 19). Copyright © 1995 by NREL (Reprinted with permission).*

Field Position	Element	Definition
002 - 006	WBAN Number	Station's Weather Bureau Army Navy number (see Table 2-1)
008 - 029	City	City where the station is located (maximum of 22 characters)
031 - 032	State	State where the station is located (abbreviated to two letters)
034 - 036	Time Zone	Time zone is the number of hours by which the local standard time is ahead of or behind Universal Time. For example, Mountain Standard Time is designated -7 because it is 7 hours behind Universal Time.
038 - 044	Latitude	Latitude of the station
038		N = North of equator
040 - 041		Degrees
043 - 044		Minutes
046 - 053	Longitude	Longitude of the station
046		W = West, E = East
048 - 050		Degrees
052 - 053		Minutes
056 - 059	Elevation	Elevation of station in meters above sea level
FORTRAN Sample Format: (1X,A5,1X,A22,1X,A2,1X,I3,1X,A1, 1X,I2,1X,I2,1X,A1,1X,I3,1X,I2,2X,I4) C Sample Format: (%s %s %s %d %s %d %d %s %d %d %d)		

Table A.3 *Data elements in the TMY2 format (Marion and Urban 1995, pp. 19-21). Copyright © 1995 by NREL (Reprinted with permission).*

Field Position	Element	Values	Definition
002 - 009	Local Standard Time		
002 - 003	Year	61 - 90	Year, 1961-1990
004 - 005	Month	1 - 12	Month
006 - 007	Day	1 - 31	Day of month
008 - 009	Hour	1 - 24	Hour of day in local standard time
010 - 013	Extraterrestrial Horizontal Radiation	0 - 1415	Amount of solar radiation in Wh/m^2 received on a horizontal surface at the top of the atmosphere during the 60 minutes preceding the hour indicated
014 - 017	Extraterrestrial Direct Normal Radiation	0 - 1415	Amount of solar radiation in Wh/m^2 received on a surface normal to the sun at the top of the atmosphere during the 60 minutes preceding the hour indicated
018 - 023	Global Horizontal Radiation		Total amount of direct and diffuse solar radiation in Wh/m^2 received on a horizontal surface during the 60 minutes preceding the hour indicated
018 - 021	Data Value	0 - 1200	
022	Flag for Data Source	A - H, ?	
023	Flag for Data Uncertainty	0 - 9	
024 - 029	Direct Normal Radiation		Amount of solar radiation in Wh/m^2 received within a 5.7° field of view centered on the sun during the 60 minutes preceding the hour indicated
024 - 027	Data Value	0 - 1100	
028	Flag for Data Source	A - H, ?	
029	Flag for Data Uncertainty	0 - 9	

Table A.3 *(continued)*

Field Position	Element	Values	Definition
030 - 035	Diffuse Horizontal Radiation		Amount of solar radiation in Wh/m^2 received from the sky (excluding the solar disk) on a horizontal surface during the 60 minutes preceding the hour indicated
030 - 033	Data Value	0 - 700	
034	Flag for Data Source	A - H, ?	
035	Flag for Data Uncertainty	0 - 9	
036 - 041	Global Horiz. Illuminance		Average total amount of direct and diffuse illuminance in hundreds of lux received on a horizontal surface during the 60 minutes preceding the hour indicated. 0 to 1300 = 0 to 130,000 lux
036 - 039	Data Value	0 - 1300	
040	Flag for Data Source	I, ?	
041	Flag for Data Uncertainty	0 - 9	
042 - 047	Direct Normal Illuminance		Average amount of direct normal illuminance in hundreds of lux received within a 5.7 degree field of view centered on the sun during the 60 minutes preceding the hour indicated. 0 to 1100 = 0 to 110,000 lux
042 - 045	Data Value	0 - 1100	
046	Flag for Data Source	I, ?	
047	Flag for Data Uncertainty	0 - 9	
048 - 053	Diffuse Horiz. Illuminance		Average amount of illuminance in hundreds of lux received from the sky (excluding the solar disk) on a horizontal surface during the 60 minutes preceding the hour indicated. 0 to 800 = 0 to 80,000 lux
048 - 051	Data Value	0 - 800	
052	Flag for Data Source	I, ?	
053	Flag for Data Uncertainty	0 - 9	
054 - 059	Zenith Luminance		Average amount of luminance at the sky's zenith in tens of Cd/m^2 during the 60 minutes preceding the hour indicated. 0 to 7000 = 0 to 70,000 Cd/m^2
054 - 057	Data Value	0 - 7000	
058	Flag for Data Source	I, ?	
059	Flag for Data Uncertainty	0 - 9	
060 - 063	Total Sky Cover		Amount of sky dome in tenths covered by clouds or obscuring phenomena at the hour indicated
060 - 061	Data Value	0 - 10	
062	Flag for Data Source	A - F	
063	Flag for Data Uncertainty	0 - 9	
064 - 067	Opaque Sky Cover		Amount of sky dome in tenths covered by clouds or obscuring phenomena that prevent observing the sky or higher cloud layers at the hour indicated
064 - 065	Data Value	0 - 10	
066	Flag for Data Source	A - F	
067	Flag for Data Uncertainty	0 - 9	
068 - 073	Dry Bulb Temperature		Dry bulb temperature in tenths of degrees C at the hour indicated. -500 to 500 = -50.0 to 50.0 degrees C
068 - 071	Data Value	-500 to 500	
072	Flag for Data Source	A - F	
073	Flag for Data Uncertainty	0 - 9	
074 - 079	Dew Point Temperature		Dew point temperature in tenths of degrees C at the hour indicated. -600 to 300 = -60.0 to 30.0 degrees C
074 - 077	Data Value	-600 to 300	
078	Flag for Data Source	A - F	
079	Flag for Data Uncertainty	0 - 9	
080 - 084	Relative Humidity		Relative humidity in percent at the hour indicated
080 - 082	Data Value	0 - 100	
083	Flag for Data Source	A - F	
084	Flag for Data Uncertainty	0 - 9	

Table A.3 *(continued)*

Field Position	Element	Values	Definition
085 - 090	Atmospheric Pressure		Atmospheric pressure at station in millibars at the hour indicated
085 - 088	Data Value	700 - 1100	
089	Flag for Data Source	A - F	
090	Flag for Data Uncertainty	0 - 9	
091 - 095	Wind Direction		Wind direction in degrees at the hour indicated. (N = 0 or 360, E = 90, S = 180,W = 270). For calm winds, wind direction equals zero.
091 - 093	Data Value	0 - 360	
094	Flag for Data Source	A - F	
095	Flag for Data Uncertainty	0 - 9	
096 - 100	Wind Speed		Wind speed in tenths of meters per second at the hour indicated. 0 to 400 = 0 to 40.0 m/s
096 - 98	Data Value	0 - 400	
99	Flag for Data Source	A - F	
100	Flag for Data Uncertainty	0 - 9	
101 - 106	Visibility		Horizontal visibility in tenths of kilometers at the hour indicated. 7777 = unlimited visibility 0 to 1609 = 0.0 to 160.9 km 9999 = missing data
101 - 104	Data Value	0 - 1609	
105	Flag for Data Source	A - F, ?	
106	Flag for Data Uncertainty	0 - 9	
107 - 113	Ceiling Height		Ceiling height in meters at the hour indicated. 77777 = unlimited ceiling height 88888 = cirroform 99999 = missing data
107 - 111	Data Value	0 - 30450	
112	Flag for Data Source	A - F, ?	
113	Flag for Data Uncertainty	0 - 9	
114 - 123	Present Weather	See Appendix B	Present weather conditions denoted by a 10-digit number. See Appendix B for key to present weather elements.
124 - 128	Precipitable Water		Precipitable water in millimeters at the hour indicated
124 - 126	Data Value	0 - 100	
127	Flag for Data Source	A - F	
128	Flag for Data Uncertainty	0 - 9	
129 - 133	Aerosol Optical Depth		Broadband aerosol optical depth (broad -band turbidity) in thousandths on the day indicated. 0 to 240 = 0.0 to 0.240
129 - 131	Data Value	0 - 240	
132	Flag for Data Source	A - F	
133	Flag for Data Uncertainty	0 - 9	
134 - 138	Snow Depth		Snow depth in centimeters on the day indicated. 999 = missing data
134 - 136	Data Value	0 - 150	
137	Flag for Data Source	A - F, ?	
138	Flag for Data Uncertainty	0 - 9	
139 - 142	Days Since Last Snowfall		Number of days since last snowfall . 88 = 88 or greater days 99 = missing data
139 - 140	Data Value	0 - 88	
141	Flag for Data Source	A - F, ?	
142	Flag for Data Uncertainty	0 - 9	

FORTRAN Sample Format:

```
(1X,4I2,2I4,7(I4,A1,I1),2(I2,A1,I1),2(I4,A1,I1),1(I3,A1,I1),
 1(I4,A1,I1),2(I3,A1,I1),1(I4,A1,I1),1(I5,A1,I1),10I1,3(I3,A1,I1),
 1(I2,A1,I1))
```

C Sample Format:

```
(%2d%2d%2d%2d%4d%4d%4d%1s%1d%4d%1s%1d%4d%1s%1d%4d%1s%1d%4d%1s%1d%4d%1s
 %1d%4d%1s%1d%2d%1s%1d%2d%1s%1d%4d%1s%1d%4d%1s%1d%3d%1s%1d%4d%1s%1d%3d
 %1s%1d%3d%1s%1d%4d%1s%1d%5ld%1s%1d%1d%1d%1d%1d%1d%1d%1d%1d%1d%1d%3d%1s
 %1d%3d%1s%1d%3d%1s%1d%2d%1s%1d)
```

Note: For ceiling height data, integer variable should accept data values as large as 99999.

```
IWEC 484560 BANGKOK                   THA 2 + 07 00 N 13 55 E 100 36 + 0012
1983 1 1 1   01415   0?9   0?9   0?9   0?9   0?9   0?9   0?9 2A7 0A7 236C9 178C9 70C91011C9270A7 10A7  40A722000A79999?00999999099999?0294E8999?099?0
1983 1 1 2   01415   0?9   0?9   0?9   0?9   0?9   0?9   0?9 2B8 0B8 224C9 181C9 77C91011C9999?0  7B8  40B899999?09999?09999999999999?0294E8999?099?0
1983 1 1 3   01415   0?9   0?9   0?9   0?9   0?9   0?9   0?9 2B8 0B8 213C9 182C9 83C91010C9999?0  3B8  40B899999?09999?09999999999999?0294E8999?099?0
1983 1 1 4   01415   0?9   0?9   0?9   0?9   0?9   0?9   0?9 2A7 0A7 204C9 182C9 87C91010C9  0A7  0A7  40A722000A79999?00999999099999?0294E8999?099?0
1983 1 1 5   01415   0?9   0?9   0?9   0?9   0?9   0?9   0?9 2B8 0B8 196C9 181C9 91C91011C9999?0  0B8  43B899999?09999?09999999999999?0294E8999?099?0
1983 1 1 6   01415   0?9   0?9   0?9   0?9   0?9   0?9   0?9 2B8 0B8 189C9 180C9 95C91011C9999?0  0B8  47B899999?09999?09999999999999?0294E8999?099?0
1983 1 1 7  111415   2G9   0G9   2G9   2I9   0I9   2I9   7I9 2A7 0A7 189A7 171A7 89E81012E8  0A7  0A7  50A722000A79999?00999999099999?0294E8999?099?0
1983 1 1 8 2431415  69H9  32H9  63H9  77I9  22I9  74I9 155I9 2B8 0B8 210B8 176C8 81E81012B8999?0 14B8  57B899999?09999?09999999999999?0294E8999?099?0
1983 1 1 9 5411415 271H9 289H9 160H9 291I9 227I9 211I9 337I9 2B8 0B8 232B8 181C8 73E81013B8999?0 27B8  63B899999?09999?09999999999999?0294E8999?099?0
1983 1 110 7941415 490G9 543G9 184G9 537I9 480I9 262I9 413I9 2A7 0A7 253A7 185A7 66E81013E8 10A7 41A7  70A722000A79999?00999999099999?0294E8999?099?0
1983 1 111 9831415 667H9 688H9 188H9 734I9 664I9 266I9 513I9 2B8 0B8 274B8 193C8 61E81013B8999?0 38B8  77B899999?09999?09999999999999?0294E8999?099?0
1983 1 11210961415 776H9 785H9 166H9 847I9 807I9 222I9 494I9 2B8 0B8 294B8 200C8 57E81012B8999?0 34B8  83B899999?09999?09999999999999?0294E8999?099?0
1983 1 11311261415 805G9 831G9 142G9 898I9 864I9 192I9 474I9 1A7 0A7 315A7 207A7 53E81011E8330A7 31A7  90A722000A79999?00999999919999?0294E8999?099?0
1983 1 11410691415 750H9 766H9 169H9 842I9 745I9 248I9 541I9 2B8 0B8 317B8 208C8 53E81010B8999?0 31B8  90B899999?09999?09999999999999?0294E8999?099?0
1983 1 115 9311415 617H9 697H9 157H9 686I9 670I9 233I9 408I9 2B8 0B8 318B8 208C8 52E81010B8999?0 31B8  90B899999?09999?09999999999999?0294E8999?099?0
1983 1 116 7201415 422G9 514G9 159G9 466I9 435I9 236I9 337I9 2A7 0A7 320A7 209A7 52E81009E8270A7 31A7  90A722000A79999?00999999919999?0294E8999?099?0
1983 1 117 4511415 199H9 225H9 127H9 215I9 156I9 175I9 258I9 2B8 0B8 311B8 206C8 54E81009B8999?0 24B8  83B899999?09999?09999999999999?0294E8999?099?0
1983 1 118 1431415  28H9   0H9  28H9  31I9   0I9  31I9  96I9 2B8 0B8 302B8 204C8 56E81010B8999?0 17B8  77B899999?09999?09999999999999?0294E8999?099?0
1983 1 119   01415   0?9   0?9   0?9   0?9   0?9   0?9   0?9 2A7 0A7 293A7 201A7 58E81010E8270A7 10A7  70A722000A79999?00999999919999?0294E8999?099?0
1983 1 120   01415   0?9   0?9   0?9   0?9   0?9   0?9   0?9 2B8 0B8 285B8 202C8 61E81010B8999?0  7B8  67B899999?09999?09999999999999?0294E8999?099?0
1983 1 121   01415   0?9   0?9   0?9   0?9   0?9   0?9   0?9 2B8 0B8 276B8 203C8 64E81011B8999?0  3B8  63B899999?09999?09999999999999?0294E8999?099?0
1983 1 122   01415   0?9   0?9   0?9   0?9   0?9   0?9   0?9 2A7 0A7 268A7 204A7 68E81011E8  0A7  0A7  60A722000A79999?00999999099999?0294E8999?099?0
1983 1 123   01415   0?9   0?9   0?9   0?9   0?9   0?9   0?9 2B8 0B8 262B8 204C8 71E81011B8999?0  0B8  53B899999?09999?09999999999999?0294E8999?099?0
1983 1 124   01415   0?9   0?9   0?9   0?9   0?9   0?9   0?9 2B8 0B8 256B8 205C8 73E81011B8999?0  0B8  47B899999?09999?09999999999999?0294E8999?099?0
```

Figure A.2 *Sample file header and data of Bangkok, Thailand, in the IWEC format for January 1.*

Table A.4 *Header elements in the IWEC format (ASHRAE 2002, p. 5). Copyright © 2001 by ASHRAE (Reprinted with permission).*

Field Position	Element	Definition
002-005	IWEC descriptor	The four characters 'IWEC'
007-012	WMO number	Unique number from the World Meteorological Organization for each station
014-035	City	City where station is located (max 22 characters)
037-038	State or province	State or province where station is located (abbreviated to 2 characters)
040-042	Country	3-character country code, according to ISO 3166 standard
044	WMO region number	One digit between 1 and 7: 1 = Africa 2 = Asia 3 = South America 4 = North and Central America 5 = South-West Pacific 6 = Europe 7 = Antarctica
046-052 046 048-049 051-052	Time zone	Number of hours by which the local standard time is ahead of or behind Universal Time Sign: + if ahead of or equal to UT, - if behind Hours Minutes
054-060 054 056-057 059-060	Latitude	Latitude of the station N = North of equator or 0, S = South of equator Degrees Minutes
062-069 062 064-066 068-069	Longitude	Longitude of the station W = West or 0, E = East Degrees Minutes
071-076 071 073-076	Elevation	Elevation of station above sea level + for above or at sea level, - for below sea level Elevation in meters

Table A.5 *Data Elements in the IWEC Format (ASHRAE 2002, pp. 5-7). Copyright © 2001 by ASHRAE (Reprinted with permission).*

Field Position	Element	Values	Definition
002 - 011	Local Standard Time		
002 - 005	Year	1982 - 1993	Year, 1982-1999
006 - 007	Month	01 - 12	Month
008 - 009	Day	01 - 31	Day of month
010 - 011	Hour	01 – 24	Hour of day in local standard time
012 - 015	Extraterrestrial Horizontal Radiation	0 – 1415	Amount of solar radiation in Wh/m2 received on a horizontal surface at the top of the atmosphere during the 60 minutes preceding the hour indicated
016 - 019	Extraterrestrial Direct Normal Radiation	1300 – 1415	Amount of solar radiation in Wh/m2 received on a surface normal to the rays of the sun at the top of the atmosphere during the 60 minutes preceding the hour indicated
020 - 025	Global Horizontal Radiation		Total amount of direct and diffuse solar radiation in Wh/m2 received on a horizontal surface during the 60 minutes preceding the hour indicated
020 - 023	Data Value	0 - 1200	
024	Flag for Data Source	A - H, ?	
025	Flag for Data Uncertainty	0 – 9	
026 - 030	Direct Normal Radiation		Amount of solar radiation in Wh/m2 received directly from the solar disk on a surface perpendicular to the sun's rays, during the 60 minutes preceding the hour indicated
026 - 029	Data Value	0 - 1100	
030	Flag for Data Source	A - H, ?	
031	Flag for Data Uncertainty	0 - 9	
032 - 037	Diffuse Horizontal Radiation		Amount of solar radiation in Wh/m2 received from the sky (excluding the solar disk) on a horizontal surface during the 60 minutes preceding the hour indicated
032 - 035	Data Value	0 - 1200	
036	Flag for Data Source	A - H, ?	
037	Flag for Data Uncertainty	0 - 9	
038 - 043	Global Horizontal Illuminance		Average total amount of direct and diffuse illuminance in hundreds of lux received on a horizontal surface during the 60 minutes preceding the hour indicated. 0 to 1,300 = 0 to 130,000 lux
038 - 041	Data Value	0 - 1300	
042	Flag for Data Source	I, ?	
043	Flag for Data Uncertainty	0 - 9	
044 - 049	Direct Normal Illuminance		Average amount of illuminance in hundreds of lux received directly from the solar disk on a surface perpendicular to the sun's rays, during the 60 minutes preceding the hour indicated 0 to 1,100 = 0 to 110,000 lux
044 - 047	Data Value	0 - 1100	
048	Flag for Data Source	I, ?	
049	Flag for Data Uncertainty	0 - 9	
050 - 055	Diffuse Horizontal Illuminance		Average amount of illuminance in hundreds of lux received from the sky (excluding the solar disk) on a horizontal surface during the 60 minutes preceding the hour indicated 0 to 800 = 0 to 80,000 lux
050 - 053	Data Value	0 - 800	
054	Flag for Data Source	I, ?	
055	Flag for Data Uncertainty	0 - 9	
056 - 061	Zenith Luminance		Average amount of luminance at the sky's zenith in tens of Cd/m2 during the 60 minutes preceding the hour indicated 0 to 7000 = 0 to 70,000 Cd/m2
056 - 059	Data Value	0 - 7000	
060	Flag for Data Source	I, ?	
061	Flag for Data Uncertainty	0 - 9	
062 - 065	Total Sky cover		Amount of sky dome in tenths covered by clouds or obscuring phenomena at the hour indicated
062 - 063	Data Value	0 - 10	
064	Flag for Data Source	A - F	
065	Flag for Data Uncertainty	0 - 9	
066 - 069	Opaque Sky Cover		Amount of sky dome in tenths covered by clouds or obscuring phenomena that prevent observing the sky or higher cloud layers at the hour indicated
066 - 067	Data Value	0 - 10	
068	Flag for Data Source	A - F	
069	Flag for Data Uncertainty	0 - 9	
070 - 075	Dry Bulb Temperature		Dry bulb temperature in tenths of Celsius at the hour indicated -500 to 500 = -50.0 to 50.0 C
070 - 073	Data Value	-600 to 500	
074	Flag for Data Source	A - F	
075	Flag for Data Uncertainty	0 - 9	
076 - 081	Dew Point Temperature		Dew point temperature in tenths of Celsius at the hour indicated -600 to 300 = -60 .0 to 30.0 C
076 - 079	Data Value	-600 to 300	
080	Flag for Data Source	A - F	
081	Flag for Data Uncertainty	0 - 9	

Table A.5 *(continued)*

082 - 086 082 - 084 085 086	Relative Humidity Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 100 A - F 0 - 9	Relative humidity in percent at the hour indicated
087 - 092 087 - 090 091 092	Atmospheric Pressure Data Value Flag for Data Source Flag for Data Uncertainty	 700 - 1100 A - F 0 - 9	Atmospheric pressure at station in hundreds of Pascal at the hour indicated 700 to 1,100 = 70,000 to 110,000 Pa
093 - 097 093 - 095 096 097	Wind Direction Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 360 A - F 0 - 9	Wind direction in degrees at the hour indicated (N = 0, E = 90, S = 180, W = 270). If calm, direction equals zero
098 - 102 098 - 100 101 102	Wind Speed Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 400 A - F 0 - 9	Wind speed in tenths of meters per second at the hour indicated 0 to 400 = 0 to 40.0 m/s
103 - 108 103 - 106 107 108	Visibility Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 1609 A - F, ? 0 - 9	Horizontal visibility in tenths of kilometers at the hour indicated. 0 to 1600 = 0.0 to 160.0 km. Values greater than 1600 are entered as 1600
109 - 115 109 - 113 114 115	Ceiling Height Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 30450 A - F, ? 0 - 9	Ceiling height in meters at the hour indicated 77777 = unlimited ceiling height 88888 = cirroform
116 - 121 116 - 119 120 121	Sky condition Data Values by Layer Flag for Data Source Flag for Data Uncertainty	 0 - 8 A, B, E, ? 0 - 9	Coded by layer in ascending order; four layers are described; if less than four layers are present the remaining positions are coded 0. The code for each layer is: 0 = Clear (less than 0.1 cover) 1 = Thin scattered 2 = Opaque scattered (0.1-0.5 cover) 3 = Thin broken 4 = Opaque broken (0.6-0.9 cover) 5 = Thin overcast 6 = Opaque overcast (1.0 cover) 7 = Obscuration 8 = Partial obscuration The flag is left as '?' only if all four layers are missing.
122 - 131	Present Weather		Present weather conditions denoted by a 10-digit number. See separate section.
132 - 136 132 - 134 135 136	Precipitable Water Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 100 A - F 0 - 9	Precipitable water in millimeters at the hour indicated
137 - 141 137 - 139 140 141	Aerosol Optical Depth Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 240 A - F 0 - 9	Broadband aerosol optical depth (broadband turbidity) in thousandths on the day indicated 0 to 240 = 0.0 to 0.240
142 - 146 142 - 144 145 146	Snow Depth Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 150 A - F, ? 0 - 9	Snow depth in centimeters on the day indicated
147 - 150 147 - 148 149 150	Days Since Last Snowfall Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 88 A - F, ? 0 - 9	Number of days since last snowfall 88 = 88 or greater days

APPENDIX B

DOE-2 INPUT FILES AND REPORTS

Examples of the DOE-2 input files (Appendix B.1), Hourly Reports (Appendix B.2), and Building Energy Performance Summary (BEPS) reports (Appendix B.3) in this study are provided:

B.1 DOE-2 INPUT FILES

In this study, the DOE-2 input file of the prototype model for each design strategy is developed from the “sngfam2st” input file of the traditional single-family house (Haberl et al., 2003c; 2004). The input files of the prototype house, which were developed for this research, include: 1) a lightweight house (base case), 2) a lightweight house without internal loads, 3) a high thermal mass house, and 4) a lightweight house with an economizer. The important parts of the input files in Section 4.2.1 and Section 5.2 that are different from the traditional house are defined in Sections B.1.1 to B.1.4.

B.1.1 Lightweight (Base Case)

```
$***************************MODIFICATIONS*****************************
$SOPA   SYSTEM = SZRH
$SOPA   NO SETBACK
$SOPA   REHEAT-DELTA-T = 55
$SOPA   FURNACE, SIZE = -999
$SOPA   HERM-REC-CHLR, SIZE = -999
$SOPA   WOOD STUDS FLOOR (ACTIVE CRAWL SPACE)
$SOPA   FLOOR INSULATION R7
$SOPA   CRAWL SPACE WALL ABOVE GROUND = 1.5 FT
$SOPA   CRAWL SPACE WALL UNDER GROUND = 1 FT

$*******************************************************************

INPUT LOADS

$***************************PARAMETERS********************************

PARAMETER
##def BLDG1[b01,b02,b03,b04,b05,b06,b07,b08,b09,b10,b11
           ,b12,b13,b14,b15,b16,b17,b18,b19,b20,b21
           ,b22,b23,b24,b25,b26,b27,b28,b29,b30,b31
           ,b32]
```

```
$b01   "T" THERMAL MASS MODE. USES CUSTOM WEIGHTING FACTORS
$      "Q" QUICK MODE. USE PRECALCULATED WEIGHTHING FACTORS

$b02   COUNTY AND WEATHER LOCATION (41 Counties)
$      NAME   CITY          LAT     LONG     ALT      AIR-CHANGE
$SOPA   BKK    BANGKOK     13.00   -107.00    10.00    0.3933
$       HOU    HOUSTON     29.98     95.37   108.00    0.4617
$SOPA   PHO    PHOENIX     33.43    112.02  1112.00    0.3876
$SOPA   SAF    SAN FRANCIS 37.62    122.38    16.00    0.5244
$SOPA   CHI    CHICAGO     41.78     87.75   623.00    0.5301
$SOPA   BOI    BOISE       43.57    116.22  2867.00    0.4959
$SOPA   BOS    BOSTON      42.37     71.03    16.00    0.6099

$b03  The azimuth of building(0:SOUTH, 90:WEST, 180:NORTH, 270:EAST)

$b04 Width of building (ft), Refer to the following drawing

$b05   Depth of building (ft), Refer to the following drawing

$b06    Height of wall (ft), Refer to the following drawing

$b07   Door height (ft)

$b08   Door width (ft)

$b09 Run Year

$b10 Number of floor (1 or 2).
$    If 1, then one-story house, or if 2, then two-story house.

$b11 Activation/ Deactivation of crawl space (C or S).
$    If C, then activate crawl space, or if S, then Slab on Grade.

$b12 Height of crawlwall overground(ft)

$b13 Height of crawlwall underground(ft)

$b14-b32      spare parameters
$
$
$
$                    --------------------------    ^
$                    |                         |    |
$                    |                         |    |
$                    |                         |    |
$                    |                         |    |
$  ^     ------------|                         |   b05(ft)
$  |    |            |         House           |    |
$  |    |            |                         |    |
$ 22ft  |   Garage   |                         |    |
$  |    |   (FIXED)  |                         |    |
$  |    |            |                         |    |
$  v     ------------|-------------------------|    v
$
$       <----22ft----><-------- b04(ft)------->
$
```

```
$                    -------------------------
$                   |       -----------        |
$                   |      |   c21(%)  |       | (If 2ndFL is activated)
$                   |       -----------        |
$                   |-------------------------|   ^
$                   |       -----------        |   |
$       |------------|      |   c21(%)  |      |  b06(ft)
$       |   Garage   |       -----------       |   |
$       |   (FIXED)  |-------------------------|   V
$       |            |          b12 (ft)       | (Height of crawlwall
$       |            |                         |   overground)
$  G.L --------------|-------------------------|--------------------G.L
$                    |          b13 (ft)       | (Height of crawlwall
$                    |-------------------------|  underground)
$
$
$

##IF #[b01 EQS "T"]                        $ T: THERMAL MASS WALL
     ##SET1 THERMALMASS #["O" // "N"]      $ ACTIVATING THE THERMAL MASS
                                           $ MODE
##ELSEIF #[b01 EQS "Q"]                    $ Q: QUICK WALL
     ##SET1 THERMALMASS #["O" // "FF"]     $ ACTIVATING QUICK WALL MODE
##ENDIF

$ ******SPECIFICATIONS FOR THE BUILDING MODEL LOCATION*****************

##IF #[b02 EQS "BKK"]                      $SOPA BKK: BANGKOK (USE MIAMI
                                           $SOPA WATHER FACTOR)
     ##SET1 P-LATITUDE #[13.00 * 1]        $SOPA LATITUDE
     ##SET1 P-LONGITUDE #[-107.00 * 1]     $SOPA LONGTITUDE
     ##SET1 P-TIME-ZONE #[-7 * 1]          $SOPA TIME ZONE
     ##SET1 P-ALTITUDE #[10 * 1]           $SOPA ALTITUDE(ft)
     ##SET1 P-AIRCHANGE #[0.57 * 0.69]     $SOPA NORMALIZED LEAKAGE x
                                           $SOPA WEATHER FACTOR
                                           $SOPA FACTOR IS DETERMINED BY
                                           $SOPA ASHRAE STD 136

##ELSEIF #[b02 EQS "HOU"]                  $HOU: HOUSTON
     ##SET1 P-LATITUDE #[29.98 * 1]        $LATITUDE
     ##SET1 P-LONGITUDE #[95.37 * 1]       $LONGTITUDE
     ##SET1 P-TIME-ZONE #[6 * 1]           $TIME ZONE
     ##SET1 P-ALTITUDE #[108 * 1]          $ALTITUDE(ft)
     ##SET1 P-AIRCHANGE #[0.57 * 0.81]     $NORMALIZED LEAKAGE x WEATHER
                                           $FACTOR, DETERMINED BY
                                           $ASHRAE STANDARD 136

##ELSEIF #[b02 EQS "PHO"]                  $SOPA PHO: PHOENIX
     ##SET1 P-LATITUDE #[33.43 * 1]        $SOPA LATITUDE
     ##SET1 P-LONGITUDE #[112.02 * 1]      $SOPA LONGTITUDE
     ##SET1 P-TIME-ZONE #[7 * 1]           $SOPA TIME ZONE
     ##SET1 P-ALTITUDE #[1112 * 1]         $SOPA ALTITUDE(ft)
     ##SET1 P-AIRCHANGE #[0.57 * 0.68]     $SOPA NORMALIZED LEAKAGE x
                                           $SOPA WEATHER FACTOR
                                           $SOPA FACTOR IS DETERMINED BY
                                           $SOPA ASHRAE STD 136

##ELSEIF #[b02 EQS "SAF"]                  $SOPA SAN: SAN FRANCISCO
     ##SET1 P-LATITUDE #[37.62 * 1]        $SOPA LATITUDE
     ##SET1 P-LONGITUDE #[122.38 * 1]      $SOPA LONGTITUDE
```

```
     ##SET1 P-TIME-ZONE #[8 * 1]          $SOPA TIME ZONE
     ##SET1 P-ALTITUDE #[16 * 1]          $SOPA ALTITUDE(ft)
     ##SET1 P-AIRCHANGE #[0.57 * 0.92]    $SOPA NORMALIZED LEAKAGE x
                                          $SOPA WEATHER FACTOR
                                          $SOPA FACTOR IS DETERMINED BY
                                          $SOPA ASHRAE STD 136

##ELSEIF #[b02 EQS "CHI"]                 $SOPA CHI: CHICAGO
     ##SET1 P-LATITUDE #[41.78 * 1]       $SOPA LATITUDE
     ##SET1 P-LONGITUDE #[87.75 * 1]      $SOPA LONGTITUDE
     ##SET1 P-TIME-ZONE #[6 * 1]          $SOPA TIME ZONE
     ##SET1 P-ALTITUDE #[623 * 1]         $SOPA ALTITUDE(ft)
     ##SET1 P-AIRCHANGE #[0.57 * 0.93]    $SOPA NORMALIZED LEAKAGE x
                                          $SOPA WEATHER FACTOR
                                          $SOPA FACTOR IS DETERMINED BY
                                          $SOPA ASHRAE STD 136

##ELSEIF #[b02 EQS "BOS"]                 $SOPA BOS: BOSTON
     ##SET1 P-LATITUDE #[42.37 * 1]       $SOPA LATITUDE
     ##SET1 P-LONGITUDE #[71.03 * 1]      $SOPA LONGTITUDE
     ##SET1 P-TIME-ZONE #[5 * 1]          $SOPA TIME ZONE
     ##SET1 P-ALTITUDE #[16 * 1]          $SOPA ALTITUDE(ft)
     ##SET1 P-AIRCHANGE #[0.57 * 1.07]    $SOPA NORMALIZED LEAKAGE x
                                          $SOPA WEATHER FACTOR
                                          $SOPA FACTOR IS DETERMINED BY
                                          $SOPA ASHRAE STD 136

##ELSEIF #[b02 EQS "BOI"]                 $SOPA BOI: BOISE
     ##SET1 P-LATITUDE #[43.57 * 1]       $SOPA LATITUDE
     ##SET1 P-LONGITUDE #[116.22 * 1]     $SOPA LONGTITUDE
     ##SET1 P-TIME-ZONE #[7 * 1]          $SOPA TIME ZONE
     ##SET1 P-ALTITUDE #[2867 * 1]        $SOPA ALTITUDE(ft)
     ##SET1 P-AIRCHANGE #[0.57 * 0.87]    $SOPA NORMALIZED LEAKAGE x
                                          $SOPA WEATHER FACTOR
                                          $SOPA FACTOR IS DETERMINED BY
                                          $SOPA ASHRAE STD 136

##ENDIF

$AIR CHANGE          ACH=NORMALIZED LEAKAGE x WEATHER FACTOR
$                    NORMALIZED LEAKAGE = 0.57, THE WEATHER
$                    FACTOR IS DETERMINED BY ASHRAE STANDARD 136,
$                    WEATHER FACTOR FOR LARGE TEXAS CITIES IS IN
$                    THE FOLLOWING TABLE
$SOPA                (NORMALIZED LEAKAGE = 0.57)
$
$                    CITY         WEATHER FACTOR
$SOPA                BANGKOK          0.69 (USE MIAMI'S WEATHER FACTOR)
$                    HOUSTON          0.81
$SOPA                PHOENIX          0.68
$SOPA                SAN FRANCISCO    0.92
$SOPA                CHICAGO          0.93
$SOPA                BOISE            0.87
$SOPA                BOSTON           1.07
```

```
$***************************MATERIALS*******************************

INSULATION-R7        = MATERIAL                $SOPA DOE2.1E (MATERIALS
                                               $SOPA LIBRARY)
                     THICKNESS    = .1882      $SOPA (FT)
                     CONDUCTIVITY = .025       $SOPA (BTU.FT/HR.FT^2.F)
                     DENSITY      = 0.6        $SOPA (LB/FT^3)
                     SPECIFIC-HEAT= .20  ..    $SOPA (BTU/LB.F)
                                               $SOPA CHANGE THICKNESS
AIR-GAP-HOR          = MATERIAL
                     RESISTANCE   = .87  ..    $SOPA (HR.FT^2.F/BTU),
                                               $SOPA AL23

HARD-WOOD-JOIST      = MATERIAL                $SOPA DOE2.1E(MATERIALS
                                               $SOPA LIBRARY)
                     THICKNESS    = .6666      $SOPA (FT)
                     CONDUCTIVITY = .0916      $SOPA (BTU.FT/HR.FT^2.F)
                     DENSITY      = 45         $SOPA (LB/FT^3)
                     SPECIFIC-HEAT= .30  ..    $SOPA (BTU/LB.F)

PLY-WOOD-2           = MATERIAL                $SOPA DOE2.1E(MATERIALS
                                               $SOPA LIBRARY)
                     THICKNESS    = .0833      $SOPA (FT)
                     CONDUCTIVITY = .0667      $SOPA (BTU.FT/HR.FT^2.F)
                     DENSITY      = 34         $SOPA (LB/FT^3)
                     SPECIFIC-HEAT = .29   ..  $SOPA (BTU/LB.F), PW03

$*************************LAYERS*************************************

WA-3 = LAYERS   $SOPA (WA-3 = FLOOR)
       MATERIAL = (INSULATION-R7, BUILDING-PAPER,
                   AIR-GAP-HOR, PLY-WOOD-2)  ..      $SOPA
                $ SOPA Insulation Part of Wall
                $ SOPA INSULATION-R7 = MINERAL WOOL/FIBER
                $ SOPA AIR-GAP-HOR = 2"
                $ SOPA PLY-WOOD-2 = SUBFLOOR HARD WOOD 1"
                $ SOPA The percentage of WA-3 = 87.5 %

WA-4 = LAYERS   $SOPA (WA-4 = FLOOR)
       MATERIAL = (HARD-WOOD-JOIST, PLY-WOOD-2)  ..  $SOPA
                $ SOPA JOIST Part of Wall
                $ SOPA HARD-WOOD-JOIST = 2*8"
                $ SOPA PLY-WOOD-2 = SUBFLOOR HARD WOOD 1"
                $ SOPA The percentage of WA-4 = 12.5 %

$**********************CONSTRUCTION*********************************

WALL-3    = CONSTRUCTION         $SOPA
            LAYERS = WA-3   ..   $SOPA

WALL-4    = CONSTRUCTION         $SOPA
            LAYERS = WA-4   ..   $SOPA

$**********************INTERNAL FLOOR/CEILING**********************

           FLOOR-RS1 = INTERIOR-WALL    $SOPA INSULATION PART
           AREA      = P-AREAS[]*.875   $SOPA (FT^2)
$          HEIGHT =                     ALT METHODS FOR DEFINING,
                                        $S.KIM, TURN OFF
$               WIDTH  =                     INTERIOR WALL(FT), TURN OFF
```

```
$          LOCATION =                    UNUSED
           NEXT-TO = RM-2
$          INT-WALL-TYPE = STANDARD     PLACED IN SET-DEFAULT
           TILT = 0                     $(DEGREES)
$SOPA      CONSTRUCTION = WALL-1
           CONSTRUCTION = WALL-3        $SOPA
$          INSIDE-VIS-REFL = (0.3,0.7)  (ARBITRARY,DOE-2 DEFAULT),
$                                       FOR DALIGHTING(0 TO 1)
$          SOLAR-FRACTION = (0.1,0.1)   FRACTION OF SOLAR ENERGY
$                                       ABSORBED(0 TO 1)
$                                       BY THE CEILING
$           X = 0                       DOE-2 DEFAULT,USED ONLY IF
$                                       EITHER SIDE OF THE
$           Y =                         DOE-2 DEFAULT,WALL IS IN A
$                                       SPACE WITH
$                                       SUNSPACE=YES
$           Z = 0.0                     DOE-2 DEFAULT(COORDINATES)
$          AZIMUTH = 170
$          INSIDE-SOL-ABS = (0.5,0.4)   (DOE-2 DEFAULT,ARBITRARY)(0-1)
                   ..                   $END OF INTERIOR WALL COMMAND
FLOOR-RS2 = INTERIOR-WALL               $SOPA INSULATION PART
           AREA = P-AREAS[]*.125        $SOPA (FT^2)
           NEXT-TO = RM-2               $SOPA
           TILT = 0                     $(DEGREES)
           CONSTRUCTION = WALL-4        $SOPA

##IF #[CRAWLSPACE[] EQS "ON"]           $ CRAWLSPACE ACTIVATED

$SOPA FLOOR1-R = INTERIOR-WALL
$SOPA      AREA = P-AREAF[]       (FT^2)PERIMETER,USED FOR FL AREA WHEN
           FLOOR1-R1 = INTERIOR-WALL
$SOPA INSULATION PART AREA = 2062
$SOPA 87.5% OF GRAOSS FL AREA
$          HEIGHT = 8                   ALTERNATE MTHODS FOR DEFINING,
$                                       S.KIM, TURN OFF
$               WIDTH =  22                 INTERIOR WALL(FT), TURN OFF
$          LOCATION = UNUSED
$          NEXT-TO = CRAWL-1
      $          INT-WALL-TYPE = STANDARD     PLACED IN SET-DEFAULT
      $          TILT = 0(DEGREES)
$SOPA      CONSTRUCTION = WALL-2
           CONSTRUCTION = WALL-3        $SOPA
$          INSIDE-VIS-REFL = (0.3,0.7)  (ARBITRARY,DOE-2 DEFAULT),FOR
$                                       DALIGHTING(0 TO 1)
$          SOLAR-FRACTION = 0.2
$          FRACTION OF SOLAR ENERGY ABSORBED(0 TO 1)BY THE CEILING
$          X = 0               DOE-2 DEFAULT,USED ONLY IF EITHER SIDE OF
$          Y = P-BUILDINGWIDTH          DOE-2 DEFAULT,WALL IS IN A
$                                       SPACE WITH
$                                       SUNSPACE=YES
$          Z = 0.0                      DOE-2 DEFAULT(COORDINATES)
$          AZIMUTH = 270
$          INSIDE-SOL-ABS = (0.5,0.4)   (DOE-2 DEFAULT,ARBITRARY)(0-1)
                   ..                   $ END OF INTERIOR WALL COMMAND
           FLOOR1-R2 = INTERIOR-WALL    $SOPA INSULATION PART
           AREA = 438                   $SOPA 12.5% OF GRAOSS FL AREA
           NEXT-TO = CRAWL-1            $SOPA
           TILT = 0                     $SOPA (DEGREES)
           CONSTRUCTION = WALL-4   ..   $SOPA
```

```
$**********************HOURLY REPORT*******************************

SCH-1          = SCHEDULE                        $SOPA
                 THRU DEC 31 (ALL)(1,24)(1)  .. $SOPA

BG1            = REPORT-BLOCK
                 VARIABLE-TYPE=GLOBAL
                 VARIABLE-LIST=(15)    ..       $SOPA 15 = GBH
                                                $SOPA(BTU/HR-SQFT)
                                                $SOPA (DOE-2.1E,
                                                $SOPA SUPPLEMENT, A.2)

BG2            = REPORT-BLOCK                   $SOPA
                 VARIABLE-TYPE=GLOBAL           $SOPA
                 VARIABLE-LIST=(17,19) ..       $SOPA 17 = WIND SPEED
                                                $SOPA (KNOTS)
                                                $SOPA 19 = WIND DIR.
                                                $SOPA (RADIANS)
                                                $SOPA (DOE-2.1E,
                                                $SOPA SUPPLEMENT, A.2)

REP2           = H-R
REPORT-SCHEDULE = SCH-1                         $SOPA
REPORT-BLOCK    = (BG2,BG2)                     $SOPA

   ..

END  ..
COMPUTE  LOADS   ..


$*****************************************************************

INPUT SYSTEMS

HEAT-1 = DAY-SCHEDULE                                 $SOPA NO SETBACK
           HOURS = (1,6)                              $SOPA
           VALUES = (68,68,68,68,68,68)               $SOPA
           HOURS = (7,17)
           VALUES = (68,68,68,68,68,68,68,68,68,68,68)
           HOURS = (18,24)
           VALUES = (68,68,68,68,68,68,68)   ..

HEAT-2 = DAY-SCHEDULE                                 $SOPA NO SETBACK
           HOURS = (1,6)                              $SOPA
           VALUES = (68,68,68,68,68,68)               $SOPA
           HOURS = (7,17)
           VALUES = (68,68,68,68,68,68,68,68,68,68,68)
           HOURS = (18,24)
           VALUES = (68,68,68,68,68,68,68)   ..

DAYHEAT = WEEK-SCHEDULE
           DAYS = (MON,FRI)
           DAY-SCHEDULE = HEAT-1
           DAYS = (WEH)
           DAY-SCHEDULE = HEAT-2   ..

THEAT = SCHEDULE
           THRU DEC 31   DAYHEAT   ..
```

```
COOL-1 = DAY-SCHEDULE                                  $SOPA NO SETBACK
           HOURS = (1,6)                               $SOPA
           VALUES = (78,78,78,78,78,78)                $SOPA
           HOURS = (7,17)
           VALUES = (78,78,78,78,78,78,78,78,78,78,78)
           HOURS = (18,24)
           VALUES = (78,78,78,78,78,78,78)   ..

COOL-2 = DAY-SCHEDULE                                  $SOPA NO SETBACK
           HOURS = (1,6)                               $SOPA
           VALUES = (78,78,78,78,78,78)                $SOPA
           HOURS = (7,17)
           VALUES = (78,78,78,78,78,78,78,78,78,78,78)
           HOURS = (18,24)
           VALUES = (78,78,78,78,78,78,78)   ..

DAYCOOL = WEEK-SCHEDULE
           DAYS = (MON,FRI)
           DAY-SCHEDULE = COOL-1
           DAYS = (WEH)
           DAY-SCHEDULE = COOL-2   ..

TCOOL = SCHEDULE
          THRU DEC 31   DAYCOOL  ..

SYSTEM-1 = SYSTEM
            SYSTEM-TYPE = SZRH          $SOPA SINGLE ZONE FAN SYSTEM
                                        $SOPA WITH OPTIONAL
                                        $SOPA SUBZONE REHEAT(SZRH)
            SYSTEM-CONTROL = S-CTRL
            SYSTEM-FANS = S-FAN
            SYSTEM-AIR = S-AIR
            SYSTEM-EQUIPMENT = S-EQUIP
            REHEAT-DELTA-T = 55         $SOPA (INPUT REQUIRED FOR SZRH)
            SYSTEM-REPORTS = YES
            ZONE-NAMES = (RM-1,RM-2,GARAGE-1,CRAWL-1)
            HEAT-SOURCE = P-HEAT-SOURCE[]        $(OR HOT WATER,
                                                 $ELECTRIC-HEAT-PUMP,
                                                 $GAS-HEAT-PUMP)
            SIZING-RATIO = 1.0                   $DOE-2 DEFAULT(0.1-2)
            COOL-SIZING-RATIO = 1.0              $DOE-2 DEFAULT(0.1-2)
            HEAT-SIZING-RATIO = 1.0              $DOE-2 DEFAULT(0.1-2)

                      ..                         $END OF SYSTEM COMMAND

$************************HOURLY REPORT**********************************

SCH-1     =SCHEDULE                       $SOPA
           THRU DEC 31 (ALL)(1,24)(1) ..  $SOPA

BG3        =REPORT-BLOCK                  $SOPA
           VARIABLE-TYPE=RM-1             $SOPA
           VARIABLE-LIST=(6) ..           $SOPA  6 = ZONE TEMP. (F)
                                          $SOPA (DOE-2.1E, SUP., A.17)

BG4       =REPORT-BLOCK                   $SOPA
           VARIABLE-TYPE=SYSTEM-1         $SOPA
           VARIABLE-LIST=(35) ..          $SOPA 35 = RETURN HUMIDITY
                                          $SOPA(LBS/LB)
                                          $SOPA (DOE-2.1E, SUP., A.29)
```

```
BG5       =REPORT-BLOCK                   $SOPA
           VARIABLE-TYPE=GLOBAL           $SOPA
           VARIABLE-LIST=(8,10) ..        $SOPA  8 = DRY BULB TEMP (F)
                                          $SOPA 10 = HUMIDITY RATIO
                                          $SOPA(FRAC,MULT)
                                          $SOPA (DOE-2.1E, SUP., A.16)

REP1      =H-R                            $SOPA
REPORT-SCHEDULE = SCH-1                   $SOPA
REPORT-BLOCK=(BG3,BG4,BG5) ..             $SOPA

END  ..

COMPUTE SYSTEMS ..

$***********************************************************************

INPUT PLANT

PLANT-1 = PLANT-ASSIGNMENT   ..

$ PLANT-EQUIPMENT

PLANT-EQUIP-1 = PLANT-EQUIPMENT
                  TYPE = FURNACE        $SOPA COMPLETE LIST ON P.48
                                        $SOPA DOE2.1E BDL SUMMARY,
                                        $SOPA COOLING-TOWER
                                        $SOPA ADDED IN VER.119
                  SIZE = -999  ..       $SOPA AUTOMATICALLY SIZE
                                        $SOPA BASED ON PEAK DEMAND

PLANT-EQUIP-2 = PLANT-EQUIPMENT         $SOPA
                  TYPE = HERM-REC-CHLR  $SOPA HERMETIC RECIPROCATING
                                        $SOPA CHILLER, MULTI-COMP.
                                        $SOPA OR UNLOADING COMPRESSOR
                  SIZE = -999  ..       $SOPA AUTOMATICALLY SIZE
                                        $SOPA BASED ON PEAK DEMAND

$*******************HOURLY REPORT**********************************

SCH-1           = SCHEDULE
                  THRU DEC 31 (ALL)(1,24)(1) ..
BG6             = REPORT-BLOCK
$SOPA             VARIABLE-TYPE=PLANT
                  VARIABLE-TYPE=END-USE       $SOPA
$SOPA             VARIABLE-LIST = (10) ..
                  VARIABLE-LIST = (15,6) ..   $SOPA 15 = HEATING FUEL
                                              $SOPA (BTU/HR)
                                              $SOPA 6 = COOLING ELEC.
                                              $SOPA (KW)
REP1            = H-R
REPORT-SCHEDULE = SCH-1
REPORT-BLOCK    = (BG6) ..

END   ..
COMPUTE PLANT   ..
STOP  ..
```

B.1.2 Lightweight without Internal Loads

```
$**********************MODIFICATIONS*********************************

$SOPA   SYSTEM = SZRH
$SOPA   NO SETBACK
$SOPA   REHEAT-DELTA-T = 55
$SOPA   FURNACE, SIZE = -999
$SOPA   HERM-REC-CHLR, SIZE = -999
$SOPA   WOOD STUDS FLOOR (ACTIVE CRAWSPACE)
$SOPA   FLOOR INSULATION R7
$SOPA   CRAWL SPACE WALL ABOVE GROUND = 1.5 FT
$SOPA   CRAWL SPACE WALL UNDER GROUND = 1 FT
$SOPA   NO INTERNAL LOADS (SCHEDULES OF OCCUPANTS, LIGHTS,
$SOPA   AND EQUIPMENT = 0)

$*******************************************************************

INPUT LOADS

$*******************************SCHEDULES***************************

$ OCCUPANCY SCHEDULE

OC-1 = DAY-SCHEDULE                 $SOPA
          HOURS = (1,8)             $SOPA
          VALUES = (0,0,0,0,
          0,0,0,0)                  $SOPA
          HOURS = (9,17)            $SOPA
          VALUES = (0,0,0,0,
          0,0,0,0,0)                $SOPA
          HOURS = (18,24)           $SOPA
          VALUES = (0,0,0,0,0,
          0,0)  ..                  $SOPA

OC-2 = DAY-SCHEDULE                 $SOPA
          HOURS = (1,15)            $SOPA
          VALUES = (0,0,0,0,0,0,
          0,0,0,0,0,0,0,0,0)        $SOPA
          HOURS = (16,22)           $SOPA
          VALUES = (0,0,0,0,0,0,0)  $SOPA
          HOURS = (23,24)           $SOPA
          VALUES = (0,0)  ..        $SOPA

OC-W = WEEK-SCHEDULE
          DAYS = (MON,FRI)
          DAY-SCHEDULE = OC-1
          DAYS = (WEH)
          DAY-SCHEDULE = OC-2  ..

OCCUPY-1 =SCHEDULE
          THRU DEC 31 OC-W  ..

$ EQUIPMENT SCHEDULE

EQ-1 = DAY-SCHEDULE                        $SOPA
          HOURS = (1,6)                    $SOPA
          VALUES = (0,0,0,0,0,0)           $SOPA
          HOURS = (7,8)                    $SOPA
```

```
          VALUES = (0,0)                      $SOPA
          HOURS = (9,17)                      $SOPA
          VALUES = (0,0,0,0,0,0,0,0,0)        $SOPA
          HOURS = (18,24)                     $SOPA
          VALUES = (0,0,0,0,0,0,0)  ..        $SOPA

EQ-2 =DAY-SCHEDULE                            $SOPA
          HOURS = (1,6)                       $SOPA
          VALUES = (0,0,0,0,0,0)              $SOPA
          HOURS = (7,8)                       $SOPA
          VALUES = (0,0)                      $SOPA
          HOURS = (9,24)                      $SOPA
          VALUES = (0,0,0,0,0,
          0,0,0,0,0,
          0,0,0,0,0,0)  ..                    $SOPA

EQ-W = WEEK-SCHEDULE
          DAYS = (MON,FRI)
          DAY-SCHEDULE = EQ-1
          DAYS = (WEH)
          DAY-SCHEDULE = EQ-2  ..

EQUIP-1 = SCHEDULE
          THRU DEC 31 EQ-W  ..

$ INFILTRATION SCHEDULE

INFIL-SCH = SCHEDULE
          THRU DEC 31 (ALL) (1,24) (1)  ..

LIGHT-1 = DAY-SCHEDULE                       $SOPA
          HOURS = (1,7)                      $SOPA
          VALUES = (0,0,0,0,0,0,0)           $SOPA
          HOURS = (8,17)                     $SOPA
          VALUES = (0,0,0,0,0,0,0
          0,0,0)                             $SOPA
          HOURS = (18,24)                    $SOPA
          VALUES = (0,0,0,0,0,0,0,) ..       $SOPA

LIGHT-WEEK = WEEK-SCHEDULE
          DAYS = (MON,FRI)
          DAY-SCHEDULE = LIGHT-1
          DAYS = (WEH)
          DAY-SCHEDULE = LIGHT-1  ..

LIGHT-3 = SCHEDULE
          THRU DEC 31 LIGHT-WEEK  ..

END  ..
COMPUTE  LOADS   ..

$***********************************************************************
```

B.1.3 High Thermal Mass

```
$***************************MODIFICATIONS****************************

$SOPA   HIGH THERMAL MASS
$SOPA   SYSTEM = SZRH
$SOPA   NO SETBACK
$SOPA   REHEAT-DELTA-T = 55
$SOPA   FURNACE, SIZE = -999
$SOPA   HERM-REC-CHLR, SIZE = -999
$SOPA   WA-1 & 2 MATERIAL = 1" STUCCO, 3" RIGID INSULATION,
$SOPA   6" CONCRETE BLOCK)
$SOPA   CL-1 & 2 = ASPHALT-SIDING, PLY-WOOD, AIR-GAP,
$SOPA   STUD-10IN, GYPSUM-BOARD
$SOPA   FL-1 = 4" CONCRETE SLAB

$*******************************************************************

INPUT LOADS

$****************************MATERIALS*******************************

INSULATION-R15       = MATERIAL               $DOE2.1E
                                              $(MATERIALS LIBRARY)
                     THICKNESS    = .405      $(FT)
                     CONDUCTIVITY = .027      $(BTU.FT/HR.FT^2.F)
                     DENSITY      = .6        $(LB/FT^3)
                     SPECIFIC-HEAT= .20  ..   $(BTU/LB.F)
                                              $CHANGE THICKNESS
STUCCO               = MATERIAL               $SOPA DOE2.1E
                                              $SOPA (MATERIALS LIBRARY)
                     THICKNESS    = .0833     $SOPA (FT)
                     CONDUCTIVITY = .4167     $SOPA (BTU.FT/HR.FT^2.F)
                     DENSITY       = 166      $SOPA (LB/FT^3)
                     SPECIFIC-HEAT = .2   ..  $SOPA (BTU/LB.F)

RIGID-IN-R10.3       = MATERIAL               $SOPA DOE2.1E
                                              $SOPA (MATERIALS LIBRARY)
                     THICKNESS    = .25       $SOPA (FT)
                     CONDUCTIVITY = .0240     $SOPA (BTU.FT/HR.FT^2.F)
                     DENSITY       = 15       $SOPA (LB/FT^3)
                     SPECIFIC-HEAT =.17   ..  $SOPA (BTU/LB.F)

CONCRETE-6IN-FILLED  = MATERIAL               $SOPA DOE2.1E
                                              $SOPA (MATERIALS LIBRARY)
                     THICKNESS    = .5        $SOPA (FT)
                     CONDUCTIVITY = .7575     $SOPA (BTU.FT/HR.FT^2.F)
                     DENSITY       = 140      $SOPA (LB/FT^3)
                     SPECIFIC-HEAT = .2   ..  $SOPA (BTU/LB.F)

MAT-FIC-1            = MATERIAL
                     RESISTANCE = P-RFIC1[] ..    $(HR.FT^2.F/BTU),
                                                  $THE RFIC VALUE
MAT-FIC-1CF          = MATERIAL
                     RESISTANCE = P-RFIC1CF[] ..  $(HR.FT^2.F/BTU),
                                                  $THE RFIC VALUE
MAT-FIC-1F            = MATERIAL
                     RESISTANCE = P-RFIC1F[] ..   $(HR.FT^2.F/BTU),
                                                  $THE RFIC VALUE
MAT-FIC-1B            = MATERIAL
```

```
                    RESISTANCE = P-RFIC1B[] ..   $(HR.FT^2.F/BTU),
                                                 $THE RFIC VALUE
MAT-FIC-1R           = MATERIAL
                    RESISTANCE = P-RFIC1R[] ..   $(HR.FT^2.F/BTU),
                                                 $THE RFIC VALUE
MAT-FIC-1L           = MATERIAL
                    RESISTANCE = P-RFIC1L[] ..   $(HR.FT^2.F/BTU),
                                                 $THE RFIC VALUE
SOIL-12IN           = MATERIAL                   $ FROM ARTICLE
                                                 $(UNDERGROUND SURFACE)
                    THICKNESS    = 1.0           $(FT)
                    CONDUCTIVITY = 1.0           $(BTU.FT/HR.FT^2.F)
                    DENSITY      = 115           $(LB/FT^3)
                    SPECIFIC-HEAT= 0.1  ..       $(BTU/LB.F)

CONCRETE-4IN        = MATERIAL                   $ CC03 IN DOE-2.1E
                                                 $LIBRARY
                    THICKNESS    = 0.3333        $(FT)
                    CONDUCTIVITY = 0.7576        $(BTU.FT/HR.FT^2.F)
                    DENSITY      = 140.0         $(LB/FT^3)
                    SPECIFIC-HEAT= 0.2 ..        $(BTU/LB.F)


$*******************************LAYERS********************************

WA-1 = LAYERS                                    $SOPA
       MATERIAL = (STUCCO, RIGID-IN-R10.3,
                  CONCRETE-6IN-FILLED)  ..       $SOPA

              $SOPA Insulation Part of Wall
              $SOPA 1" STUCCO (SC01)
              $SOPA RIGID-IN-R10.3 = 3" PREFORMED MINERAL BOARD (IN24)
              $SOPA 6" HEAVY WEIGHT CONCRETE-BLOCK, FILLED (CB07)
              $SOPA The percentage of WA-1 = 87.5 %


WA-2 = LAYERS                                    $SOPA
       MATERIAL = (STUCCO, RIGID-IN-R10.3,
                  CONCRETE-6IN-FILLED)  ..       $SOPA

              $SOPA Stud Part of Wall (no stud)
              $SOPA SIMILAR TO WA-1
              $SOPA The percentage of WA-2 = 12.5 %

$********ADD LAYERS FOR NEW GROUND SURFACE, 06/12/2003, S.KIM**********

$***********ADD LAYERS FOR CRAWL SPACE, 11/17/2003, JAYA.M*************

LAY-SLAB-1 =  LAYERS
              MATERIAL = (MAT-FIC-1,SOIL-12IN,CONCRETE-4IN)
               INSIDE-FILM-RES = 0.77   ..
LAY-FLOOR-1 = LAYERS
              MATERIAL = (MAT-FIC-1CF,SOIL-12IN)
              INSIDE-FILM-RES = 0.77   ..
LAY-FLOOR-1F = LAYERS
              MATERIAL = (MAT-FIC-1F, SOIL-12IN)
              INSIDE-FILM-RES = 0.68   ..
LAY-FLOOR-1B = LAYERS
              MATERIAL = (MAT-FIC-1B, SOIL-12IN)
              INSIDE-FILM-RES = 0.68   ..
```

```
LAY-FLOOR-1R = LAYERS
              MATERIAL = (MAT-FIC-1R, SOIL-12IN)
              INSIDE-FILM-RES = 0.68   ..
LAY-FLOOR-1L = LAYERS
              MATERIAL = (MAT-FIC-1L, SOIL-12IN)
              INSIDE-FILM-RES = 0.68   ..

$**************************CONSTRUCTION********************************

WALL-1    = CONSTRUCTION
            LAYERS = WA-1   ..

WALL-2    = CONSTRUCTION
            LAYERS = WA-2   ..

$*******ADD CONSTRUCTION FOR NEW GROUND SURFACE, 06/12/2003, S.KIM*****

CON-SLAB-1 = CONSTRUCTION
             LAYERS = LAY-SLAB-1   ..

CON-FLOOR-1 = CONSTRUCTION
              LAYERS = LAY-FLOOR-1 ..

CON-FLOOR-1F = CONSTRUCTION
              LAYERS = LAY-FLOOR-1F ..

CON-FLOOR-1B = CONSTRUCTION
              LAYERS = LAY-FLOOR-1B ..

CON-FLOOR-1R = CONSTRUCTION
              LAYERS = LAY-FLOOR-1R ..

CON-FLOOR-1L = CONSTRUCTION
              LAYERS = LAY-FLOOR-1L ..

END  ..
COMPUTE  LOADS   ..

$**********************************************************************
```

B.1.4 Lightweight with an Economizer

```
$****************************MODIFICATIONS****************************

$SOPA   SYSTEM = SZRH (WITH ECONOMIZER)
$SOPA   NO SETBACK
$SOPA   REHEAT-DELTA-T = 55
$SOPA   FURNACE, SIZE = -999
$SOPA   HERM-REC-CHLR, SIZE = -999
$SOPA   WOOD STUDS FLOOR (ACTIVE CRAWSPACE)
$SOPA   FLOOR INSULATION R7
$SOPA   CRAWL SPACE WALL ABOVE GROUND = 1.5 FT
$SOPA   CRAWL SPACE WALL UNDER GROUND = 1 FT
$SOPA   OA-CFM/PER = 15
$SOPA   DRYBULB-LIMIT = 65
$SOPA   OA-CONTROL =  TEMP
$SOPA   MAX-OA-FRACTION =  1.0

$*********************************************************************

INPUT SYSTEMS

$ ZONE DATA

HOUSE-ZONE-AIR1 = ZONE-AIR
$          AIR-CHANGES/HR =          CFM/SQFT OR AIR-CHANGES/HR
           CFM/SQFT = 1              $ASSUMED
           OA-CFM/PER = 15           $SOPA
                     ..              $END OF ZONE COMMANDS

$ SYSTEM DATA

S-CTRL = SYSTEM-CONTROL
          MAX-SUPPLY-T = 120         $ARBITRARY VALUE(DEG F)
          MIN-SUPPLY-T = 55          $ARBITRARY VALUE(DEG F)
          COOLING-SCHEDULE = COOLON
          HEATING-SCHEDULE = HEATON
          DRYBULB-LIMIT = 65         $SOPA TEMPERATURE ABOVE WHICH THE
                                     $OA DAMPER RETURNS TO MIN.(DEG F)
                      ..             $END OF SYSTEM CONTROL COMMAND

S-AIR = SYSTEM-AIR
          OA-CONTROL =  TEMP         $SOPA TO TURN ON ECONOMIZER
          MAX-OA-FRACTION =  1.0     $SOPA
          DUCT-AIR-LOSS = 0.0        $DOE-2 DEFAULT(0 TO 1)
          DUCT-DELTA-T =  0.0        $DOE-2 DEFAULT(0 TO 10)(DEG F)
          VENT-METHOD =  AIR-CHANGE  $DOE-2 DEFAULT(OR S-G)
                    ..               $END OF SYSTEM-AIR COMMAND

END  ..
COMPUTE  SYSTEMS   ..

      $***********************************************************************
```

B.2 DOE-2 HOURLY REPORT: LIGHTWEIGHT HOUSE (BASE CASE) IN HOUSTON, TEXAS

Examples of the output from the DOE-2 hourly report of the lightweight house (base case) in Houston, Texas, are provided. The four months of data for each season are March (spring), June (summer), September (fall), and December (winter). Each month contains date, time, hourly data of the indoor dry-bulb temperature (Tdb, °F), humidity ratio (W, lbw/lba), global horizontal solar radiation (GBH, Btu/ft^2), heating energy use (Btu/hr), cooling energy use (kW), the outdoor dry-bulb temperature (Tdb, °F), and humidity ratio (W, lbw/lba); respectively.

B.2.1 Spring Season: (March)

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
3/1/01	0:00	75.5	0.011	0	800	0	63	0.0103
3/1/01	1:00	75.4	0.0117	0	800	0	63	0.0110
3/1/01	2:00	75.5	0.0115	0	800	0	64	0.0107
3/1/01	3:00	75.5	0.0122	0	800	0	64	0.0114
3/1/01	4:00	75.5	0.0119	0	800	0.124	64	0.0114
3/1/01	5:00	75.5	0.0123	0	800	0.101	63	0.0116
3/1/01	6:00	75.4	0.013	1	800	0	63	0.0123
3/1/01	7:00	75.5	0.013	11	800	0	64	0.0120
3/1/01	8:00	75.7	0.0117	48	800	0.357	65	0.0125
3/1/01	9:00	75.9	0.0109	58	800	0.586	68	0.0125
3/1/01	10:00	76	0.0105	79	800	0.772	70	0.0120
3/1/01	11:00	76.3	0.01	178	800	1.109	73	0.0120
3/1/01	12:00	76.4	0.0096	93	800	1.107	72	0.0109
3/1/01	13:00	76.5	0.0099	167	800	1.264	73	0.0121
3/1/01	14:00	76.5	0.0097	152	800	1.294	72	0.0116
3/1/01	15:00	-76.5	0.0099	112	800	1.276	70	0.0121
3/1/01	16:00	76.3	0.01	67	800	1.12	68	0.0118
3/1/01	17:00	76.1	0.0102	11	800	0.83	66	0.0116
3/1/01	18:00	75.8	0.0109	2	800	0.552	64	0.0121
3/1/01	19:00	75.7	0.0114	0	800	0.373	64	0.0121
3/1/01	20:00	75.6	0.0113	0	800	0.252	64	0.0114
3/1/01	21:00	75.6	0.0115	0	800	0.192	64	0.0114
3/1/01	22:00	75.6	0.0118	0	800	0.23	65	0.0119
3/1/01	23:00	75.6	0.0114	0	800	0.171	65	0.0112
3/2/01	0:00	75.6	0.0111	0	800	0.247	65	0.0112
3/2/01	1:00	75.6	0.0113	0	800	0.192	65	0.0112
3/2/01	2:00	75.6	0.0112	0	800	0.22	65	0.0112
3/2/01	3:00	75.6	0.0116	0	800	0.188	64	0.0115
3/2/01	4:00	75.5	0.0118	0	800	0.153	64	0.0115
3/2/01	5:00	75.5	0.0116	0	800	0.114	65	0.0112
3/2/01	6:00	75.5	0.0116	1	800	0.121	65	0.0112
3/2/01	7:00	75.6	0.0116	14	800	0.234	66	0.0117
3/2/01	8:00	75.7	0.0115	40	800	0.386	66	0.0123
3/2/01	9:00	75.7	0.0116	43	800	0.422	66	0.0123
3/2/01	10:00	75.8	0.0113	58	800	0.527	66	0.0124
3/2/01	11:00	75.9	0.0116	65	800	0.621	66	0.0131
3/2/01	12:00	75.9	0.0116	72	800	0.67	66	0.0131
3/2/01	13:00	76	0.0111	68	800	0.793	67	0.0136
3/2/01	14:00	76	0.0111	60	800	0.763	66	0.0131
3/2/01	15:00	76	0.0107	88	800	0.816	65	0.0127
3/2/01	16:00	76	0.0102	56	800	0.735	63	0.0118
3/2/01	17:00	75.9	0.0103	12	800	0.619	64	0.0122
3/2/01	18:00	75.8	0.0107	2	800	0.468	64	0.0122
3/2/01	19:00	75.7	0.0112	0	800	0.3	63	0.0118
3/2/01	20:00	75.6	0.012	0	800	0.163	63	0.0118
3/2/01	21:00	75.5	0.0123	0	800	0.114	63	0.0117
3/2/01	22:00	75.5	0.0121	0	800	0	61	0.0109
3/2/01	23:00	75.2	0.0116	0	800	0	60	0.0105
3/3/01	0:00	75	0.0116	0	800	0	60	0.0105
3/3/01	1:00	74.9	0.0121	0	800	0	62	0.0113
3/3/01	2:00	75	0.0122	0	800	0	62	0.0113
3/3/01	3:00	75.1	0.0128	0	800	0	61	0.0109
3/3/01	4:00	75.1	0.0125	0	800	0	62	0.0113
3/3/01	5:00	74.6	0.0109	0	800	0	58	0.0103
3/3/01	6:00	73.8	0.0083	0	800	0	52	0.0077
3/3/01	7:00	73.2	0.0078	15	800	0	52	0.0072
3/3/01	8:00	72.9	0.0068	32	800	0	50	0.0061
3/3/01	9:00	72.9	0.0068	64	800	0	52	0.0062
3/3/01	10:00	73.2	0.0062	92	800	0	54	0.0057
3/3/01	11:00	74.3	0.0068	110	800	0	57	0.0060
3/3/01	12:00	75	0.0064	122	800	0	56	0.0058
3/3/01	13:00	75.6	0.0064	111	800	0	58	0.0058
3/3/01	14:00	75.7	0.0065	99	800	0.338	58	0.0058
3/3/01	15:00	75.8	0.007	86	800	0.481	58	0.0058
3/3/01	16:00	75.8	0.0071	32	800	0.371	59	0.0061
3/3/01	17:00	75.7	0.0073	29	800	0.319	60	0.0064
3/3/01	18:00	75.5	0.0072	3	800	0.074	56	0.0063
3/3/01	19:00	74.8	0.0067	0	800	0	55	0.0060
3/3/01	20:00	73.3	0.0061	0	800	0	50	0.0056
3/3/01	21:00	72.6	0.0057	0	800	0	47	0.0049
3/3/01	22:00	71.5	0.0053	0	800	0	46	0.0047
3/3/01	23:00	70.7	0.0052	0	800	0	45	0.0045

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
3/4/01	0:00	70.5	0.0051	0	800	0	44	0.0043
3/4/01	1:00	70.4	0.0059	0	6776.026	0	43	0.0045
3/4/01	2:00	70.4	0.0051	0	9941.796	0	42	0.0043
3/4/01	3:00	70.4	0.005	0	11116.322	0	42	0.0043
3/4/01	4:00	70.4	0.0053	0	10084.815	0	42	0.0043
3/4/01	5:00	70.4	0.0052	0	10866.271	0	42	0.0043
3/4/01	6:00	70.4	0.0055	1	10026.092	0	42	0.0043
3/4/01	7:00	70.4	0.0049	20	10183.007	0	43	0.0041
3/4/01	8:00	70.4	0.005	52	7461.447	0	44	0.0043
3/4/01	9:00	71.3	0.0054	119	800	0	49	0.0044
3/4/01	10:00	72.2	0.0054	122	800	0	52	0.0047
3/4/01	11:00	74	0.0059	192	800	0	54	0.0047
3/4/01	12:00	75.3	0.0062	95	800	0	59	0.0050
3/4/01	13:00	75.7	0.0061	150	800	0.388	58	0.0053
3/4/01	14:00	75.9	0.0065	128	800	0.622	60	0.0053
3/4/01	15:00	76	0.0066	85	800	0.662	62	0.0054
3/4/01	16:00	75.9	0.0068	57	800	0.571	61	0.0056
3/4/01	17:00	75.7	0.0075	19	800	0.33	58	0.0063
3/4/01	18:00	75.5	0.0082	4	800	0.093	54	0.0067
3/4/01	19:00	75.2	0.009	0	800	0	52	0.0066
3/4/01	20:00	74.5	0.0082	0	800	0	51	0.0064
3/4/01	21:00	74	0.0079	0	800	0	52	0.0061
3/4/01	22:00	73.6	0.009	0	800	0	50	0.0066
3/4/01	23:00	73.1	0.009	0	800	0	48	0.0066
3/5/01	0:00	72.9	0.0058	0	800	0	47	0.0058
3/5/01	1:00	72.5	0.0058	0	800	0	47	0.0058
3/5/01	2:00	72	0.0061	0	800	0	46	0.0061
3/5/01	3:00	71.2	0.0074	0	800	0	46	0.0056
3/5/01	4:00	71	0.0058	0	800	0	45	0.0058
3/5/01	5:00	70.6	0.0058	0	800	0	45	0.0058
3/5/01	6:00	70.5	0.0074	3	800	0	44	0.0056
3/5/01	7:00	70.6	0.0073	35	800	0	48	0.0061
3/5/01	8:00	72.1	0.0076	106	800	0	54	0.0067
3/5/01	9:00	74.2	0.0073	139	800	0	60	0.0063
3/5/01	10:00	75.8	0.007	213	800	0	64	0.0060
3/5/01	11:00	76.2	0.0073	221	800	0.968	66	0.0061
3/5/01	12:00	76.5	0.0077	276	800	1.173	69	0.0065
3/5/01	13:00	76.7	0.0076	267	800	1.355	71	0.0061
3/5/01	14:00	76.8	0.0074	235	800	1.46	72	0.0064
3/5/01	15:00	76.9	0.0071	182	800	1.478	73	0.0062
3/5/01	16:00	76.8	0.0072	115	800	1.408	73	0.0062
3/5/01	17:00	76.5	0.0082	41	800	1.173	70	0.0075
3/5/01	18:00	76.1	0.0084	6	800	0.837	65	0.0080
3/5/01	19:00	75.8	0.0086	0	800	0.492	62	0.0081
3/5/01	20:00	75.6	0.0088	0	800	0.225	60	0.0080
3/5/01	21:00	75.5	0.0095	0	800	0.097	56	0.0078
3/5/01	22:00	75.1	0.0098	0	800	0	54	0.0083
3/5/01	23:00	74.7	0.0095	0	800	0	54	0.0077
3/6/01	0:00	74.2	0.0095	0	800	0	53	0.0080
3/6/01	1:00	73.8	0.0098	0	800	0	51	0.0074
3/6/01	2:00	73.2	0.0086	0	800	0	49	0.0068
3/6/01	3:00	72.5	0.0084	0	800	0	51	0.0074
3/6/01	4:00	72	0.0082	0	800	0	49	0.0068
3/6/01	5:00	71.5	0.0075	0	800	0	48	0.0061
3/6/01	6:00	71.1	0.0074	4	800	0	46	0.0060
3/6/01	7:00	71.7	0.0071	38	800	0	50	0.0061
3/6/01	8:00	73.4	0.0071	109	800	0	56	0.0062
3/6/01	9:00	75.6	0.0071	162	800	0	62	0.0059
3/6/01	10:00	76.2	0.007	206	800	0.972	67	0.0058
3/6/01	11:00	76.5	0.0066	243	800	1.201	69	0.0054
3/6/01	12:00	76.7	0.0062	255	800	1.343	73	0.0050
3/6/01	13:00	76.8	0.0063	217	800	1.42	73	0.0045
3/6/01	14:00	76.9	0.0058	211	800	1.492	75	0.0046
3/6/01	15:00	76.9	0.0056	176	800	1.527	76	0.0044
3/6/01	16:00	76.9	0.0062	110	800	1.477	76	0.0044
3/6/01	17:00	76.7	0.0069	46	800	1.322	74	0.0054
3/6/01	18:00	76.3	0.007	7	800	0.949	64	0.0055
3/6/01	19:00	75.9	0.0067	0	800	0.574	64	0.0055
3/6/01	20:00	75.7	0.0084	0	800	0.352	62	0.0070
3/6/01	21:00	75.6	0.0089	0	800	0.208	60	0.0080
3/6/01	22:00	75.4	0.009	0	4234.253	0	54	0.0072
3/6/01	23:00	75.3	0.0074	0	800	0	53	0.0074

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
3/7/01	0:00	75	0.0069	0	800	0	51	0.0069
3/7/01	1:00	74.3	0.0093	0	800	0	54	0.0078
3/7/01	2:00	73.8	0.0098	0	800	0	55	0.0086
3/7/01	3:00	73.5	0.0101	0	800	0	54	0.0083
3/7/01	4:00	73.4	0.0068	0	800	0	49	0.0068
3/7/01	5:00	72.6	0.0081	0	800	0	48	0.0066
3/7/01	6:00	72.1	0.0091	3	800	0	50	0.0076
3/7/01	7:00	71.9	0.0091	14	800	0	51	0.0079
3/7/01	8:00	72.1	0.0097	50	800	0	54	0.0088
3/7/01	9:00	72.8	0.0111	55	800	0	58	0.0102
3/7/01	10:00	74.5	0.012	129	800	0	63	0.0110
3/7/01	11:00	75.7	0.0113	96	800	0	70	0.0107
3/7/01	12:00	76	0.0096	117	800	0.718	72	0.0095
3/7/01	13:00	76.1	0.009	83	800	0.821	72	0.0089
3/7/01	14:00	76.1	0.0092	95	800	0.925	71	0.0098
3/7/01	15:00	76.1	0.0099	60	800	0.918	69	0.0116
3/7/01	16:00	76	0.01	43	800	0.767	68	0.0112
3/7/01	17:00	76	0.0105	28	800	0.716	67	0.0121
3/7/01	18:00	75.8	0.0106	3	800	0.509	66	0.0116
3/7/01	19:00	75.7	0.0113	0	800	0.407	66	0.0123
3/7/01	20:00	75.6	0.0118	0	800	0.296	66	0.0123
3/7/01	21:00	75.6	0.0119	0	800	0.267	66	0.0123
3/7/01	22:00	75.6	0.0127	0	800	0.242	66	0.0130
3/7/01	23:00	75.6	0.0122	0	800	0.286	67	0.0128
3/8/01	0:00	75.7	0.0124	0	800	0.332	67	0.0135
3/8/01	1:00	75.7	0.0124	0	800	0.335	67	0.0135
3/8/01	2:00	75.6	0.0129	0	800	0.283	67	0.0135
3/8/01	3:00	75.7	0.0128	0	800	0.351	68	0.0140
3/8/01	4:00	75.7	0.0121	0	800	0.395	68	0.0140
3/8/01	5:00	75.7	0.0127	0	800	0.374	68	0.0140
3/8/01	6:00	75.7	0.0124	2	800	0.399	68	0.0140
3/8/01	7:00	75.8	0.0119	19	800	0.49	69	0.0138
3/8/01	8:00	75.9	0.0116	45	800	0.675	70	0.0143
3/8/01	9:00	76.2	0.0108	109	800	1.01	72	0.0138
3/8/01	10:00	76.4	0.0103	117	800	1.158	73	0.0136
3/8/01	11:00	76.6	0.0102	203	800	1.411	75	0.0139
3/8/01	12:00	76.5	0.0096	97	800	1.153	68	0.0105
3/8/01	13:00	76.5	0.0096	224	800	1.215	65	0.0112
3/8/01	14:00	76.6	0.0093	192	800	1.331	69	0.0110
3/8/01	15:00	76.5	0.0091	72	800	1.199	70	0.0101
3/8/01	16:00	76.3	0.0091	48	800	1.065	70	0.0101
3/8/01	17:00	76.2	0.0091	23	800	0.899	68	0.0099
3/8/01	18:00	75.9	0.0091	3	800	0.586	66	0.0091
3/8/01	19:00	75.8	0.009	0	800	0.457	65	0.0087
3/8/01	20:00	75.7	0.0081	0	800	0.252	63	0.0074
3/8/01	21:00	75.6	0.008	0	800	0.13	61	0.0073
3/8/01	22:00	75.5	0.0072	0	4070.68	0	60	0.0064
3/8/01	23:00	75.2	0.007	0	800	0	59	0.0061
3/9/01	0:00	74.9	0.0063	0	800	0	59	0.0056
3/9/01	1:00	74.5	0.006	0	800	0	58	0.0053
3/9/01	2:00	74.2	0.0057	0	800	0	57	0.0050
3/9/01	3:00	73.9	0.0056	0	800	0	56	0.0047
3/9/01	4:00	73.7	0.0057	0	800	0	55	0.0045
3/9/01	5:00	73.4	0.0062	0	800	0	54	0.0052
3/9/01	6:00	73.1	0.0052	4	800	0	54	0.0042
3/9/01	7:00	73.1	0.0057	19	800	0	53	0.0045
3/9/01	8:00	74.6	0.0053	107	800	0	58	0.0043
3/9/01	9:00	75.8	0.0051	175	800	0	62	0.0044
3/9/01	10:00	76.1	0.0035	155	800	0.825	65	0.0029
3/9/01	11:00	76.3	0.0034	248	800	0.995	67	0.0029
3/9/01	12:00	76.4	0.0035	257	800	1.069	68	0.0031
3/9/01	13:00	76.5	0.0034	278	800	1.18	69	0.0029
3/9/01	14:00	76.6	0.0036	243	800	1.276	70	0.0031
3/9/01	15:00	76.6	0.0029	191	800	1.262	69	0.0025
3/9/01	16:00	76.5	0.0029	123	800	1.203	69	0.0024
3/9/01	17:00	76.4	0.0031	49	800	1.04	67	0.0025
3/9/01	18:00	76	0.0045	8	800	0.686	60	0.0033
3/9/01	19:00	75.7	0.0055	0	800	0.308	55	0.0040
3/9/01	20:00	75.5	0.0063	0	4160.88	0	51	0.0045
3/9/01	21:00	75.4	0.0042	0	800	0	52	0.0042
3/9/01	22:00	74.9	0.0045	0	800	0	49	0.0045
3/9/01	23:00	73.7	0.0061	0	800	0	47	0.0049

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
3/10/01	0:00	73	0.007	0	800	0	44	0.0052
3/10/01	1:00	72.3	0.0071	0	800	0	44	0.0047
3/10/01	2:00	71.6	0.0067	0	800	0	42	0.0043
3/10/01	3:00	71.3	0.0043	0	800	0	42	0.0043
3/10/01	4:00	70.8	0.0046	0	800	0	41	0.0046
3/10/01	5:00	70.5	0.0044	0	800	0	40	0.0044
3/10/01	6:00	70.4	0.0066	5	8147.392	0	40	0.0048
3/10/01	7:00	70.9	0.007	43	800	0	48	0.0052
3/10/01	8:00	72.8	0.0076	115	800	0	60	0.0064
3/10/01	9:00	75.5	0.0065	184	800	0	65	0.0053
3/10/01	10:00	76.3	0.0062	239	800	1.043	71	0.0050
3/10/01	11:00	76.6	0.0058	275	800	1.299	74	0.0049
3/10/01	12:00	76.8	0.0055	286	800	1.424	77	0.0048
3/10/01	13:00	76.9	0.0056	275	800	1.524	79	0.0049
3/10/01	14:00	77	0.0061	241	800	1.588	79	0.0055
3/10/01	15:00	77	0.0088	186	800	1.631	77	0.0098
3/10/01	16:00	76.9	0.0078	120	800	1.48	77	0.0072
3/10/01	17:00	76.6	0.0071	48	800	1.297	75	0.0064
3/10/01	18:00	76.3	0.0079	7	800	0.978	70	0.0070
3/10/01	19:00	76	0.0085	0	800	0.658	67	0.0083
3/10/01	20:00	75.8	0.0092	0	800	0.459	65	0.0093
3/10/01	21:00	75.7	0.0103	0	800	0.288	63	0.0104
3/10/01	22:00	75.6	0.0105	0	800	0.172	62	0.0100
3/10/01	23:00	75.5	0.0108	0	800	0.078	62	0.0100
3/11/01	0:00	75.4	0.0116	0	800	0	62	0.0107
3/11/01	1:00	75.3	0.0116	0	800	0	62	0.0107
3/11/01	2:00	75.2	0.0118	0	800	0	61	0.0109
3/11/01	3:00	75	0.012	0	800	0	61	0.0109
3/11/01	4:00	74.8	0.0111	0	800	0	61	0.0103
3/11/01	5:00	74.6	0.0111	0	800	0	61	0.0103
3/11/01	6:00	74.7	0.0112	5	800	0	61	0.0103
3/11/01	7:00	75.5	0.0108	42	800	0	64	0.0102
3/11/01	8:00	76	0.0097	108	800	0.744	67	0.0101
3/11/01	9:00	76.4	0.0095	171	800	1.144	72	0.0103
3/11/01	10:00	76.6	0.0091	214	800	1.337	74	0.0098
3/11/01	11:00	76.7	0.0092	234	800	1.467	75	0.0103
3/11/01	12:00	76.7	0.0091	158	800	1.42	76	0.0101
3/11/01	13:00	76.7	0.0091	139	800	1.381	76	0.0101
3/11/01	14:00	76.6	0.0092	97	800	1.316	76	0.0101
3/11/01	15:00	76.4	0.0095	79	800	1.216	73	0.0108
3/11/01	16:00	76.3	0.0096	38	800	1.062	72	0.0110
3/11/01	17:00	76.1	0.01	11	800	0.904	71	0.0113
3/11/01	18:00	76	0.0102	3	800	0.733	70	0.0115
3/11/01	19:00	75.9	0.0109	0	800	0.635	69	0.0124
3/11/01	20:00	75.8	0.0113	0	800	0.545	68	0.0127
3/11/01	21:00	75.8	0.0118	0	800	0.511	69	0.0131
3/11/01	22:00	75.7	0.0118	0	800	0.435	68	0.0127
3/11/01	23:00	75.8	0.0119	0	800	0.471	69	0.0131
3/12/01	0:00	75.7	0.0124	0	800	0.413	68	0.0134
3/12/01	1:00	75.7	0.0116	0	800	0.422	69	0.0124
3/12/01	2:00	75.7	0.0113	0	800	0.438	68	0.0126
3/12/01	3:00	75.7	0.0112	0	800	0.437	68	0.0126
3/12/01	4:00	75.7	0.011	0	800	0.405	66	0.0124
3/12/01	5:00	75.7	0.0114	0	800	0.352	67	0.0122
3/12/01	6:00	75.7	0.0109	5	800	0.332	63	0.0117
3/12/01	7:00	75.8	0.0099	20	800	0.447	67	0.0129
3/12/01	8:00	75.9	0.0104	57	800	0.688	69	0.0124
3/12/01	9:00	76.3	0.0086	153	800	0.971	71	0.0079
3/12/01	10:00	76.5	0.0055	180	800	1.184	72	0.0048
3/12/01	11:00	76.7	0.0053	265	800	1.362	75	0.0047
3/12/01	12:00	76.8	0.006	202	800	1.411	77	0.0054
3/12/01	13:00	76.9	0.0057	248	800	1.498	78	0.0051
3/12/01	14:00	77	0.0051	232	800	1.571	78	0.0045
3/12/01	15:00	76.9	0.0042	144	800	1.515	77	0.0035
3/12/01	16:00	76.7	0.0037	88	800	1.359	74	0.0030
3/12/01	17:00	76.5	0.0029	37	800	1.136	72	0.0023
3/12/01	18:00	76.2	0.0036	7	800	0.835	67	0.0027
3/12/01	19:00	75.9	0.0043	0	800	0.505	64	0.0035
3/12/01	20:00	75.7	0.0049	0	800	0.327	62	0.0039
3/12/01	21:00	75.6	0.005	0	800	0.141	59	0.0041
3/12/01	22:00	75.5	0.005	0	4085.913	0	57	0.0038
3/12/01	23:00	75.3	0.0056	0	800	0	55	0.0038

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
3/13/01	0:00	74.5	0.0043	0	800	0	54	0.0036
3/13/01	1:00	73.9	0.0043	0	800	0	52	0.0034
3/13/01	2:00	73.3	0.0043	0	800	0	50	0.0034
3/13/01	3:00	72.8	0.0045	0	800	0	49	0.0033
3/13/01	4:00	72	0.0042	0	800	0	47	0.0033
3/13/01	5:00	71.2	0.0038	0	800	0	47	0.0030
3/13/01	6:00	70.5	0.0035	6	800	0	46	0.0030
3/13/01	7:00	70.6	0.0035	45	800	0	48	0.0030
3/13/01	8:00	72.3	0.0038	119	800	0	53	0.0031
3/13/01	9:00	74.6	0.0042	187	800	0	57	0.0033
3/13/01	10:00	75.9	0.0039	242	800	0	60	0.0031
3/13/01	11:00	76.3	0.004	278	800	1.02	63	0.0031
3/13/01	12:00	76.5	0.0039	290	800	1.178	66	0.0030
3/13/01	13:00	76.7	0.0041	280	800	1.33	68	0.0029
3/13/01	14:00	76.8	0.0045	246	800	1.454	70	0.0030
3/13/01	15:00	76.9	0.0033	191	800	1.523	69	0.0033
3/13/01	16:00	76.8	0.0038	122	800	1.4	69	0.0031
3/13/01	17:00	76.5	0.0042	41	800	1.16	67	0.0030
3/13/01	18:00	76.1	0.0043	6	800	0.752	62	0.0033
3/13/01	19:00	75.6	0.0037	0	800	0.139	59	0.0033
3/13/01	20:00	75.2	0.0039	0	800	0	54	0.0033
3/13/01	21:00	74.1	0.0032	0	800	0	51	0.0027
3/13/01	22:00	73.1	0.0029	0	800	0	48	0.0023
3/13/01	23:00	72.4	0.003	0	800	0	46	0.0022
3/14/01	0:00	71.5	0.0028	0	800	0	43	0.0019
3/14/01	1:00	70.5	0.0023	0	800	0	42	0.0017
3/14/01	2:00	70.4	0.0024	0	10777.248	0	41	0.0019
3/14/01	3:00	70.4	0.0025	0	11468.221	0	39	0.0019
3/14/01	4:00	70.3	0.0025	0	12567.863	0	37	0.0018
3/14/01	5:00	70.4	0.0026	0	11930.217	0	36	0.0016
3/14/01	6:00	70.4	0.0027	4	12348.932	0	35	0.0017
3/14/01	7:00	70.4	0.0027	44	8046.336	0	40	0.0018
3/14/01	8:00	70.9	0.0029	100	800	0	42	0.0017
3/14/01	9:00	71.8	0.0022	166	800	0	47	0.0016
3/14/01	10:00	73.3	0.0021	224	800	0	50	0.0015
3/14/01	11:00	75	0.0023	239	800	0	52	0.0015
3/14/01	12:00	75.7	0.0022	281	800	0	54	0.0016
3/14/01	13:00	75.9	0.0023	259	800	0.598	56	0.0018
3/14/01	14:00	76.1	0.0025	245	800	0.88	58	0.0018
3/14/01	15:00	76.1	0.0021	193	800	0.79	57	0.0017
3/14/01	16:00	76.1	0.0023	123	800	0.769	57	0.0017
3/14/01	17:00	75.9	0.0024	49	800	0.545	55	0.0017
3/14/01	18:00	75.6	0.0028	7	800	0.171	50	0.0018
3/14/01	19:00	74.8	0.0035	0	800	0	46	0.0023
3/14/01	20:00	73.7	0.004	0	800	0	42	0.0028
3/14/01	21:00	72.5	0.0037	0	800	0	41	0.0025
3/14/01	22:00	71.6	0.0036	0	800	0	42	0.0022
3/14/01	23:00	71.2	0.003	0	800	0	38	0.0030
3/15/01	0:00	70.5	0.0031	0	800	0	35	0.0031
3/15/01	1:00	70.4	0.003	0	7406.967	0	34	0.0030
3/15/01	2:00	70.4	0.0028	0	8818.742	0	34	0.0028
3/15/01	3:00	70.4	0.0031	0	9644.245	0	34	0.0031
3/15/01	4:00	70.4	0.003	0	10402.323	0	32	0.0030
3/15/01	5:00	70.3	0.0055	0	12587.378	0	34	0.0031
3/15/01	6:00	70.4	0.0028	5	10084.13	0	35	0.0028
3/15/01	7:00	70.4	0.004	44	8318.094	0	45	0.0031
3/15/01	8:00	71.3	0.0043	115	800	0	51	0.0033
3/15/01	9:00	73.5	0.0035	188	800	0	56	0.0023
3/15/01	10:00	75.6	0.0035	243	800	0	59	0.0025
3/15/01	11:00	76.1	0.0033	277	800	0.858	62	0.0025
3/15/01	12:00	76.4	0.004	291	800	1.095	64	0.0026
3/15/01	13:00	76.5	0.0037	278	800	1.203	63	0.0027
3/15/01	14:00	76.6	0.0035	244	800	1.228	64	0.0028
3/15/01	15:00	76.5	0.0038	189	800	1.164	62	0.0031
3/15/01	16:00	76.3	0.004	119	800	1.033	61	0.0033
3/15/01	17:00	76.1	0.0042	42	800	0.747	58	0.0034
3/15/01	18:00	75.7	0.0045	5	800	0.319	55	0.0036
3/15/01	19:00	75.5	0.0045	0	4115.841	0	55	0.0036
3/15/01	20:00	75	0.0044	0	800	0	55	0.0036
3/15/01	21:00	74.6	0.0048	0	800	0	54	0.0038
3/15/01	22:00	74	0.0047	0	800	0	53	0.0038
3/15/01	23:00	73.6	0.0056	0	800	0	53	0.0044

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
3/16/01	0:00	73.4	0.0058	0	800	0	53	0.0044
3/16/01	1:00	73.1	0.0063	0	800	0	53	0.0049
3/16/01	2:00	72.7	0.0063	0	800	0	52	0.0051
3/16/01	3:00	72.3	0.0061	0	800	0	52	0.0051
3/16/01	4:00	71.8	0.0058	0	800	0	52	0.0051
3/16/01	5:00	71.2	0.0056	0	800	0	51	0.0049
3/16/01	6:00	71	0.0055	1	800	0	52	0.0047
3/16/01	7:00	70.6	0.006	19	800	0	51	0.0054
3/16/01	8:00	70.8	0.0057	30	800	0	53	0.0049
3/16/01	9:00	71.4	0.006	68	800	0	54	0.0051
3/16/01	10:00	71.9	0.0058	63	800	0	58	0.0052
3/16/01	11:00	72.3	0.0061	66	800	0	58	0.0057
3/16/01	12:00	73	0.0049	86	800	0	61	0.0045
3/16/01	13:00	73.6	0.0053	82	800	0	60	0.0048
3/16/01	14:00	73.9	0.0054	67	800	0	59	0.0050
3/16/01	15:00	74.2	0.0053	62	800	0	60	0.0048
3/16/01	16:00	74.4	0.0053	54	800	0	58	0.0047
3/16/01	17:00	74.4	0.0056	30	800	0	57	0.0050
3/16/01	18:00	74	0.0058	8	800	0	56	0.0052
3/16/01	19:00	73.5	0.0061	0	800	0	55	0.0054
3/16/01	20:00	73.1	0.0067	0	800	0	55	0.0059
3/16/01	21:00	72.7	0.0065	0	800	0	54	0.0056
3/16/01	22:00	72.3	0.0072	0	800	0	53	0.0064
3/16/01	23:00	71.9	0.008	0	800	0	52	0.0071
3/17/01	0:00	71.4	0.0081	0	800	0	53	0.0074
3/17/01	1:00	71.2	0.0083	0	800	0	53	0.0074
3/17/01	2:00	71.1	0.0086	0	800	0	54	0.0077
3/17/01	3:00	71.1	0.0093	0	800	0	55	0.0081
3/17/01	4:00	70.8	0.009	0	800	0	56	0.0084
3/17/01	5:00	70.7	0.0094	0	800	0	57	0.0087
3/17/01	6:00	70.8	0.0092	6	800	0	58	0.0085
3/17/01	7:00	71.1	0.0094	27	800	0	59	0.0088
3/17/01	8:00	71.7	0.0098	45	800	0	62	0.0093
3/17/01	9:00	72.5	0.0099	71	800	0	64	0.0095
3/17/01	10:00	73.7	0.0102	111	800	0	63	0.0097
3/17/01	11:00	74.9	0.01	135	800	0	64	0.0095
3/17/01	12:00	75.4	0.0104	80	800	0	62	0.0100
3/17/01	13:00	75.6	0.0111	72	800	0	62	0.0106
3/17/01	14:00	75.6	0.0107	64	800	0.243	62	0.0106
3/17/01	15:00	75.6	0.0113	48	800	0.206	62	0.0113
3/17/01	16:00	75.5	0.0116	32	800	0.102	62	0.0113
3/17/01	17:00	75.4	0.0104	16	800	0	58	0.0097
3/17/01	18:00	74.7	0.0105	3	800	0	59	0.0101
3/17/01	19:00	74.6	0.0109	0	800	0	59	0.0101
3/17/01	20:00	73.9	0.0098	0	800	0	57	0.0093
3/17/01	21:00	73.3	0.0092	0	800	0	55	0.0086
3/17/01	22:00	72.6	0.008	0	800	0	53	0.0075
3/17/01	23:00	71.7	0.0079	0	800	0	51	0.0074
3/18/01	0:00	71.1	0.0069	0	800	0	49	0.0063
3/18/01	1:00	70.5	0.0063	0	800	0	47	0.0058
3/18/01	2:00	70.4	0.0064	0	8259.797	0	45	0.0058
3/18/01	3:00	70.4	0.0053	0	12010.376	0	45	0.0049
3/18/01	4:00	70.4	0.0056	0	9377.562	0	45	0.0049
3/18/01	5:00	70.4	0.0054	0	10002.146	0	44	0.0047
3/18/01	6:00	70.3	0.0049	5	13294.489	0	43	0.0045
3/18/01	7:00	70.4	0.0045	25	11932.276	0	43	0.0040
3/18/01	8:00	70.4	0.0046	57	9358.983	0	43	0.0040
3/18/01	9:00	70.4	0.0045	87	8236.959	0	43	0.0040
3/18/01	10:00	70.4	0.0046	106	7598.346	0	44	0.0042
3/18/01	11:00	70.5	0.0044	197	5257.614	0	45	0.0040
3/18/01	12:00	70.7	0.0042	167	800	0	46	0.0038
3/18/01	13:00	71.3	0.0044	217	800	0	49	0.0040
3/18/01	14:00	71.7	0.0041	157	800	0	50	0.0037
3/18/01	15:00	72.3	0.004	152	800	0	50	0.0036
3/18/01	16:00	72.9	0.0042	108	800	0	50	0.0036
3/18/01	17:00	72.8	0.004	32	800	0	50	0.0034
3/18/01	18:00	72.2	0.0042	8	800	0	47	0.0034
3/18/01	19:00	71.4	0.0048	0	800	0	44	0.0036
3/18/01	20:00	70.6	0.0054	0	800	0	42	0.0036
3/18/01	21:00	70.4	0.0045	0	800	0	41	0.0036
3/18/01	22:00	70.4	0.0034	0	6938.447	0	40	0.0034
3/18/01	23:00	70.4	0.006	0	10138.711	0	37	0.0036

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
3/19/01	0:00	70.4	0.0054	0	11539.752	0	37	0.0036
3/19/01	1:00	70.4	0.0052	0	12338.471	0	35	0.0034
3/19/01	2:00	70.3	0.0051	0	12776.197	0	35	0.0033
3/19/01	3:00	70.3	0.0051	0	13268.542	0	34	0.0033
3/19/01	4:00	70.3	0.0045	0	14211.996	0	34	0.0031
3/19/01	5:00	70.3	0.0049	0	14152.963	0	32	0.0031
3/19/01	6:00	70.3	0.0045	7	13913.406	0	34	0.0031
3/19/01	7:00	70.4	0.0046	50	8665.845	0	40	0.0034
3/19/01	8:00	70.9	0.0042	124	800	0	46	0.0032
3/19/01	9:00	72.4	0.0036	194	800	0	50	0.0028
3/19/01	10:00	74.4	0.0037	249	800	0	52	0.0028
3/19/01	11:00	75.6	0.0037	284	800	0	54	0.0030
3/19/01	12:00	76	0.004	295	800	0.721	56	0.0030
3/19/01	13:00	76.2	0.0038	284	800	0.931	59	0.0030
3/19/01	14:00	76.3	0.0037	250	800	1.048	62	0.0030
3/19/01	15:00	76.4	0.0041	195	800	1.099	61	0.0031
3/19/01	16:00	76.3	0.004	124	800	1.008	62	0.0033
3/19/01	17:00	76.1	0.0044	50	800	0.805	60	0.0034
3/19/01	18:00	75.8	0.0051	7	800	0.383	54	0.0037
3/19/01	19:00	75.5	0.0062	0	4181.754	0	51	0.0044
3/19/01	20:00	75.1	0.0046	0	800	0	48	0.0046
3/19/01	21:00	74.5	0.0046	0	800	0	48	0.0046
3/19/01	22:00	73.8	0.0046	0	800	0	46	0.0046
3/19/01	23:00	72.5	0.0054	0	800	0	46	0.0042
3/20/01	0:00	71.6	0.0052	0	800	0	48	0.0042
3/20/01	1:00	71	0.0056	0	800	0	46	0.0042
3/20/01	2:00	70.5	0.0056	0	800	0	45	0.0044
3/20/01	3:00	70.5	0.0065	0	6707.077	0	44	0.0047
3/20/01	4:00	70.5	0.0049	0	5986.023	0	43	0.0049
3/20/01	5:00	70.4	0.0071	0	8486.648	0	42	0.0047
3/20/01	6:00	70.5	0.0049	7	6681.125	0	43	0.0049
3/20/01	7:00	70.5	0.0071	48	4922.631	0	51	0.0063
3/20/01	8:00	71.7	0.006	121	800	0	57	0.0054
3/20/01	9:00	74	0.006	191	800	0	62	0.0053
3/20/01	10:00	75.7	0.005	246	800	0	66	0.0044
3/20/01	11:00	76.2	0.0054	280	800	0.939	67	0.0047
3/20/01	12:00	76.4	0.0051	293	800	1.091	70	0.0046
3/20/01	13:00	76.5	0.0053	280	800	1.23	72	0.0047
3/20/01	14:00	76.7	0.0057	245	800	1.329	73	0.0050
3/20/01	15:00	76.7	0.0049	190	800	1.333	73	0.0044
3/20/01	16:00	76.6	0.0059	120	800	1.249	72	0.0052
3/20/01	17:00	76.4	0.0058	47	800	1.056	70	0.0051
3/20/01	18:00	76	0.006	7	800	0.668	65	0.0052
3/20/01	19:00	75.8	0.0057	0	800	0.344	62	0.0048
3/20/01	20:00	75.6	0.0055	0	800	0.164	61	0.0045
3/20/01	21:00	75.2	0.005	0	800	0	58	0.0042
3/20/01	22:00	74.6	0.0057	0	800	0	55	0.0049
3/20/01	23:00	74	0.0065	0	800	0	54	0.0056
3/21/01	0:00	73.5	0.0071	0	800	0	54	0.0062
3/21/01	1:00	73	0.0073	0	800	0	52	0.0061
3/21/01	2:00	72.6	0.0076	0	800	0	53	0.0064
3/21/01	3:00	72.1	0.0077	0	800	0	49	0.0063
3/21/01	4:00	72	0.0058	0	800	0	47	0.0058
3/21/01	5:00	71.2	0.0081	0	800	0	45	0.0063
3/21/01	6:00	71.1	0.006	7	800	0	46	0.0060
3/21/01	7:00	71.5	0.0084	48	800	0	54	0.0072
3/21/01	8:00	73.2	0.0084	120	800	0	61	0.0077
3/21/01	9:00	75.3	0.0082	188	800	0	64	0.0076
3/21/01	10:00	76	0.0081	243	800	0.822	67	0.0075
3/21/01	11:00	76.4	0.0075	277	800	1.099	70	0.0068
3/21/01	12:00	76.6	0.0082	290	800	1.273	72	0.0070
3/21/01	13:00	76.8	0.0074	278	800	1.422	74	0.0065
3/21/01	14:00	76.9	0.0075	243	800	1.504	76	0.0067
3/21/01	15:00	76.9	0.008	187	800	1.5	76	0.0073
3/21/01	16:00	76.8	0.0083	118	800	1.424	76	0.0073
3/21/01	17:00	76.6	0.0076	46	800	1.236	75	0.0069
3/21/01	18:00	76.2	0.0082	5	800	0.894	70	0.0075
3/21/01	19:00	75.9	0.0081	0	800	0.51	65	0.0074
3/21/01	20:00	75.7	0.0088	0	800	0.32	63	0.0085
3/21/01	21:00	75.6	0.0094	0	800	0.185	60	0.0086
3/21/01	22:00	75.4	0.0097	0	800	0	59	0.0088
3/21/01	23:00	75.2	0.01	0	800	0	58	0.0085

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
3/22/01	0:00	75.1	0.0106	0	800	0	59	0.0088
3/22/01	1:00	74.9	0.01	0	800	0	58	0.0085
3/22/01	2:00	74.6	0.0105	0	800	0	57	0.0087
3/22/01	3:00	74.3	0.0099	0	800	0	56	0.0084
3/22/01	4:00	73.9	0.0092	0	800	0	52	0.0077
3/22/01	5:00	73.5	0.0095	0	800	0	52	0.0077
3/22/01	6:00	73.2	0.0095	5	800	0	52	0.0077
3/22/01	7:00	73.4	0.0104	27	800	0	59	0.0094
3/22/01	8:00	74.7	0.0107	88	800	0	63	0.0097
3/22/01	9:00	75.7	0.01	114	800	0	67	0.0094
3/22/01	10:00	76.1	0.0091	189	800	0.852	69	0.0089
3/22/01	11:00	76.2	0.0089	102	800	0.983	71	0.0091
3/22/01	12:00	76.4	0.0087	178	800	1.086	72	0.0089
3/22/01	13:00	76.3	0.0089	75	800	1.07	72	0.0095
3/22/01	14:00	76.4	0.0091	170	800	1.186	73	0.0100
3/22/01	15:00	76.3	0.009	80	800	1.09	71	0.0098
3/22/01	16:00	76.2	0.009	60	800	0.964	70	0.0093
3/22/01	17:00	76.1	0.0091	31	800	0.835	69	0.0096
3/22/01	18:00	75.9	0.0092	5	800	0.547	65	0.0092
3/22/01	19:00	75.7	0.0096	0	800	0.352	63	0.0097
3/22/01	20:00	75.6	0.0104	0	800	0.25	63	0.0103
3/22/01	21:00	75.6	0.0107	0	800	0.17	63	0.0103
3/22/01	22:00	75.5	0.0109	0	800	0.116	63	0.0103
3/22/01	23:00	75.5	0.011	0	800	0.104	63	0.0103
3/23/01	0:00	75.5	0.0117	0	800	0.126	63	0.0110
3/23/01	1:00	75.5	0.0117	0	800	0.124	63	0.0110
3/23/01	2:00	75.5	0.0123	0	800	0.12	63	0.0116
3/23/01	3:00	75.5	0.0125	0	800	0.077	63	0.0116
3/23/01	4:00	75.5	0.0123	0	800	0	64	0.0114
3/23/01	5:00	75.5	0.0123	0	800	0.166	64	0.0121
3/23/01	6:00	75.5	0.0125	2	800	0.136	64	0.0121
3/23/01	7:00	75.6	0.0117	20	800	0.222	65	0.0118
3/23/01	8:00	75.8	0.0108	53	800	0.472	67	0.0120
3/23/01	9:00	76	0.0106	83	800	0.728	70	0.0120
3/23/01	10:00	76.2	0.0101	129	800	0.982	71	0.0118
3/23/01	11:00	76.4	0.0099	134	800	1.15	73	0.0120
3/23/01	12:00	76.4	0.0099	110	800	1.194	73	0.0121
3/23/01	13:00	76.5	0.0097	117	800	1.232	75	0.0116
3/23/01	14:00	76.5	0.01	116	800	1.298	74	0.0126
3/23/01	15:00	76.5	0.0102	78	800	1.256	74	0.0133
3/23/01	16:00	76.5	0.0102	103	800	1.24	72	0.0130
3/23/01	17:00	76.3	0.0105	33	800	1.11	71	0.0133
3/23/01	18:00	76.1	0.0107	7	800	0.835	68	0.0125
3/23/01	19:00	75.9	0.011	0	800	0.624	67	0.0128
3/23/01	20:00	75.8	0.0112	0	800	0.554	68	0.0132
3/23/01	21:00	75.8	0.0113	0	800	0.47	67	0.0128
3/23/01	22:00	75.7	0.0118	0	800	0.401	66	0.0130
3/23/01	23:00	75.7	0.0121	0	800	0.348	66	0.0130
3/24/01	0:00	75.7	0.0119	0	800	0.394	67	0.0135
3/24/01	1:00	75.7	0.0119	0	800	0.391	67	0.0135
3/24/01	2:00	75.7	0.012	0	800	0.387	67	0.0135
3/24/01	3:00	75.7	0.0119	0	800	0.422	68	0.0140
3/24/01	4:00	75.7	0.0119	0	800	0.428	68	0.0140
3/24/01	5:00	75.7	0.0119	0	800	0.431	68	0.0140
3/24/01	6:00	75.7	0.0121	2	800	0.467	69	0.0145
3/24/01	7:00	75.8	0.0119	17	800	0.532	69	0.0145
3/24/01	8:00	75.9	0.0113	52	800	0.724	70	0.0150
3/24/01	9:00	76.1	0.011	71	800	0.94	71	0.0155
3/24/01	10:00	76.3	0.0111	104	800	1.178	75	0.0154
3/24/01	11:00	76.5	0.0105	124	800	1.304	78	0.0147
3/24/01	12:00	76.7	0.01	121	800	1.383	79	0.0129
3/24/01	13:00	76.7	0.01	113	800	1.471	80	0.0135
3/24/01	14:00	76.7	0.0098	104	800	1.416	79	0.0130
3/24/01	15:00	76.7	0.0101	95	800	1.471	79	0.0137
3/24/01	16:00	76.6	0.0106	61	800	1.399	76	0.0144
3/24/01	17:00	76.4	0.0104	25	800	1.188	75	0.0139
3/24/01	18:00	76.2	0.0108	3	800	1.034	73	0.0143
3/24/01	19:00	76.1	0.011	0	800	0.886	72	0.0138
3/24/01	20:00	76	0.0113	0	800	0.817	72	0.0146
3/24/01	21:00	75.9	0.0119	0	800	0.754	71	0.0148
3/24/01	22:00	75.9	0.0122	0	800	0.708	71	0.0148
3/24/01	23:00	75.9	0.0122	0	800	0.657	70	0.0150

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
3/25/01	0:00	75.8	0.0132	0	800	0.682	71	0.0156
3/25/01	1:00	75.9	0.0127	0	800	0.667	71	0.0156
3/25/01	2:00	75.9	0.0119	0	800	0.628	71	0.0148
3/25/01	3:00	75.9	0.0113	0	800	0.616	71	0.0156
3/25/01	4:00	75.9	0.011	0	800	0.602	71	0.0148
3/25/01	5:00	75.9	0.011	0	800	0.589	70	0.0150
3/25/01	6:00	75.9	0.0111	3	800	0.586	70	0.0150
3/25/01	7:00	75.9	0.0108	27	800	0.701	72	0.0153
3/25/01	8:00	76.2	0.0108	78	800	1.043	75	0.0146
3/25/01	9:00	76.5	0.0103	139	800	1.303	77	0.0149
3/25/01	10:00	76.7	0.01	120	800	1.424	79	0.0145
3/25/01	11:00	76.8	0.0099	120	800	1.523	82	0.0154
3/25/01	12:00	76.9	0.0098	258	800	1.667	82	0.0138
3/25/01	13:00	76.9	0.0098	86	800	1.611	80	0.0135
3/25/01	14:00	76.8	0.01	90	800	1.583	81	0.0140
3/25/01	15:00	76.9	0.0098	153	800	1.585	81	0.0140
3/25/01	16:00	76.9	0.0095	91	800	1.558	82	0.0138
3/25/01	17:00	76.8	0.0096	53	800	1.516	81	0.0140
3/25/01	18:00	76.5	0.0097	10	800	1.255	76	0.0136
3/25/01	19:00	76.3	0.0098	0	800	1.042	76	0.0136
3/25/01	20:00	76.1	0.0103	0	800	0.911	73	0.0143
3/25/01	21:00	76	0.0108	0	800	0.755	71	0.0140
3/25/01	22:00	75.9	0.0109	0	800	0.617	69	0.0137
3/25/01	23:00	75.8	0.0113	0	800	0.543	68	0.0140
3/26/01	0:00	75.8	0.0115	0	800	0.515	68	0.0140
3/26/01	1:00	75.8	0.0116	0	800	0.518	69	0.0137
3/26/01	2:00	75.8	0.0111	0	800	0.515	68	0.0140
3/26/01	3:00	75.8	0.0114	0	800	0.513	68	0.0140
3/26/01	4:00	75.8	0.0111	0	800	0.503	68	0.0140
3/26/01	5:00	75.8	0.011	0	800	0.497	68	0.0139
3/26/01	6:00	75.8	0.0113	5	800	0.535	69	0.0144
3/26/01	7:00	75.9	0.0106	23	800	0.604	70	0.0135
3/26/01	8:00	76	0.0103	57	800	0.827	72	0.0145
3/26/01	9:00	76.2	0.0097	77	800	0.996	74	0.0140
3/26/01	10:00	76.5	0.0097	151	800	1.297	77	0.0141
3/26/01	11:00	76.8	0.0096	254	800	1.558	80	0.0142
3/26/01	12:00	77.1	0.0094	276	800	1.723	83	0.0143
3/26/01	13:00	77.2	0.0094	274	800	1.911	85	0.0138
3/26/01	14:00	77.3	0.0094	231	800	1.952	83	0.0135
3/26/01	15:00	77.3	0.0095	188	800	1.959	84	0.0133
3/26/01	16:00	77.1	0.0093	110	800	1.782	82	0.0122
3/26/01	17:00	76.9	0.0093	34	800	1.559	81	0.0124
3/26/01	18:00	76.6	0.0093	5	800	1.263	78	0.0116
3/26/01	19:00	76.3	0.0098	0	800	1.127	76	0.0136
3/26/01	20:00	76.2	0.01	0	800	0.965	74	0.0148
3/26/01	21:00	76	0.0102	0	800	0.779	70	0.0134
3/26/01	22:00	75.9	0.0112	0	800	0.612	67	0.0134
3/26/01	23:00	75.9	0.0098	0	800	0.506	67	0.0134
3/27/01	0:00	75.8	0.0095	0	800	0.44	66	0.0129
3/27/01	1:00	75.7	0.0108	0	800	0.375	65	0.0125
3/27/01	2:00	75.6	0.0102	0	800	0.244	63	0.0097
3/27/01	3:00	75.6	0.0095	0	800	0.133	61	0.0084
3/27/01	4:00	75.4	0.0083	0	800	0	59	0.0071
3/27/01	5:00	75.5	0.0093	0	800	0	60	0.0069
3/27/01	6:00	75.4	0.0068	10	800	0	60	0.0058
3/27/01	7:00	75.6	0.0068	36	800	0.222	64	0.0060
3/27/01	8:00	75.9	0.0074	108	800	0.648	68	0.0067
3/27/01	9:00	76.3	0.0076	176	800	1.071	73	0.0068
3/27/01	10:00	76.6	0.008	166	800	1.241	76	0.0073
3/27/01	11:00	76.7	0.0082	262	800	1.402	78	0.0075
3/27/01	12:00	76.9	0.0082	271	800	1.505	80	0.0077
3/27/01	13:00	76.9	0.0083	244	800	1.543	79	0.0079
3/27/01	14:00	76.9	0.0086	190	800	1.584	79	0.0093
3/27/01	15:00	76.9	0.0086	191	800	1.559	77	0.0091
3/27/01	16:00	76.8	0.0089	128	800	1.52	75	0.0102
3/27/01	17:00	76.6	0.0094	52	800	1.37	72	0.0116
3/27/01	18:00	76.2	0.0097	6	800	1.012	68	0.0111
3/27/01	19:00	76	0.0099	0	800	0.779	67	0.0114
3/27/01	20:00	75.9	0.0105	0	800	0.695	69	0.0123
3/27/01	21:00	75.9	0.0108	0	800	0.604	68	0.0125
3/27/01	22:00	75.8	0.0111	0	800	0.544	68	0.0125
3/27/01	23:00	75.8	0.011	0	800	0.521	68	0.0125

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
3/28/01	0:00	75.8	0.0112	0	800	0.487	68	0.0125
3/28/01	1:00	75.8	0.0113	0	800	0.468	68	0.0125
3/28/01	2:00	75.8	0.0113	0	800	0.506	69	0.0130
3/28/01	3:00	75.8	0.0114	0	800	0.491	68	0.0132
3/28/01	4:00	75.8	0.0116	0	800	0.516	69	0.0137
3/28/01	5:00	75.8	0.0114	0	800	0.496	69	0.0130
3/28/01	6:00	75.8	0.0114	6	800	0.517	69	0.0130
3/28/01	7:00	75.8	0.0115	15	800	0.592	70	0.0135
3/28/01	8:00	76	0.0109	66	800	0.801	71	0.0132
3/28/01	9:00	76.2	0.0108	81	800	1.013	73	0.0135
3/28/01	10:00	76.4	0.0104	116	800	1.192	76	0.0128
3/28/01	11:00	76.5	0.0104	109	800	1.271	75	0.0131
3/28/01	12:00	76.6	0.0102	145	800	1.342	76	0.0128
3/28/01	13:00	76.7	0.0102	152	800	1.46	77	0.0134
3/28/01	14:00	76.8	0.0102	173	800	1.564	78	0.0132
3/28/01	15:00	76.8	0.01	121	800	1.502	77	0.0126
3/28/01	16:00	76.7	0.01	98	800	1.468	77	0.0126
3/28/01	17:00	76.5	0.0102	27	800	1.292	75	0.0131
3/28/01	18:00	76.3	0.0108	4	800	1.118	73	0.0143
3/28/01	19:00	76.1	0.0111	0	800	0.981	73	0.0143
3/28/01	20:00	76.1	0.0114	0	800	0.911	73	0.0143
3/28/01	21:00	76	0.0116	0	800	0.857	73	0.0143
3/28/01	22:00	76	0.0115	0	800	0.767	72	0.0138
3/28/01	23:00	76	0.0117	0	800	0.763	72	0.0146
3/29/01	0:00	75.9	0.0121	0	800	0.73	71	0.0148
3/29/01	1:00	75.9	0.0116	0	800	0.688	72	0.0138
3/29/01	2:00	75.9	0.0115	0	800	0.685	72	0.0138
3/29/01	3:00	75.9	0.0118	0	800	0.663	71	0.0141
3/29/01	4:00	75.9	0.0115	0	800	0.635	71	0.0141
3/29/01	5:00	75.8	0.0121	0	800	0.634	71	0.0141
3/29/01	6:00	75.9	0.0115	4	800	0.637	71	0.0141
3/29/01	7:00	75.9	0.0116	11	800	0.687	72	0.0138
3/29/01	8:00	76.1	0.011	61	800	0.893	73	0.0136
3/29/01	9:00	76.2	0.0108	74	800	1.075	75	0.0139
3/29/01	10:00	76.5	0.0104	134	800	1.268	77	0.0134
3/29/01	11:00	76.8	0.0101	189	800	1.512	81	0.0132
3/29/01	12:00	76.7	0.01	77	800	1.447	79	0.0129
3/29/01	13:00	76.6	0.0106	61	800	1.423	77	0.0150
3/29/01	14:00	76.1	0.0094	49	800	0.691	57	0.0093
3/29/01	15:00	75.8	0.0083	83	800	0.385	54	0.0078
3/29/01	16:00	75.6	0.0078	30	800	0.188	52	0.0072
3/29/01	17:00	75.1	0.0077	21	800	0	52	0.0072
3/29/01	18:00	74.7	0.0076	7	800	0	51	0.0069
3/29/01	19:00	74.2	0.0073	0	800	0	52	0.0066
3/29/01	20:00	73.4	0.0075	0	800	0	51	0.0069
3/29/01	21:00	73	0.0072	0	800	0	51	0.0064
3/29/01	22:00	72.6	0.007	0	800	0	50	0.0061
3/29/01	23:00	71.9	0.0067	0	800	0	50	0.0061
3/30/01	0:00	71.7	0.0065	0	800	0	50	0.0056
3/30/01	1:00	71.4	0.0064	0	800	0	49	0.0054
3/30/01	2:00	70.7	0.0061	0	800	0	49	0.0054
3/30/01	3:00	70.5	0.0063	0	800	0	49	0.0054
3/30/01	4:00	70.5	0.0063	0	6314.196	0	48	0.0056
3/30/01	5:00	70.4	0.0063	0	7041.835	0	48	0.0056
3/30/01	6:00	70.5	0.0065	4	6529.209	0	48	0.0056
3/30/01	7:00	70.5	0.007	19	5439.654	0	47	0.0058
3/30/01	8:00	70.5	0.0072	68	800	0.079	47	0.0063
3/30/01	9:00	70.9	0.0076	64	800	0	48	0.0066
3/30/01	10:00	71.2	0.0076	71	800	0	49	0.0068
3/30/01	11:00	71.7	0.008	77	800	0	50	0.0071
3/30/01	12:00	72.4	0.0088	82	800	0	50	0.0076
3/30/01	13:00	73.1	0.0083	82	800	0	50	0.0071
3/30/01	14:00	73.1	0.0078	70	800	0	50	0.0071
3/30/01	15:00	73.4	0.0086	58	800	0	50	0.0076
3/30/01	16:00	73.4	0.0089	41	800	0	51	0.0079
3/30/01	17:00	73.1	0.0087	21	800	0	53	0.0080
3/30/01	18:00	73	0.0098	4	800	0	53	0.0086
3/30/01	19:00	72.7	0.0095	0	800	0	54	0.0083
3/30/01	20:00	72.5	0.0099	0	800	0	56	0.0090
3/30/01	21:00	72.2	0.0098	0	800	0	56	0.0090
3/30/01	22:00	72.2	0.0103	0	800	0	57	0.0093
3/30/01	23:00	72.2	0.0105	0	800	0	57	0.0093

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
3/31/01	0:00	72.2	0.0106	0	800	0	57	0.0094
3/31/01	1:00	72.2	0.0106	0	800	0	57	0.0094
3/31/01	2:00	72.1	0.0106	0	800	0	58	0.0097
3/31/01	3:00	72.1	0.0115	0	800	0	59	0.0107
3/31/01	4:00	72.3	0.0118	0	800	0	61	0.0109
3/31/01	5:00	72.6	0.0132	0	800	0	63	0.0124
3/31/01	6:00	72.8	0.0131	8	800	0	65	0.0126
3/31/01	7:00	73.3	0.0116	20	800	0	66	0.0110
3/31/01	8:00	74.3	0.0141	72	800	0	67	0.0135
3/31/01	9:00	75.3	0.0142	55	800	0	67	0.0135
3/31/01	10:00	75.9	0.0115	122	800	0.644	69	0.0131
3/31/01	11:00	76.1	0.0107	137	800	0.944	69	0.0131
3/31/01	12:00	76.4	0.0101	208	800	1.15	72	0.0124
3/31/01	13:00	76.4	0.0099	111	800	1.19	73	0.0114
3/31/01	14:00	76.4	0.0098	77	800	1.124	73	0.0115
3/31/01	15:00	76.3	0.0099	84	800	1.089	72	0.0117
3/31/01	16:00	76.2	0.0097	31	800	0.944	70	0.0115
3/31/01	17:00	76	0.01	14	800	0.793	70	0.0115
3/31/01	18:00	75.9	0.0104	5	800	0.642	69	0.0117
3/31/01	19:00	75.8	0.0109	0	800	0.514	67	0.0122
3/31/01	20:00	75.7	0.0109	0	800	0.385	67	0.0115
3/31/01	21:00	75.7	0.011	0	800	0.334	67	0.0115
3/31/01	22:00	75.7	0.0112	0	800	0.301	66	0.0117
3/31/01	23:00	75.7	0.0115	0	800	0.317	66	0.0124

B.2.2 Summer Season: (June)

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
6/1/01	0:00	76	0.011	0	800	0.86	74	0.0165
6/1/01	1:00	76	0.011	0	800	0.853	74	0.0165
6/1/01	2:00	76	0.0108	0	800	0.825	74	0.0165
6/1/01	3:00	76	0.0107	0	800	0.789	73	0.0159
6/1/01	4:00	76	0.0108	0	800	0.757	72	0.0161
6/1/01	5:00	76	0.0107	8	800	0.767	71	0.0156
6/1/01	6:00	76.1	0.0109	36	800	0.98	74	0.0157
6/1/01	7:00	76.5	0.0109	94	800	1.307	77	0.0166
6/1/01	8:00	76.7	0.0109	120	800	1.566	81	0.0165
6/1/01	9:00	77	0.0107	175	800	1.759	83	0.0169
6/1/01	10:00	77.1	0.0105	249	800	1.877	85	0.0164
6/1/01	11:00	77.2	0.0105	293	800	1.953	87	0.0168
6/1/01	12:00	77.3	0.0104	292	800	2.006	87	0.0169
6/1/01	13:00	77.3	0.0103	279	800	2.042	88	0.0166
6/1/01	14:00	77.4	0.0103	184	800	2.118	88	0.0175
6/1/01	15:00	77.3	0.0102	158	800	2.039	86	0.0171
6/1/01	16:00	77.1	0.0103	65	800	1.879	85	0.0174
6/1/01	17:00	76.9	0.0102	43	800	1.687	83	0.0169
6/1/01	18:00	76.8	0.0102	23	800	1.518	81	0.0165
6/1/01	19:00	76.5	0.0105	2	800	1.351	79	0.0170
6/1/01	20:00	76.4	0.0105	0	800	1.167	77	0.0166
6/1/01	21:00	76.2	0.0106	0	800	1.053	76	0.0160
6/1/01	22:00	76.2	0.0106	0	800	0.971	75	0.0162
6/1/01	23:00	76.1	0.0106	0	800	0.905	74	0.0156
6/2/01	0:00	76.1	0.0105	0	800	0.84	74	0.0156
6/2/01	1:00	76	0.0106	0	800	0.806	73	0.0159
6/2/01	2:00	76	0.0104	0	800	0.754	73	0.0159
6/2/01	3:00	76	0.0107	0	800	0.757	73	0.0159
6/2/01	4:00	76	0.0107	0	800	0.713	72	0.0153
6/2/01	5:00	76	0.0109	6	800	0.735	72	0.0153
6/2/01	6:00	76.2	0.0108	41	800	1.019	75	0.0154
6/2/01	7:00	76.5	0.0108	95	800	1.366	79	0.0161
6/2/01	8:00	76.8	0.0108	118	800	1.582	82	0.0162
6/2/01	9:00	77	0.0105	193	800	1.747	83	0.0160
6/2/01	10:00	77.1	0.0102	215	800	1.847	85	0.0155
6/2/01	11:00	77.2	0.0101	210	800	1.916	86	0.0153
6/2/01	12:00	77.2	0.01	201	800	1.934	86	0.0153
6/2/01	13:00	77.3	0.01	197	800	1.962	87	0.0151
6/2/01	14:00	77.3	0.01	248	800	1.996	87	0.0151
6/2/01	15:00	77.3	0.0101	202	800	2.037	86	0.0153
6/2/01	16:00	77.3	0.0102	143	800	2.002	84	0.0158
6/2/01	17:00	77.2	0.0105	84	800	1.938	83	0.0160
6/2/01	18:00	76.9	0.0105	24	800	1.668	80	0.0159
6/2/01	19:00	76.6	0.0104	2	800	1.34	77	0.0149
6/2/01	20:00	76.3	0.0103	0	800	1.098	74	0.0148
6/2/01	21:00	76.2	0.0103	0	800	0.969	73	0.0143
6/2/01	22:00	76.1	0.0105	0	800	0.854	71	0.0148
6/2/01	23:00	76	0.0106	0	800	0.751	70	0.0142
6/3/01	0:00	75.9	0.0104	0	800	0.662	69	0.0137
6/3/01	1:00	75.9	0.0104	0	800	0.597	68	0.0132
6/3/01	2:00	75.8	0.0104	0	800	0.547	67	0.0134
6/3/01	3:00	75.8	0.0101	0	800	0.521	68	0.0132
6/3/01	4:00	75.8	0.0099	0	800	0.512	69	0.0137
6/3/01	5:00	75.9	0.0094	4	800	0.519	70	0.0142
6/3/01	6:00	75.9	0.0097	23	800	0.706	73	0.0150
6/3/01	7:00	76.2	0.0099	68	800	1.031	76	0.0151
6/3/01	8:00	76.5	0.0101	90	800	1.279	79	0.0160
6/3/01	9:00	76.8	0.0102	173	800	1.557	81	0.0164
6/3/01	10:00	77	0.01	184	800	1.735	84	0.0157
6/3/01	11:00	77.1	0.01	171	800	1.854	86	0.0152
6/3/01	12:00	77.2	0.0099	288	800	1.891	86	0.0144
6/3/01	13:00	77.3	0.01	197	800	1.968	85	0.0146
6/3/01	14:00	77.3	0.0099	206	800	1.952	85	0.0138
6/3/01	15:00	77.2	0.0098	155	800	1.88	84	0.0141
6/3/01	16:00	77.1	0.0099	127	800	1.835	84	0.0149
6/3/01	17:00	77	0.0097	77	800	1.715	83	0.0143
6/3/01	18:00	76.8	0.0098	20	800	1.518	80	0.0150
6/3/01	19:00	76.5	0.0099	1	800	1.265	77	0.0149
6/3/01	20:00	76.3	0.01	0	800	1.069	74	0.0148
6/3/01	21:00	76.2	0.0099	0	800	0.928	73	0.0150
6/3/01	22:00	76.1	0.0097	0	800	0.791	72	0.0145
6/3/01	23:00	76	0.0092	0	800	0.66	71	0.0147

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
6/4/01	0:00	75.9	0.0095	0	800	0.629	71	0.0147
6/4/01	1:00	75.9	0.0099	0	800	0.608	71	0.0147
6/4/01	2:00	75.9	0.0104	0	800	0.598	71	0.0147
6/4/01	3:00	75.9	0.0102	0	800	0.555	70	0.0142
6/4/01	4:00	75.9	0.0099	0	800	0.533	70	0.0142
6/4/01	5:00	75.9	0.0094	6	800	0.531	69	0.0136
6/4/01	6:00	76	0.0091	27	800	0.667	72	0.0144
6/4/01	7:00	76.2	0.0089	54	800	0.903	75	0.0153
6/4/01	8:00	76.3	0.0087	60	800	1.056	78	0.0162
6/4/01	9:00	76.5	0.0091	118	800	1.343	81	0.0155
6/4/01	10:00	76.9	0.0093	233	800	1.623	83	0.0151
6/4/01	11:00	77.1	0.0094	299	800	1.824	86	0.0144
6/4/01	12:00	77.2	0.0095	256	800	1.906	87	0.0141
6/4/01	13:00	77.3	0.0096	236	800	1.975	87	0.0142
6/4/01	14:00	77.4	0.0097	218	800	2.023	88	0.0139
6/4/01	15:00	77.3	0.0097	219	800	2.022	87	0.0142
6/4/01	16:00	77.3	0.0098	147	800	1.98	85	0.0146
6/4/01	17:00	77.2	0.0098	91	800	1.877	84	0.0140
6/4/01	18:00	76.9	0.0099	28	800	1.661	81	0.0147
6/4/01	19:00	76.6	0.0099	2	800	1.364	79	0.0144
6/4/01	20:00	76.4	0.0097	0	800	1.112	76	0.0143
6/4/01	21:00	76.2	0.0096	0	800	0.957	74	0.0140
6/4/01	22:00	76.1	0.0094	0	800	0.778	71	0.0139
6/4/01	23:00	76	0.0091	0	800	0.642	69	0.0137
6/5/01	0:00	75.9	0.0091	0	800	0.554	68	0.0132
6/5/01	1:00	75.8	0.0092	0	800	0.48	66	0.0129
6/5/01	2:00	75.8	0.0094	0	800	0.421	65	0.0125
6/5/01	3:00	75.7	0.0099	0	800	0.382	65	0.0125
6/5/01	4:00	75.7	0.0104	0	800	0.361	66	0.0122
6/5/01	5:00	75.7	0.0106	7	800	0.42	66	0.0129
6/5/01	6:00	76	0.0102	41	800	0.784	71	0.0139
6/5/01	7:00	76.4	0.0098	114	800	1.193	76	0.0151
6/5/01	8:00	76.8	0.0096	155	800	1.495	81	0.0156
6/5/01	9:00	76.9	0.0095	155	800	1.619	83	0.0151
6/5/01	10:00	77.1	0.0093	245	800	1.734	84	0.0140
6/5/01	11:00	77.2	0.0091	318	800	1.812	86	0.0128
6/5/01	12:00	77.2	0.0092	282	800	1.912	87	0.0134
6/5/01	13:00	77.3	0.0092	293	800	1.971	89	0.0129
6/5/01	14:00	77.4	0.0094	226	800	2.054	90	0.0135
6/5/01	15:00	77.4	0.0094	230	800	2.032	88	0.0132
6/5/01	16:00	77.3	0.0094	150	800	1.966	87	0.0134
6/5/01	17:00	77.2	0.0094	89	800	1.864	85	0.0131
6/5/01	18:00	76.9	0.0096	27	800	1.665	81	0.0140
6/5/01	19:00	76.6	0.0097	2	800	1.353	78	0.0139
6/5/01	20:00	76.3	0.0099	0	800	1.123	74	0.0141
6/5/01	21:00	76.2	0.0099	0	800	0.945	72	0.0137
6/5/01	22:00	76	0.0096	0	800	0.759	69	0.0130
6/5/01	23:00	75.9	0.0092	0	800	0.616	67	0.0127
6/6/01	0:00	75.9	0.0092	0	800	0.522	66	0.0123
6/6/01	1:00	75.8	0.0093	0	800	0.458	66	0.0123
6/6/01	2:00	75.8	0.0094	0	800	0.409	65	0.0125
6/6/01	3:00	75.7	0.0096	0	800	0.373	65	0.0118
6/6/01	4:00	75.7	0.0098	0	800	0.339	64	0.0121
6/6/01	5:00	75.7	0.0097	7	800	0.374	64	0.0121
6/6/01	6:00	76	0.0095	43	800	0.731	70	0.0128
6/6/01	7:00	76.4	0.0094	111	800	1.156	75	0.0146
6/6/01	8:00	76.7	0.0095	165	800	1.504	81	0.0156
6/6/01	9:00	77	0.0095	218	800	1.712	83	0.0152
6/6/01	10:00	77.2	0.0093	252	800	1.807	85	0.0139
6/6/01	11:00	77.3	0.0092	270	800	1.895	87	0.0134
6/6/01	12:00	77.3	0.0094	265	800	1.971	87	0.0142
6/6/01	13:00	77.3	0.0097	288	800	2.053	88	0.0149
6/6/01	14:00	77.4	0.01	232	800	2.13	88	0.0157
6/6/01	15:00	77.4	0.01	196	800	2.083	87	0.0151
6/6/01	16:00	77.3	0.0099	134	800	1.978	86	0.0145
6/6/01	17:00	77.2	0.0098	80	800	1.866	85	0.0139
6/6/01	18:00	76.9	0.01	24	800	1.675	82	0.0146
6/6/01	19:00	76.6	0.0102	2	800	1.419	80	0.0151
6/6/01	20:00	76.4	0.0104	0	800	1.211	77	0.0150
6/6/01	21:00	76.3	0.0104	0	800	1.063	76	0.0144
6/6/01	22:00	76.2	0.0105	0	800	0.967	74	0.0149
6/6/01	23:00	76.1	0.0106	0	800	0.877	73	0.0151

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
6/7/01	0:00	76	0.0106	0	800	0.791	72	0.0146
6/7/01	1:00	76	0.0105	0	800	0.695	70	0.0143
6/7/01	2:00	75.9	0.0107	0	800	0.637	69	0.0145
6/7/01	3:00	75.9	0.0108	0	800	0.571	68	0.0140
6/7/01	4:00	75.8	0.0105	0	800	0.517	68	0.0133
6/7/01	5:00	75.9	0.0104	8	800	0.567	67	0.0135
6/7/01	6:00	76.1	0.0103	44	800	0.941	72	0.0146
6/7/01	7:00	76.5	0.0101	114	800	1.324	78	0.0147
6/7/01	8:00	76.9	0.0102	177	800	1.677	83	0.0160
6/7/01	9:00	77.1	0.01	200	800	1.809	85	0.0156
6/7/01	10:00	77.2	0.0097	179	800	1.813	87	0.0151
6/7/01	11:00	77.2	0.0094	217	800	1.803	89	0.0138
6/7/01	12:00	77.2	0.0094	267	800	1.901	90	0.0144
6/7/01	13:00	77.3	0.0093	241	800	1.92	90	0.0136
6/7/01	14:00	77.4	0.0093	220	800	1.99	91	0.0134
6/7/01	15:00	77.4	0.0094	179	800	2.041	90	0.0144
6/7/01	16:00	77.4	0.0096	160	800	2.041	88	0.0141
6/7/01	17:00	77.3	0.0097	85	800	1.977	87	0.0143
6/7/01	18:00	77	0.0099	25	800	1.752	84	0.0142
6/7/01	19:00	76.7	0.0101	2	800	1.48	81	0.0149
6/7/01	20:00	76.5	0.0102	0	800	1.255	78	0.0147
6/7/01	21:00	76.3	0.0103	0	800	1.103	77	0.0150
6/7/01	22:00	76.2	0.0103	0	800	0.998	75	0.0154
6/7/01	23:00	76.1	0.0101	0	800	0.884	74	0.0156
6/8/01	0:00	76	0.0101	0	800	0.779	72	0.0145
6/8/01	1:00	76	0.0101	0	800	0.7	71	0.0140
6/8/01	2:00	75.9	0.0102	0	800	0.624	69	0.0137
6/8/01	3:00	75.9	0.0107	0	800	0.602	69	0.0145
6/8/01	4:00	75.9	0.0108	0	800	0.58	70	0.0142
6/8/01	5:00	75.9	0.011	8	800	0.68	70	0.0150
6/8/01	6:00	76.2	0.0106	45	800	1.034	74	0.0156
6/8/01	7:00	76.6	0.0102	111	800	1.36	79	0.0153
6/8/01	8:00	76.9	0.0101	155	800	1.633	83	0.0160
6/8/01	9:00	77.1	0.0099	230	800	1.824	85	0.0155
6/8/01	10:00	77.2	0.0098	245	800	1.917	87	0.0151
6/8/01	11:00	77.3	0.0096	272	800	1.952	89	0.0138
6/8/01	12:00	77.3	0.0097	260	800	2.031	88	0.0149
6/8/01	13:00	77.4	0.0098	267	800	2.055	88	0.0149
6/8/01	14:00	77.4	0.01	215	800	2.096	87	0.0160
6/8/01	15:00	77.4	0.01	198	800	2.047	87	0.0151
6/8/01	16:00	77.3	0.01	143	800	2.017	87	0.0151
6/8/01	17:00	77.3	0.01	89	800	1.969	87	0.0151
6/8/01	18:00	77	0.01	28	800	1.761	84	0.0150
6/8/01	19:00	76.7	0.0101	3	800	1.458	80	0.0151
6/8/01	20:00	76.4	0.0101	0	800	1.211	77	0.0150
6/8/01	21:00	76.3	0.0102	0	800	1.06	75	0.0154
6/8/01	22:00	76.1	0.0102	0	800	0.936	73	0.0151
6/8/01	23:00	76.1	0.0101	0	800	0.8	71	0.0148
6/9/01	0:00	76	0.0099	0	800	0.698	70	0.0143
6/9/01	1:00	75.9	0.0096	0	800	0.633	70	0.0143
6/9/01	2:00	75.9	0.0093	0	800	0.574	69	0.0145
6/9/01	3:00	75.9	0.0096	0	800	0.566	69	0.0145
6/9/01	4:00	75.8	0.0103	0	800	0.584	70	0.0143
6/9/01	5:00	75.9	0.0108	5	800	0.627	70	0.0150
6/9/01	6:00	76.1	0.0106	35	800	0.91	75	0.0154
6/9/01	7:00	76.5	0.0103	95	800	1.257	79	0.0161
6/9/01	8:00	76.8	0.0101	137	800	1.556	84	0.0167
6/9/01	9:00	77.1	0.0099	227	800	1.786	86	0.0162
6/9/01	10:00	77.3	0.0096	252	800	1.895	88	0.0157
6/9/01	11:00	77.3	0.0095	203	800	1.965	90	0.0162
6/9/01	12:00	77.3	0.0096	209	800	2.044	90	0.0162
6/9/01	13:00	77.4	0.0099	252	800	2.141	91	0.0159
6/9/01	14:00	77.5	0.0102	243	800	2.255	91	0.0169
6/9/01	15:00	77.5	0.0102	169	800	2.198	90	0.0162
6/9/01	16:00	77.4	0.0102	122	800	2.1	89	0.0164
6/9/01	17:00	77.3	0.0102	71	800	1.982	88	0.0158
6/9/01	18:00	77	0.0102	26	800	1.785	85	0.0156
6/9/01	19:00	76.7	0.0105	2	800	1.518	81	0.0165
6/9/01	20:00	76.5	0.0105	0	800	1.278	78	0.0156
6/9/01	21:00	76.3	0.0106	0	800	1.14	77	0.0158
6/9/01	22:00	76.2	0.0107	0	800	1.043	76	0.0160
6/9/01	23:00	76.2	0.0107	0	800	0.968	75	0.0163

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
6/10/01	0:00	76.1	0.0108	0	800	0.922	74	0.0165
6/10/01	1:00	76.1	0.0106	0	800	0.837	74	0.0157
6/10/01	2:00	76	0.0106	0	800	0.802	73	0.0159
6/10/01	3:00	76	0.0105	0	800	0.754	73	0.0159
6/10/01	4:00	76	0.0098	0	800	0.664	72	0.0153
6/10/01	5:00	76	0.0093	7	800	0.647	72	0.0153
6/10/01	6:00	76.1	0.0095	38	800	0.954	77	0.0158
6/10/01	7:00	76.4	0.01	67	800	1.219	81	0.0165
6/10/01	8:00	76.7	0.0103	96	800	1.513	86	0.0180
6/10/01	9:00	76.9	0.0101	167	800	1.694	87	0.0169
6/10/01	10:00	77.2	0.01	212	800	1.904	89	0.0173
6/10/01	11:00	77.3	0.0098	226	800	1.979	90	0.0162
6/10/01	12:00	77.3	0.0099	233	800	2.017	89	0.0164
6/10/01	13:00	77.4	0.0099	211	800	2.097	89	0.0164
6/10/01	14:00	77.4	0.0101	176	800	2.109	88	0.0166
6/10/01	15:00	77.3	0.0102	148	800	2.013	84	0.0167
6/10/01	16:00	77.1	0.0105	107	800	1.897	79	0.0170
6/10/01	17:00	76.9	0.0108	73	800	1.729	75	0.0171
6/10/01	18:00	76.7	0.0108	20	800	1.505	76	0.0169
6/10/01	19:00	76.5	0.0106	2	800	1.271	77	0.0166
6/10/01	20:00	76.3	0.0104	0	800	1.123	78	0.0164
6/10/01	21:00	76.2	0.0105	0	800	1.053	77	0.0166
6/10/01	22:00	76.2	0.0104	0	800	0.981	77	0.0166
6/10/01	23:00	76.1	0.0105	0	800	0.943	76	0.0168
6/11/01	0:00	76.1	0.0107	0	800	0.906	75	0.0171
6/11/01	1:00	76.1	0.0107	0	800	0.854	74	0.0165
6/11/01	2:00	76	0.0108	0	800	0.822	73	0.0167
6/11/01	3:00	76	0.0108	0	800	0.809	74	0.0165
6/11/01	4:00	76	0.0111	0	800	0.827	74	0.0165
6/11/01	5:00	76.1	0.0111	8	800	0.896	75	0.0171
6/11/01	6:00	76.2	0.0113	33	800	1.129	78	0.0172
6/11/01	7:00	76.5	0.0113	71	800	1.368	80	0.0176
6/11/01	8:00	76.7	0.0113	109	800	1.632	83	0.0177
6/11/01	9:00	76.9	0.011	131	800	1.761	85	0.0173
6/11/01	10:00	77.2	0.0109	223	800	1.976	88	0.0175
6/11/01	11:00	77.3	0.0105	277	800	2.038	90	0.0161
6/11/01	12:00	77.4	0.0104	252	800	2.104	90	0.0161
6/11/01	13:00	77.4	0.0103	234	800	2.094	91	0.0159
6/11/01	14:00	77.5	0.0102	213	800	2.142	91	0.0159
6/11/01	15:00	77.5	0.0102	205	800	2.161	90	0.0161
6/11/01	16:00	77.4	0.0101	150	800	2.111	89	0.0155
6/11/01	17:00	77.3	0.0102	88	800	2.051	88	0.0157
6/11/01	18:00	77.1	0.0103	27	800	1.854	85	0.0164
6/11/01	19:00	76.8	0.0105	3	800	1.581	82	0.0171
6/11/01	20:00	76.5	0.0106	0	800	1.329	79	0.0169
6/11/01	21:00	76.4	0.0106	0	800	1.187	78	0.0172
6/11/01	22:00	76.3	0.0109	0	800	1.105	77	0.0174
6/11/01	23:00	76.2	0.0109	0	800	1.02	76	0.0176
6/12/01	0:00	76.1	0.0109	0	800	0.964	75	0.0170
6/12/01	1:00	76.1	0.0106	0	800	0.897	75	0.0162
6/12/01	2:00	76.1	0.0106	0	800	0.872	74	0.0164
6/12/01	3:00	76.1	0.0106	0	800	0.851	74	0.0164
6/12/01	4:00	76	0.011	0	800	0.888	75	0.0170
6/12/01	5:00	76.1	0.0112	7	800	0.923	75	0.0178
6/12/01	6:00	76.2	0.0109	29	800	1.052	78	0.0180
6/12/01	7:00	76.5	0.0105	90	800	1.32	81	0.0173
6/12/01	8:00	76.9	0.01	159	800	1.589	84	0.0166
6/12/01	9:00	77.1	0.0097	175	800	1.754	86	0.0161
6/12/01	10:00	77.2	0.0096	240	800	1.908	88	0.0165
6/12/01	11:00	77.3	0.0095	252	800	1.993	90	0.0161
6/12/01	12:00	77.4	0.0095	277	800	2.068	91	0.0150
6/12/01	13:00	77.5	0.0095	275	800	2.131	92	0.0148
6/12/01	14:00	77.5	0.0096	249	800	2.194	93	0.0145
6/12/01	15:00	77.5	0.0096	207	800	2.192	92	0.0148
6/12/01	16:00	77.5	0.0098	146	800	2.145	90	0.0153
6/12/01	17:00	77.3	0.0099	83	800	2.053	89	0.0155
6/12/01	18:00	77.1	0.0101	27	800	1.851	85	0.0164
6/12/01	19:00	76.8	0.0102	3	800	1.541	82	0.0163
6/12/01	20:00	76.5	0.0104	0	800	1.305	78	0.0163
6/12/01	21:00	76.3	0.0105	0	800	1.134	76	0.0160
6/12/01	22:00	76.2	0.0104	0	800	1.003	74	0.0156
6/12/01	23:00	76.1	0.0103	0	800	0.886	72	0.0153

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
6/13/01	0:00	76	0.0101	0	800	0.748	70	0.0142
6/13/01	1:00	76	0.0097	0	800	0.635	69	0.0137
6/13/01	2:00	75.9	0.0093	0	800	0.542	67	0.0135
6/13/01	3:00	75.8	0.0096	0	800	0.522	68	0.0140
6/13/01	4:00	75.8	0.0101	0	800	0.544	69	0.0145
6/13/01	5:00	75.9	0.0105	5	800	0.617	70	0.0150
6/13/01	6:00	76	0.0107	19	800	0.828	74	0.0165
6/13/01	7:00	76.4	0.0105	88	800	1.219	79	0.0170
6/13/01	8:00	76.8	0.0102	167	800	1.564	83	0.0169
6/13/01	9:00	77.1	0.0098	233	800	1.762	85	0.0164
6/13/01	10:00	77.2	0.0096	265	800	1.89	88	0.0157
6/13/01	11:00	77.3	0.0093	251	800	1.929	90	0.0153
6/13/01	12:00	77.4	0.0093	294	800	1.993	92	0.0148
6/13/01	13:00	77.4	0.0093	253	800	2.075	93	0.0146
6/13/01	14:00	77.5	0.0094	266	800	2.164	95	0.0150
6/13/01	15:00	77.6	0.0093	207	800	2.169	94	0.0144
6/13/01	16:00	77.5	0.0094	150	800	2.155	93	0.0146
6/13/01	17:00	77.4	0.0096	87	800	2.103	92	0.0158
6/13/01	18:00	77.2	0.0098	28	800	1.884	88	0.0158
6/13/01	19:00	76.8	0.0099	3	800	1.587	84	0.0150
6/13/01	20:00	76.6	0.01	0	800	1.343	80	0.0151
6/13/01	21:00	76.4	0.0102	0	800	1.188	78	0.0148
6/13/01	22:00	76.3	0.0105	0	800	1.088	76	0.0152
6/13/01	23:00	76.2	0.0108	0	800	1.011	74	0.0157
6/14/01	0:00	76.1	0.0107	0	800	0.927	74	0.0149
6/14/01	1:00	76.1	0.0106	0	800	0.851	73	0.0151
6/14/01	2:00	76	0.0105	0	800	0.79	73	0.0151
6/14/01	3:00	76	0.0103	0	800	0.716	72	0.0146
6/14/01	4:00	75.9	0.0098	0	800	0.617	70	0.0143
6/14/01	5:00	76	0.0093	9	800	0.64	69	0.0145
6/14/01	6:00	76.2	0.0098	46	800	1.036	74	0.0157
6/14/01	7:00	76.5	0.0103	99	800	1.394	79	0.0162
6/14/01	8:00	76.9	0.0106	157	800	1.749	84	0.0167
6/14/01	9:00	77.2	0.0103	224	800	1.895	86	0.0162
6/14/01	10:00	77.3	0.01	235	800	1.951	88	0.0158
6/14/01	11:00	77.3	0.0096	307	800	1.957	90	0.0144
6/14/01	12:00	77.4	0.0095	307	800	1.999	91	0.0142
6/14/01	13:00	77.4	0.0093	297	800	2.033	91	0.0134
6/14/01	14:00	77.5	0.0092	248	800	2.063	92	0.0132
6/14/01	15:00	77.5	0.0093	209	800	2.088	91	0.0134
6/14/01	16:00	77.4	0.0094	154	800	2.084	91	0.0143
6/14/01	17:00	77.3	0.0096	77	800	2.018	90	0.0145
6/14/01	18:00	77.1	0.0098	32	800	1.859	87	0.0152
6/14/01	19:00	76.8	0.0099	3	800	1.576	83	0.0153
6/14/01	20:00	76.6	0.0101	0	800	1.335	80	0.0151
6/14/01	21:00	76.4	0.0103	0	800	1.208	79	0.0154
6/14/01	22:00	76.3	0.0107	0	800	1.136	77	0.0158
6/14/01	23:00	76.2	0.011	0	800	1.068	76	0.0160
6/15/01	0:00	76.2	0.0107	0	800	0.971	75	0.0163
6/15/01	1:00	76.1	0.0103	0	800	0.871	74	0.0157
6/15/01	2:00	76.1	0.0094	0	800	0.736	73	0.0159
6/15/01	3:00	76	0.0098	0	800	0.768	73	0.0159
6/15/01	4:00	76	0.0103	0	800	0.759	72	0.0162
6/15/01	5:00	76	0.011	4	800	0.786	72	0.0162
6/15/01	6:00	76.1	0.0112	22	800	0.942	76	0.0160
6/15/01	7:00	76.4	0.0109	80	800	1.266	80	0.0168
6/15/01	8:00	76.8	0.0106	138	800	1.598	84	0.0167
6/15/01	9:00	77.1	0.0105	194	800	1.855	86	0.0171
6/15/01	10:00	77.3	0.0103	220	800	2.015	89	0.0164
6/15/01	11:00	77.4	0.0101	232	800	2.078	91	0.0151
6/15/01	12:00	77.5	0.0099	294	800	2.081	92	0.0148
6/15/01	13:00	77.5	0.0096	271	800	2.082	93	0.0146
6/15/01	14:00	77.5	0.0092	233	800	2.071	94	0.0135
6/15/01	15:00	77.5	0.0094	196	800	2.177	92	0.0149
6/15/01	16:00	77.5	0.0097	136	800	2.164	90	0.0153
6/15/01	17:00	77.3	0.0103	73	800	2.137	88	0.0167
6/15/01	18:00	77	0.0105	20	800	1.801	83	0.0170
6/15/01	19:00	76.7	0.0104	2	800	1.421	78	0.0164
6/15/01	20:00	76.4	0.0101	0	800	1.138	73	0.0159
6/15/01	21:00	76.2	0.0103	0	800	1.036	73	0.0159
6/15/01	22:00	76.1	0.0105	0	800	0.961	73	0.0159
6/15/01	23:00	76.1	0.0109	0	800	0.931	73	0.0159

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
6/16/01	0:00	76.1	0.0111	0	800	0.927	74	0.0165
6/16/01	1:00	76.1	0.011	0	800	0.895	74	0.0165
6/16/01	2:00	76.1	0.011	0	800	0.932	75	0.0171
6/16/01	3:00	76.1	0.0105	0	800	0.879	75	0.0171
6/16/01	4:00	76.1	0.0101	0	800	0.833	75	0.0171
6/16/01	5:00	76.1	0.0093	8	800	0.766	75	0.0179
6/16/01	6:00	76.2	0.0097	30	800	0.988	77	0.0183
6/16/01	7:00	76.4	0.0103	59	800	1.246	80	0.0185
6/16/01	8:00	76.6	0.0105	78	800	1.43	82	0.0180
6/16/01	9:00	76.7	0.0104	87	800	1.527	83	0.0178
6/16/01	10:00	76.9	0.0103	108	800	1.656	85	0.0173
6/16/01	11:00	77	0.0102	119	800	1.744	86	0.0171
6/16/01	12:00	77.1	0.0102	173	800	1.881	88	0.0166
6/16/01	13:00	77.3	0.0101	182	800	2.004	91	0.0159
6/16/01	14:00	77.3	0.0101	108	800	2.046	93	0.0155
6/16/01	15:00	77.3	0.0101	165	800	2.027	91	0.0169
6/16/01	16:00	77.2	0.0101	100	800	1.945	88	0.0176
6/16/01	17:00	77	0.0099	46	800	1.728	86	0.0180
6/16/01	18:00	76.8	0.0098	24	800	1.59	85	0.0174
6/16/01	19:00	76.6	0.0101	2	800	1.443	83	0.0169
6/16/01	20:00	76.5	0.0102	0	800	1.31	82	0.0163
6/16/01	21:00	76.4	0.0104	0	800	1.222	80	0.0168
6/16/01	22:00	76.3	0.0106	0	800	1.121	77	0.0166
6/16/01	23:00	76.2	0.0107	0	800	1.028	75	0.0162
6/17/01	0:00	76.1	0.0109	0	800	0.977	75	0.0162
6/17/01	1:00	76.1	0.011	0	800	0.945	75	0.0171
6/17/01	2:00	76.1	0.011	0	800	0.926	75	0.0171
6/17/01	3:00	76.1	0.0105	0	800	0.819	74	0.0165
6/17/01	4:00	76	0.0102	0	800	0.738	72	0.0161
6/17/01	5:00	76	0.0094	7	800	0.663	71	0.0155
6/17/01	6:00	76.1	0.0098	39	800	0.969	75	0.0162
6/17/01	7:00	76.4	0.01	81	800	1.265	80	0.0167
6/17/01	8:00	76.7	0.0104	93	800	1.533	84	0.0175
6/17/01	9:00	77	0.0101	216	800	1.726	86	0.0171
6/17/01	10:00	77.2	0.0098	246	800	1.862	87	0.0159
6/17/01	11:00	77.3	0.0095	299	800	1.919	89	0.0155
6/17/01	12:00	77.3	0.0095	293	800	2.017	90	0.0153
6/17/01	13:00	77.4	0.0098	200	800	2.12	91	0.0159
6/17/01	14:00	77.4	0.0101	165	800	2.19	92	0.0166
6/17/01	15:00	77.4	0.01	188	800	2.127	91	0.0159
6/17/01	16:00	77.4	0.0098	140	800	2.02	89	0.0155
6/17/01	17:00	77.3	0.0097	90	800	1.948	88	0.0157
6/17/01	18:00	77.1	0.0098	32	800	1.798	85	0.0164
6/17/01	19:00	76.8	0.0101	3	800	1.538	81	0.0165
6/17/01	20:00	76.5	0.0102	0	800	1.29	78	0.0163
6/17/01	21:00	76.3	0.0102	0	800	1.115	76	0.0160
6/17/01	22:00	76.2	0.0103	0	800	1.011	75	0.0154
6/17/01	23:00	76.1	0.0104	0	800	0.924	73	0.0159
6/18/01	0:00	76.1	0.0105	0	800	0.86	73	0.0159
6/18/01	1:00	76	0.0104	0	800	0.786	73	0.0159
6/18/01	2:00	76	0.0104	0	800	0.75	73	0.0159
6/18/01	3:00	76	0.0105	0	800	0.727	73	0.0159
6/18/01	4:00	75.9	0.0104	0	800	0.69	72	0.0153
6/18/01	5:00	75.9	0.0104	5	800	0.695	72	0.0153
6/18/01	6:00	76.1	0.0104	35	800	0.953	75	0.0162
6/18/01	7:00	76.5	0.0102	90	800	1.26	79	0.0169
6/18/01	8:00	76.7	0.0102	127	800	1.527	82	0.0180
6/18/01	9:00	76.9	0.0101	170	800	1.688	80	0.0176
6/18/01	10:00	77.1	0.01	263	800	1.784	79	0.0161
6/18/01	11:00	77.1	0.0099	249	800	1.809	77	0.0157
6/18/01	12:00	77.1	0.01	186	800	1.797	76	0.0160
6/18/01	13:00	77	0.01	167	800	1.767	76	0.0160
6/18/01	14:00	76.9	0.0101	94	800	1.632	75	0.0154
6/18/01	15:00	76.9	0.0101	145	800	1.644	77	0.0157
6/18/01	16:00	76.8	0.0105	86	800	1.674	78	0.0172
6/18/01	17:00	76.8	0.0106	46	800	1.584	80	0.0167
6/18/01	18:00	76.6	0.0105	17	800	1.381	78	0.0163
6/18/01	19:00	76.4	0.0104	1	800	1.174	76	0.0160
6/18/01	20:00	76.2	0.0102	0	800	1.004	74	0.0156
6/18/01	21:00	76.1	0.0101	0	800	0.918	74	0.0148
6/18/01	22:00	76.1	0.0103	0	800	0.85	73	0.0150
6/18/01	23:00	76	0.0104	0	800	0.812	73	0.0150

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
6/19/01	0:00	76	0.0104	0	800	0.793	73	0.0150
6/19/01	1:00	76	0.0106	0	800	0.805	73	0.0150
6/19/01	2:00	76	0.0107	0	800	0.807	73	0.0150
6/19/01	3:00	76	0.0107	0	800	0.806	73	0.0143
6/19/01	4:00	76	0.0108	0	800	0.794	72	0.0145
6/19/01	5:00	76	0.0109	4	800	0.805	72	0.0145
6/19/01	6:00	76.1	0.0108	13	800	0.864	74	0.0148
6/19/01	7:00	76.2	0.0104	56	800	1.049	76	0.0159
6/19/01	8:00	76.4	0.01	67	800	1.168	78	0.0163
6/19/01	9:00	76.5	0.0105	71	800	1.37	80	0.0175
6/19/01	10:00	76.8	0.0106	132	800	1.599	83	0.0177
6/19/01	11:00	77	0.011	185	800	1.89	85	0.0191
6/19/01	12:00	77.1	0.0109	178	800	1.951	86	0.0179
6/19/01	13:00	77.2	0.0109	207	800	2.003	86	0.0179
6/19/01	14:00	77.3	0.0107	196	800	2.056	87	0.0168
6/19/01	15:00	77.3	0.0105	175	800	2.011	86	0.0170
6/19/01	16:00	77.2	0.0105	130	800	1.967	84	0.0175
6/19/01	17:00	77.1	0.0104	71	800	1.827	83	0.0177
6/19/01	18:00	76.8	0.0104	24	800	1.614	81	0.0173
6/19/01	19:00	76.6	0.0104	3	800	1.345	78	0.0172
6/19/01	20:00	76.4	0.0104	0	800	1.153	76	0.0168
6/19/01	21:00	76.2	0.0109	0	800	1.103	76	0.0168
6/19/01	22:00	76.2	0.0115	0	800	1.075	75	0.0170
6/19/01	23:00	76.2	0.0121	0	800	1.065	75	0.0170
6/20/01	0:00	76.1	0.0116	0	800	0.968	74	0.0164
6/20/01	1:00	76.1	0.0111	0	800	0.885	73	0.0158
6/20/01	2:00	76	0.0104	0	800	0.777	72	0.0153
6/20/01	3:00	76	0.0103	0	800	0.759	72	0.0153
6/20/01	4:00	76	0.0106	0	800	0.79	73	0.0158
6/20/01	5:00	76	0.0106	3	800	0.802	73	0.0158
6/20/01	6:00	76.1	0.0109	22	800	0.949	75	0.0170
6/20/01	7:00	76.3	0.0107	63	800	1.143	78	0.0180
6/20/01	8:00	76.5	0.0106	75	800	1.335	80	0.0184
6/20/01	9:00	76.7	0.0103	107	800	1.457	80	0.0175
6/20/01	10:00	76.8	0.0103	104	800	1.562	80	0.0175
6/20/01	11:00	76.8	0.0101	118	800	1.602	80	0.0167
6/20/01	12:00	76.9	0.0098	137	800	1.629	81	0.0156
6/20/01	13:00	76.9	0.0096	110	800	1.614	81	0.0156
6/20/01	14:00	76.9	0.0094	146	800	1.612	82	0.0154
6/20/01	15:00	77	0.0095	125	800	1.688	82	0.0162
6/20/01	16:00	77	0.0096	128	800	1.736	81	0.0165
6/20/01	17:00	76.9	0.01	54	800	1.676	81	0.0173
6/20/01	18:00	76.7	0.0101	24	800	1.519	80	0.0176
6/20/01	19:00	76.5	0.0104	3	800	1.347	79	0.0178
6/20/01	20:00	76.4	0.0105	0	800	1.188	78	0.0180
6/20/01	21:00	76.3	0.0102	0	800	1.031	77	0.0174
6/20/01	22:00	76.2	0.01	0	800	0.933	75	0.0179
6/20/01	23:00	76.1	0.0093	0	800	0.762	74	0.0172
6/21/01	0:00	76	0.0094	0	800	0.748	74	0.0164
6/21/01	1:00	76	0.0099	0	800	0.741	73	0.0167
6/21/01	2:00	76	0.0105	0	800	0.747	73	0.0167
6/21/01	3:00	76	0.0102	0	800	0.691	73	0.0158
6/21/01	4:00	76	0.0098	0	800	0.649	73	0.0158
6/21/01	5:00	75.9	0.0093	5	800	0.624	73	0.0158
6/21/01	6:00	76.1	0.0093	34	800	0.88	76	0.0159
6/21/01	7:00	76.5	0.0094	97	800	1.257	80	0.0167
6/21/01	8:00	76.8	0.0095	147	800	1.539	83	0.0168
6/21/01	9:00	77	0.0095	207	800	1.747	83	0.0168
6/21/01	10:00	77.1	0.0094	148	800	1.79	84	0.0157
6/21/01	11:00	77	0.0095	88	800	1.753	84	0.0157
6/21/01	12:00	77.1	0.0095	141	800	1.755	86	0.0153
6/21/01	13:00	77.1	0.0094	140	800	1.755	87	0.0142
6/21/01	14:00	77.1	0.0092	164	800	1.777	89	0.0129
6/21/01	15:00	77.1	0.0093	133	800	1.828	88	0.0140
6/21/01	16:00	77.1	0.0095	122	800	1.836	86	0.0153
6/21/01	17:00	77.1	0.0097	74	800	1.809	85	0.0156
6/21/01	18:00	76.8	0.0099	21	800	1.603	83	0.0160
6/21/01	19:00	76.6	0.0099	2	800	1.368	81	0.0165
6/21/01	20:00	76.4	0.0099	0	800	1.204	79	0.0161
6/21/01	21:00	76.3	0.0098	0	800	1.085	77	0.0166
6/21/01	22:00	76.2	0.0094	0	800	0.943	75	0.0162
6/21/01	23:00	76.1	0.0091	0	800	0.805	73	0.0158

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
6/22/01	0:00	76	0.0089	0	800	0.728	73	0.0159
6/22/01	1:00	76	0.0089	0	800	0.668	72	0.0153
6/22/01	2:00	75.9	0.009	0	800	0.624	72	0.0153
6/22/01	3:00	75.9	0.009	0	800	0.584	71	0.0148
6/22/01	4:00	75.9	0.0091	0	800	0.558	71	0.0148
6/22/01	5:00	75.9	0.0091	6	800	0.553	70	0.0150
6/22/01	6:00	76	0.0092	35	800	0.795	75	0.0154
6/22/01	7:00	76.4	0.0093	88	800	1.156	79	0.0169
6/22/01	8:00	76.8	0.0093	168	800	1.534	84	0.0175
6/22/01	9:00	77	0.0092	181	800	1.731	86	0.0170
6/22/01	10:00	77.2	0.0091	249	800	1.859	87	0.0159
6/22/01	11:00	77.3	0.009	184	800	1.899	89	0.0155
6/22/01	12:00	77.3	0.0092	286	800	2.003	88	0.0157
6/22/01	13:00	77.4	0.0096	241	800	2.122	87	0.0160
6/22/01	14:00	77.3	0.01	100	800	2.073	86	0.0162
6/22/01	15:00	77.1	0.01	103	800	1.835	82	0.0163
6/22/01	16:00	76.9	0.0096	56	800	1.569	78	0.0164
6/22/01	17:00	76.6	0.009	16	800	1.269	74	0.0157
6/22/01	18:00	76.4	0.0088	13	800	1.125	74	0.0156
6/22/01	19:00	76.3	0.0087	3	800	1.011	75	0.0162
6/22/01	20:00	76.2	0.0087	0	800	0.921	75	0.0162
6/22/01	21:00	76.1	0.0091	0	800	0.871	74	0.0165
6/22/01	22:00	76.1	0.0093	0	800	0.801	74	0.0156
6/22/01	23:00	76	0.0097	0	800	0.785	73	0.0159
6/23/01	0:00	76	0.0095	0	800	0.704	72	0.0153
6/23/01	1:00	75.9	0.0095	0	800	0.659	71	0.0148
6/23/01	2:00	75.9	0.0092	0	800	0.591	70	0.0150
6/23/01	3:00	75.9	0.0099	0	800	0.622	71	0.0148
6/23/01	4:00	75.9	0.0104	0	800	0.645	71	0.0155
6/23/01	5:00	75.9	0.0112	3	800	0.728	72	0.0161
6/23/01	6:00	76	0.011	17	800	0.858	75	0.0162
6/23/01	7:00	76.3	0.011	60	800	1.14	77	0.0183
6/23/01	8:00	76.6	0.0106	118	800	1.394	80	0.0185
6/23/01	9:00	76.8	0.0103	155	800	1.614	82	0.0189
6/23/01	10:00	77	0.0102	161	800	1.77	84	0.0184
6/23/01	11:00	77.1	0.0101	175	800	1.85	86	0.0180
6/23/01	12:00	77.2	0.0099	257	800	1.937	88	0.0175
6/23/01	13:00	77.3	0.0098	275	800	2.007	89	0.0164
6/23/01	14:00	77.4	0.0097	255	800	2.058	91	0.0159
6/23/01	15:00	77.4	0.0095	194	800	2.022	90	0.0153
6/23/01	16:00	77.4	0.0095	160	800	2.015	90	0.0153
6/23/01	17:00	77.3	0.0094	94	800	1.924	89	0.0147
6/23/01	18:00	77.1	0.0094	32	800	1.747	86	0.0145
6/23/01	19:00	76.7	0.0096	4	800	1.477	82	0.0146
6/23/01	20:00	76.5	0.0098	0	800	1.259	79	0.0145
6/23/01	21:00	76.3	0.0099	0	800	1.113	78	0.0139
6/23/01	22:00	76.2	0.01	0	800	1.008	76	0.0144
6/23/01	23:00	76.1	0.0101	0	800	0.929	75	0.0138
6/24/01	0:00	76.1	0.01	0	800	0.834	74	0.0148
6/24/01	1:00	76	0.0099	0	800	0.751	73	0.0151
6/24/01	2:00	76	0.0093	0	800	0.638	72	0.0161
6/24/01	3:00	75.9	0.0095	0	800	0.631	72	0.0153
6/24/01	4:00	75.9	0.01	0	800	0.627	71	0.0155
6/24/01	5:00	75.9	0.0105	6	800	0.655	71	0.0155
6/24/01	6:00	76	0.0107	28	800	0.868	74	0.0156
6/24/01	7:00	76.4	0.0107	90	800	1.252	77	0.0165
6/24/01	8:00	76.7	0.0108	145	800	1.579	80	0.0176
6/24/01	9:00	77	0.0105	189	800	1.751	83	0.0177
6/24/01	10:00	77.2	0.0102	277	800	1.879	85	0.0173
6/24/01	11:00	77.3	0.0098	291	800	1.941	88	0.0166
6/24/01	12:00	77.4	0.0096	296	800	1.992	89	0.0155
6/24/01	13:00	77.4	0.0094	264	800	2.022	91	0.0150
6/24/01	14:00	77.4	0.0092	241	800	2.042	92	0.0139
6/24/01	15:00	77.5	0.0093	221	800	2.097	91	0.0150
6/24/01	16:00	77.4	0.0094	153	800	2.076	90	0.0153
6/24/01	17:00	77.3	0.0096	91	800	2.047	89	0.0164
6/24/01	18:00	77.1	0.0097	28	800	1.819	86	0.0162
6/24/01	19:00	76.8	0.0099	3	800	1.516	82	0.0163
6/24/01	20:00	76.5	0.01	0	800	1.276	79	0.0161
6/24/01	21:00	76.3	0.0101	0	800	1.134	78	0.0155
6/24/01	22:00	76.2	0.0101	0	800	1.022	76	0.0160
6/24/01	23:00	76.1	0.0103	0	800	0.957	75	0.0162

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
6/25/01	0:00	76.1	0.0105	0	800	0.899	74	0.0164
6/25/01	1:00	76	0.0103	0	800	0.808	74	0.0156
6/25/01	2:00	76	0.0103	0	800	0.766	73	0.0159
6/25/01	3:00	76	0.0104	0	800	0.738	73	0.0159
6/25/01	4:00	76	0.0104	0	800	0.697	72	0.0153
6/25/01	5:00	76	0.0104	6	800	0.716	72	0.0153
6/25/01	6:00	76.2	0.01	39	800	0.99	75	0.0162
6/25/01	7:00	76.4	0.0097	72	800	1.19	79	0.0161
6/25/01	8:00	76.7	0.0095	150	800	1.469	82	0.0171
6/25/01	9:00	77	0.0092	206	800	1.688	84	0.0166
6/25/01	10:00	77.2	0.0091	253	800	1.837	87	0.0168
6/25/01	11:00	77.3	0.009	274	800	1.913	89	0.0155
6/25/01	12:00	77.3	0.0091	274	800	1.975	89	0.0164
6/25/01	13:00	77.4	0.0093	262	800	2.077	89	0.0164
6/25/01	14:00	77.4	0.0095	208	800	2.104	89	0.0164
6/25/01	15:00	77.4	0.0097	144	800	2.069	88	0.0166
6/25/01	16:00	77.3	0.0098	143	800	2.053	88	0.0157
6/25/01	17:00	77.2	0.01	81	800	1.991	87	0.0160
6/25/01	18:00	77	0.01	30	800	1.762	84	0.0158
6/25/01	19:00	76.7	0.0103	2	800	1.51	81	0.0165
6/25/01	20:00	76.5	0.0103	0	800	1.268	78	0.0163
6/25/01	21:00	76.3	0.0103	0	800	1.108	76	0.0160
6/25/01	22:00	76.2	0.0103	0	800	1.006	75	0.0154
6/25/01	23:00	76.1	0.0104	0	800	0.915	73	0.0159
6/26/01	0:00	76.1	0.0105	0	800	0.848	73	0.0159
6/26/01	1:00	76	0.0104	0	800	0.777	73	0.0159
6/26/01	2:00	76	0.0104	0	800	0.744	73	0.0159
6/26/01	3:00	76	0.0102	0	800	0.696	73	0.0159
6/26/01	4:00	76	0.0098	0	800	0.655	73	0.0159
6/26/01	5:00	75.9	0.0093	4	800	0.624	73	0.0159
6/26/01	6:00	76	0.0097	24	800	0.83	76	0.0168
6/26/01	7:00	76.4	0.01	87	800	1.214	80	0.0176
6/26/01	8:00	76.7	0.0101	129	800	1.526	83	0.0178
6/26/01	9:00	77	0.01	189	800	1.751	84	0.0175
6/26/01	10:00	77.2	0.0101	177	800	1.909	86	0.0171
6/26/01	11:00	77.3	0.0101	178	800	1.991	87	0.0168
6/26/01	12:00	77.3	0.0101	261	800	2.039	87	0.0168
6/26/01	13:00	77.4	0.01	244	800	2.064	88	0.0166
6/26/01	14:00	77.4	0.0099	216	800	2.11	88	0.0166
6/26/01	15:00	77.4	0.0098	169	800	2.068	87	0.0169
6/26/01	16:00	77.3	0.0099	100	800	1.953	85	0.0165
6/26/01	17:00	77	0.0099	31	800	1.729	84	0.0167
6/26/01	18:00	76.8	0.0099	23	800	1.516	82	0.0163
6/26/01	19:00	76.5	0.0101	4	800	1.33	79	0.0161
6/26/01	20:00	76.4	0.0101	0	800	1.157	77	0.0158
6/26/01	21:00	76.3	0.0103	0	800	1.062	76	0.0160
6/26/01	22:00	76.2	0.0105	0	800	1.005	76	0.0160
6/26/01	23:00	76.1	0.0106	0	800	0.963	75	0.0162
6/27/01	0:00	76.1	0.0103	0	800	0.88	75	0.0162
6/27/01	1:00	76.1	0.01	0	800	0.82	74	0.0165
6/27/01	2:00	76	0.0093	0	800	0.725	74	0.0165
6/27/01	3:00	76	0.0091	0	800	0.709	74	0.0157
6/27/01	4:00	76	0.009	0	800	0.686	73	0.0159
6/27/01	5:00	76	0.0089	4	800	0.684	73	0.0159
6/27/01	6:00	76.1	0.0098	24	800	0.93	77	0.0166
6/27/01	7:00	76.3	0.0103	59	800	1.171	80	0.0176
6/27/01	8:00	76.6	0.0107	92	800	1.479	84	0.0185
6/27/01	9:00	76.9	0.0107	178	800	1.764	85	0.0182
6/27/01	10:00	77.2	0.0105	205	800	1.903	87	0.0169
6/27/01	11:00	77.3	0.0105	276	800	2.036	88	0.0166
6/27/01	12:00	77.3	0.0102	252	800	1.957	85	0.0164
6/27/01	13:00	77.2	0.0099	147	800	1.874	83	0.0169
6/27/01	14:00	77.1	0.0096	133	800	1.744	80	0.0168
6/27/01	15:00	77	0.0096	133	800	1.767	81	0.0165
6/27/01	16:00	77	0.0097	112	800	1.75	82	0.0155
6/27/01	17:00	77	0.0097	70	800	1.707	83	0.0144
6/27/01	18:00	76.8	0.01	19	800	1.538	82	0.0154
6/27/01	19:00	76.6	0.0101	1	800	1.35	81	0.0165
6/27/01	20:00	76.4	0.0102	0	800	1.216	80	0.0168
6/27/01	21:00	76.3	0.0104	0	800	1.133	78	0.0172
6/27/01	22:00	76.2	0.0103	0	800	1.03	77	0.0166
6/27/01	23:00	76.2	0.0104	0	800	0.958	75	0.0162

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
6/28/01	0:00	76.1	0.0107	0	800	0.937	75	0.0163
6/28/01	1:00	76.1	0.011	0	800	0.92	75	0.0171
6/28/01	2:00	76.1	0.0113	0	800	0.922	75	0.0171
6/28/01	3:00	76.1	0.0113	0	800	0.918	76	0.0169
6/28/01	4:00	76.1	0.0113	0	800	0.913	76	0.0177
6/28/01	5:00	76.1	0.0111	5	800	0.938	77	0.0175
6/28/01	6:00	76.2	0.0109	26	800	1.048	79	0.0179
6/28/01	7:00	76.5	0.0107	73	800	1.284	80	0.0194
6/28/01	8:00	76.6	0.0104	51	800	1.364	82	0.0189
6/28/01	9:00	76.7	0.0105	101	800	1.547	83	0.0196
6/28/01	10:00	76.9	0.0104	129	800	1.716	85	0.0192
6/28/01	11:00	77.1	0.0104	156	800	1.861	86	0.0189
6/28/01	12:00	77.2	0.0103	176	800	1.929	86	0.0180
6/28/01	13:00	77.3	0.0105	195	800	2.034	86	0.0180
6/28/01	14:00	77.3	0.0106	218	800	2.091	86	0.0180
6/28/01	15:00	77.2	0.0105	104	800	1.983	85	0.0173
6/28/01	16:00	77.1	0.0103	80	800	1.838	85	0.0173
6/28/01	17:00	76.9	0.0103	47	800	1.709	84	0.0176
6/28/01	18:00	76.7	0.0104	17	800	1.541	82	0.0180
6/28/01	19:00	76.6	0.0106	2	800	1.376	81	0.0174
6/28/01	20:00	76.4	0.0107	0	800	1.231	79	0.0179
6/28/01	21:00	76.3	0.0109	0	800	1.157	79	0.0178
6/28/01	22:00	76.3	0.011	0	800	1.115	79	0.0178
6/28/01	23:00	76.2	0.011	0	800	1.091	79	0.0178
6/29/01	0:00	76.2	0.0107	0	800	1.018	78	0.0181
6/29/01	1:00	76.2	0.0101	0	800	0.929	77	0.0174
6/29/01	2:00	76.1	0.0093	0	800	0.82	76	0.0177
6/29/01	3:00	76.1	0.0094	0	800	0.844	76	0.0168
6/29/01	4:00	76	0.0099	0	800	0.85	75	0.0179
6/29/01	5:00	76	0.0104	5	800	0.866	75	0.0179
6/29/01	6:00	76.2	0.0107	30	800	1.049	79	0.0178
6/29/01	7:00	76.4	0.0108	70	800	1.3	82	0.0189
6/29/01	8:00	76.8	0.0107	121	800	1.62	86	0.0189
6/29/01	9:00	77	0.0105	162	800	1.812	87	0.0177
6/29/01	10:00	77.2	0.0102	204	800	1.914	87	0.0168
6/29/01	11:00	77.3	0.0101	217	800	2.023	88	0.0166
6/29/01	12:00	77.4	0.0101	236	800	2.083	89	0.0164
6/29/01	13:00	77.4	0.0103	167	800	2.141	89	0.0173
6/29/01	14:00	77.5	0.0105	192	800	2.23	90	0.0180
6/29/01	15:00	77.4	0.0106	123	800	2.174	89	0.0182
6/29/01	16:00	77.3	0.0105	114	800	2.089	88	0.0175
6/29/01	17:00	77.2	0.0106	63	800	1.947	87	0.0177
6/29/01	18:00	76.9	0.0106	25	800	1.743	85	0.0182
6/29/01	19:00	76.7	0.0107	2	800	1.514	82	0.0180
6/29/01	20:00	76.5	0.0107	0	800	1.314	80	0.0185
6/29/01	21:00	76.4	0.0109	0	800	1.221	79	0.0187
6/29/01	22:00	76.3	0.0111	0	800	1.164	79	0.0187
6/29/01	23:00	76.3	0.0111	0	800	1.104	78	0.0180
6/30/01	0:00	76.2	0.0112	0	800	1.075	78	0.0181
6/30/01	1:00	76.2	0.0113	0	800	1.044	77	0.0183
6/30/01	2:00	76.2	0.0112	0	800	1	77	0.0174
6/30/01	3:00	76.1	0.0111	0	800	0.949	76	0.0176
6/30/01	4:00	76.1	0.0108	0	800	0.846	74	0.0164
6/30/01	5:00	76.1	0.0105	5	800	0.827	73	0.0167
6/30/01	6:00	76.3	0.0105	40	800	1.134	78	0.0172
6/30/01	7:00	76.7	0.0103	98	800	1.46	82	0.0171
6/30/01	8:00	77	0.0104	149	800	1.777	87	0.0177
6/30/01	9:00	77.2	0.0101	230	800	1.933	88	0.0165
6/30/01	10:00	77.4	0.0098	261	800	2.038	90	0.0152
6/30/01	11:00	77.4	0.0097	285	800	2.075	91	0.0150
6/30/01	12:00	77.4	0.0096	288	800	2.056	92	0.0148
6/30/01	13:00	77.5	0.0096	275	800	2.106	92	0.0148
6/30/01	14:00	77.5	0.0095	264	800	2.142	93	0.0154
6/30/01	15:00	77.5	0.0095	206	800	2.166	92	0.0148
6/30/01	16:00	77.5	0.0095	157	800	2.094	90	0.0144
6/30/01	17:00	77.4	0.0095	98	800	2.02	89	0.0138
6/30/01	18:00	77.1	0.0097	34	800	1.832	84	0.0158
6/30/01	19:00	76.8	0.01	4	800	1.553	81	0.0165
6/30/01	20:00	76.5	0.0103	0	800	1.322	78	0.0172
6/30/01	21:00	76.4	0.0103	0	800	1.148	77	0.0166
6/30/01	22:00	76.2	0.0106	0	800	1.074	76	0.0176
6/30/01	23:00	76.2	0.0108	0	800	1.02	76	0.0176

B.2.3 Fall Season: (September)

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
9/1/01	0:00	76.2	0.0109	0	800	1.049	76	0.0168
9/1/01	1:00	76.2	0.0107	0	800	1.016	76	0.0168
9/1/01	2:00	76.2	0.0106	0	800	0.985	75	0.0162
9/1/01	3:00	76.1	0.0107	0	800	0.961	74	0.0164
9/1/01	4:00	76.1	0.0104	0	800	0.913	74	0.0156
9/1/01	5:00	76.1	0.0104	0	800	0.904	74	0.0156
9/1/01	6:00	76.2	0.0103	11	800	0.971	76	0.0160
9/1/01	7:00	76.5	0.0099	73	800	1.226	78	0.0163
9/1/01	8:00	76.8	0.0096	152	800	1.521	81	0.0165
9/1/01	9:00	77.1	0.0094	195	800	1.739	83	0.0160
9/1/01	10:00	77.3	0.0093	234	800	1.915	84	0.0158
9/1/01	11:00	77.3	0.0092	216	800	1.955	86	0.0153
9/1/01	12:00	77.3	0.0093	229	800	1.993	87	0.0151
9/1/01	13:00	77.4	0.0093	174	800	2.006	88	0.0149
9/1/01	14:00	77.4	0.0092	194	800	2.017	89	0.0138
9/1/01	15:00	77.4	0.0092	177	800	1.99	87	0.0134
9/1/01	16:00	77.1	0.0092	55	800	1.8	84	0.0141
9/1/01	17:00	76.9	0.0094	18	800	1.57	82	0.0138
9/1/01	18:00	76.6	0.0095	4	800	1.365	80	0.0143
9/1/01	19:00	76.5	0.0095	0	800	1.217	79	0.0145
9/1/01	20:00	76.3	0.0095	0	800	1.107	77	0.0149
9/1/01	21:00	76.3	0.0096	0	800	1.051	77	0.0149
9/1/01	22:00	76.2	0.0096	0	800	1.016	77	0.0149
9/1/01	23:00	76.2	0.0097	0	800	0.993	77	0.0149
9/2/01	0:00	76.2	0.0097	0	800	0.978	77	0.0149
9/2/01	1:00	76.2	0.01	0	800	0.981	76	0.0152
9/2/01	2:00	76.2	0.0102	0	800	0.978	76	0.0160
9/2/01	3:00	76.2	0.0105	0	800	0.989	76	0.0160
9/2/01	4:00	76.1	0.0108	0	800	0.99	75	0.0171
9/2/01	5:00	76.1	0.011	0	800	0.997	75	0.0170
9/2/01	6:00	76.2	0.0109	8	800	0.987	75	0.0162
9/2/01	7:00	76.2	0.0108	37	800	1.049	74	0.0156
9/2/01	8:00	76.3	0.0107	33	800	1.081	74	0.0156
9/2/01	9:00	76.4	0.0104	85	800	1.233	77	0.0149
9/2/01	10:00	76.6	0.0102	103	800	1.396	79	0.0153
9/2/01	11:00	76.8	0.01	138	800	1.573	82	0.0146
9/2/01	12:00	77	0.01	145	800	1.703	82	0.0154
9/2/01	13:00	77	0.0101	130	800	1.764	81	0.0165
9/2/01	14:00	76.9	0.0102	77	800	1.701	81	0.0165
9/2/01	15:00	76.9	0.0104	89	800	1.692	81	0.0174
9/2/01	16:00	76.8	0.0105	53	800	1.594	80	0.0176
9/2/01	17:00	76.7	0.0106	23	800	1.486	80	0.0176
9/2/01	18:00	76.5	0.0106	7	800	1.326	79	0.0170
9/2/01	19:00	76.4	0.0106	0	800	1.203	78	0.0172
9/2/01	20:00	76.3	0.0105	0	800	1.096	77	0.0166
9/2/01	21:00	76.2	0.0107	0	800	1.07	77	0.0175
9/2/01	22:00	76.2	0.011	0	800	1.074	77	0.0175
9/2/01	23:00	76.2	0.011	0	800	1.062	77	0.0175
9/3/01	0:00	76.2	0.0109	0	800	1.023	76	0.0177
9/3/01	1:00	76.2	0.0107	0	800	0.988	76	0.0177
9/3/01	2:00	76.2	0.0103	0	800	0.939	75	0.0171
9/3/01	3:00	76.1	0.0103	0	800	0.919	75	0.0171
9/3/01	4:00	76.1	0.0103	0	800	0.889	75	0.0171
9/3/01	5:00	76.1	0.0105	0	800	0.874	75	0.0179
9/3/01	6:00	76.1	0.011	10	800	0.964	76	0.0177
9/3/01	7:00	76.3	0.0109	43	800	1.113	77	0.0175
9/3/01	8:00	76.5	0.0108	99	800	1.362	78	0.0172
9/3/01	9:00	76.8	0.0109	128	800	1.635	81	0.0183
9/3/01	10:00	77.1	0.0109	190	800	1.91	85	0.0192
9/3/01	11:00	77.3	0.0112	232	800	2.187	88	0.0204
9/3/01	12:00	77.4	0.011	217	800	2.227	85	0.0192
9/3/01	13:00	77.3	0.0108	162	800	2.111	83	0.0187
9/3/01	14:00	77.2	0.0107	142	800	1.969	80	0.0177
9/3/01	15:00	77.2	0.0105	145	800	1.912	82	0.0172
9/3/01	16:00	77.1	0.0106	86	800	1.89	84	0.0176
9/3/01	17:00	77	0.0106	48	800	1.82	86	0.0180
9/3/01	18:00	76.8	0.0108	8	800	1.636	84	0.0185
9/3/01	19:00	76.6	0.0111	0	800	1.462	81	0.0183
9/3/01	20:00	76.5	0.0113	0	800	1.322	79	0.0187
9/3/01	21:00	76.4	0.0115	0	800	1.256	79	0.0187
9/3/01	22:00	76.3	0.0116	0	800	1.213	79	0.0187
9/3/01	23:00	76.3	0.0117	0	800	1.183	79	0.0187

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
9/4/01	0:00	76.3	0.0117	0	800	1.164	79	0.0187
9/4/01	1:00	76.2	0.0117	0	800	1.119	78	0.0190
9/4/01	2:00	76.2	0.0117	0	800	1.105	78	0.0190
9/4/01	3:00	76.2	0.0115	0	800	1.069	78	0.0190
9/4/01	4:00	76.2	0.0115	0	800	1.063	78	0.0190
9/4/01	5:00	76.2	0.0113	0	800	1.03	78	0.0190
9/4/01	6:00	76.2	0.0114	9	800	1.11	80	0.0194
9/4/01	7:00	76.4	0.0114	36	800	1.284	82	0.0199
9/4/01	8:00	76.6	0.0115	75	800	1.534	84	0.0213
9/4/01	9:00	76.8	0.0116	87	800	1.751	85	0.0211
9/4/01	10:00	76.9	0.0118	61	800	1.859	86	0.0218
9/4/01	11:00	77.1	0.0119	120	800	2.057	87	0.0216
9/4/01	12:00	77.1	0.0115	109	800	2.004	85	0.0211
9/4/01	13:00	77.1	0.011	120	800	1.923	83	0.0196
9/4/01	14:00	76.9	0.0108	55	800	1.721	81	0.0192
9/4/01	15:00	76.9	0.0106	97	800	1.713	83	0.0197
9/4/01	16:00	76.9	0.0107	57	800	1.71	84	0.0204
9/4/01	17:00	76.8	0.0105	32	800	1.618	86	0.0199
9/4/01	18:00	76.7	0.0111	5	800	1.581	84	0.0203
9/4/01	19:00	76.6	0.0117	0	800	1.55	83	0.0196
9/4/01	20:00	76.5	0.0124	0	800	1.521	81	0.0201
9/4/01	21:00	76.4	0.0119	0	800	1.314	79	0.0187
9/4/01	22:00	76.3	0.0116	0	800	1.18	77	0.0183
9/4/01	23:00	76.2	0.0109	0	800	1.019	75	0.0170
9/5/01	0:00	76.2	0.0112	0	800	1.021	75	0.0179
9/5/01	1:00	76.2	0.0115	0	800	1.03	76	0.0176
9/5/01	2:00	76.2	0.0117	0	800	1.052	76	0.0177
9/5/01	3:00	76.2	0.0116	0	800	1.02	75	0.0170
9/5/01	4:00	76.1	0.0115	0	800	0.962	73	0.0158
9/5/01	5:00	76.1	0.0115	0	800	0.906	72	0.0153
9/5/01	6:00	76.1	0.0115	12	800	0.949	73	0.0158
9/5/01	7:00	76.2	0.0114	25	800	1.012	74	0.0164
9/5/01	8:00	76.2	0.0113	36	800	1.102	75	0.0170
9/5/01	9:00	76.4	0.0112	74	800	1.234	75	0.0170
9/5/01	10:00	76.5	0.011	89	800	1.334	75	0.0170
9/5/01	11:00	76.5	0.0112	76	800	1.413	75	0.0178
9/5/01	12:00	76.7	0.0112	119	800	1.521	76	0.0176
9/5/01	13:00	76.7	0.011	109	800	1.576	77	0.0174
9/5/01	14:00	76.8	0.011	110	800	1.632	78	0.0171
9/5/01	15:00	76.8	0.0108	89	800	1.569	77	0.0165
9/5/01	16:00	76.7	0.0108	62	800	1.512	77	0.0165
9/5/01	17:00	76.6	0.0108	29	800	1.362	76	0.0159
9/5/01	18:00	76.4	0.0108	7	800	1.23	76	0.0159
9/5/01	19:00	76.3	0.0111	0	800	1.138	75	0.0162
9/5/01	20:00	76.2	0.0111	0	800	1.06	75	0.0161
9/5/01	21:00	76.2	0.0112	0	800	1.019	75	0.0161
9/5/01	22:00	76.1	0.0113	0	800	0.967	74	0.0164
9/5/01	23:00	76.1	0.0114	0	800	0.938	74	0.0164
9/6/01	0:00	76.1	0.0114	0	800	0.918	74	0.0164
9/6/01	1:00	76	0.0113	0	800	0.875	73	0.0166
9/6/01	2:00	76	0.0113	0	800	0.872	73	0.0166
9/6/01	3:00	76	0.0113	0	800	0.867	73	0.0158
9/6/01	4:00	76	0.0113	0	800	0.866	73	0.0158
9/6/01	5:00	76	0.0113	0	800	0.85	73	0.0150
9/6/01	6:00	76.1	0.0113	10	800	0.948	75	0.0153
9/6/01	7:00	76.2	0.0111	44	800	1.079	76	0.0151
9/6/01	8:00	76.6	0.0107	119	800	1.378	78	0.0154
9/6/01	9:00	76.8	0.0104	145	800	1.573	80	0.0158
9/6/01	10:00	77.1	0.0102	223	800	1.79	82	0.0161
9/6/01	11:00	77.2	0.0101	224	800	1.9	84	0.0165
9/6/01	12:00	77.3	0.0099	247	800	1.955	84	0.0165
9/6/01	13:00	77.3	0.0096	220	800	1.959	85	0.0155
9/6/01	14:00	77.3	0.0095	154	800	1.925	85	0.0155
9/6/01	15:00	77.2	0.0094	130	800	1.856	84	0.0157
9/6/01	16:00	77.1	0.0094	92	800	1.785	84	0.0157
9/6/01	17:00	76.9	0.0094	47	800	1.643	83	0.0160
9/6/01	18:00	76.7	0.0096	8	800	1.475	82	0.0162
9/6/01	19:00	76.5	0.0099	0	800	1.301	80	0.0166
9/6/01	20:00	76.4	0.0104	0	800	1.215	79	0.0169
9/6/01	21:00	76.3	0.0105	0	800	1.124	78	0.0163
9/6/01	22:00	76.2	0.0104	0	800	1.035	77	0.0157
9/6/01	23:00	76.2	0.0105	0	800	0.997	76	0.0159

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
9/7/01	0:00	76.1	0.0105	0	800	0.946	75	0.0153
9/7/01	1:00	76.1	0.0106	0	800	0.907	74	0.0156
9/7/01	2:00	76	0.0106	0	800	0.837	73	0.0150
9/7/01	3:00	76	0.0107	0	800	0.805	73	0.0150
9/7/01	4:00	76	0.0106	0	800	0.761	72	0.0145
9/7/01	5:00	76	0.0107	0	800	0.749	72	0.0145
9/7/01	6:00	76	0.0105	11	800	0.839	74	0.0140
9/7/01	7:00	76.2	0.0103	44	800	0.993	76	0.0143
9/7/01	8:00	76.3	0.0103	50	800	1.135	78	0.0146
9/7/01	9:00	76.6	0.0101	126	800	1.397	81	0.0155
9/7/01	10:00	76.9	0.0098	202	800	1.633	84	0.0157
9/7/01	11:00	77.2	0.0096	256	800	1.85	87	0.0167
9/7/01	12:00	77.3	0.0096	282	800	1.974	87	0.0168
9/7/01	13:00	77.4	0.0095	250	800	2.058	87	0.0168
9/7/01	14:00	77.4	0.0095	214	800	2.088	87	0.0168
9/7/01	15:00	77.4	0.0095	152	800	2.052	86	0.0161
9/7/01	16:00	77.2	0.0097	107	800	1.951	84	0.0166
9/7/01	17:00	77.1	0.0099	50	800	1.832	83	0.0169
9/7/01	18:00	76.8	0.0102	8	800	1.579	81	0.0173
9/7/01	19:00	76.6	0.0103	0	800	1.364	80	0.0175
9/7/01	20:00	76.4	0.0105	0	800	1.211	78	0.0180
9/7/01	21:00	76.3	0.0107	0	800	1.13	77	0.0182
9/7/01	22:00	76.2	0.0105	0	800	1.043	77	0.0174
9/7/01	23:00	76.2	0.0105	0	800	1.014	76	0.0176
9/8/01	0:00	76.2	0.0106	0	800	0.997	76	0.0176
9/8/01	1:00	76.2	0.0103	0	800	0.963	76	0.0176
9/8/01	2:00	76.2	0.0103	0	800	0.96	76	0.0176
9/8/01	3:00	76.1	0.0104	0	800	0.967	76	0.0185
9/8/01	4:00	76.2	0.0104	0	800	0.971	77	0.0183
9/8/01	5:00	76.2	0.0105	0	800	0.983	77	0.0192
9/8/01	6:00	76.2	0.0103	8	800	1.019	79	0.0187
9/8/01	7:00	76.3	0.0105	41	800	1.171	80	0.0194
9/8/01	8:00	76.5	0.0103	72	800	1.34	82	0.0198
9/8/01	9:00	76.7	0.01	97	800	1.497	83	0.0196
9/8/01	10:00	76.8	0.0097	91	800	1.554	85	0.0191
9/8/01	11:00	77	0.0095	123	800	1.672	86	0.0189
9/8/01	12:00	77.1	0.0098	111	800	1.847	87	0.0187
9/8/01	13:00	77.2	0.0101	161	800	1.967	87	0.0187
9/8/01	14:00	77.2	0.0105	95	800	2.038	88	0.0184
9/8/01	15:00	77.1	0.0102	93	800	1.84	85	0.0182
9/8/01	16:00	77	0.0097	82	800	1.654	82	0.0171
9/8/01	17:00	76.8	0.009	24	800	1.364	79	0.0169
9/8/01	18:00	76.5	0.009	4	800	1.223	78	0.0172
9/8/01	19:00	76.3	0.0093	0	800	1.114	77	0.0174
9/8/01	20:00	76.2	0.0099	0	800	1.042	76	0.0176
9/8/01	21:00	76.2	0.0098	0	800	0.932	75	0.0170
9/8/01	22:00	76.1	0.0096	0	800	0.823	75	0.0170
9/8/01	23:00	76	0.0091	0	800	0.715	74	0.0173
9/9/01	0:00	76	0.0095	0	800	0.72	74	0.0173
9/9/01	1:00	76	0.0096	0	800	0.697	74	0.0173
9/9/01	2:00	76	0.0101	0	800	0.728	74	0.0173
9/9/01	3:00	76	0.0102	0	800	0.706	73	0.0167
9/9/01	4:00	75.9	0.0105	0	800	0.706	72	0.0161
9/9/01	5:00	75.9	0.0105	0	800	0.67	71	0.0155
9/9/01	6:00	76	0.0108	12	800	0.855	74	0.0173
9/9/01	7:00	76.3	0.011	51	800	1.134	77	0.0183
9/9/01	8:00	76.5	0.0111	65	800	1.34	80	0.0193
9/9/01	9:00	76.7	0.0106	121	800	1.479	78	0.0180
9/9/01	10:00	76.7	0.0102	88	800	1.45	77	0.0165
9/9/01	11:00	76.6	0.01	66	800	1.374	75	0.0154
9/9/01	12:00	76.8	0.0099	178	800	1.536	79	0.0153
9/9/01	13:00	77	0.0098	222	800	1.752	84	0.0158
9/9/01	14:00	77.2	0.0097	193	800	1.933	88	0.0157
9/9/01	15:00	77.2	0.0096	133	800	1.923	87	0.0160
9/9/01	16:00	77.1	0.0096	72	800	1.802	86	0.0162
9/9/01	17:00	76.9	0.0097	23	800	1.624	85	0.0173
9/9/01	18:00	76.7	0.0098	5	800	1.416	82	0.0163
9/9/01	19:00	76.5	0.0101	0	800	1.273	80	0.0159
9/9/01	20:00	76.3	0.0103	0	800	1.138	77	0.0157
9/9/01	21:00	76.2	0.0106	0	800	1.061	76	0.0160
9/9/01	22:00	76.2	0.0107	0	800	1.019	76	0.0160
9/9/01	23:00	76.2	0.0108	0	800	0.995	75	0.0162

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
9/10/01	0:00	76.1	0.0108	0	800	0.953	74	0.0156
9/10/01	1:00	76.1	0.0106	0	800	0.875	73	0.0143
9/10/01	2:00	76	0.0105	0	800	0.808	72	0.0138
9/10/01	3:00	76	0.0106	0	800	0.746	71	0.0133
9/10/01	4:00	75.9	0.0109	0	800	0.663	69	0.0130
9/10/01	5:00	75.9	0.011	0	800	0.573	68	0.0125
9/10/01	6:00	75.9	0.0106	13	800	0.664	71	0.0125
9/10/01	7:00	76.1	0.0102	52	800	0.934	73	0.0128
9/10/01	8:00	76.4	0.0096	93	800	1.134	76	0.0121
9/10/01	9:00	76.7	0.0094	180	800	1.452	78	0.0123
9/10/01	10:00	77	0.0094	213	800	1.674	80	0.0126
9/10/01	11:00	77.1	0.0094	251	800	1.812	82	0.0122
9/10/01	12:00	77.2	0.0094	208	800	1.823	83	0.0119
9/10/01	13:00	77.2	0.0095	239	800	1.91	84	0.0125
9/10/01	14:00	77.3	0.0095	203	800	1.94	85	0.0123
9/10/01	15:00	77.2	0.0094	152	800	1.881	84	0.0125
9/10/01	16:00	77	0.0093	75	800	1.686	82	0.0122
9/10/01	17:00	76.8	0.0093	26	800	1.468	81	0.0124
9/10/01	18:00	76.5	0.0095	3	800	1.283	79	0.0129
9/10/01	19:00	76.3	0.0095	0	800	1.093	77	0.0118
9/10/01	20:00	76.2	0.0095	0	800	0.977	75	0.0116
9/10/01	21:00	76.1	0.0096	0	800	0.9	74	0.0118
9/10/01	22:00	76.1	0.0097	0	800	0.826	73	0.0121
9/10/01	23:00	76	0.0099	0	800	0.773	72	0.0123
9/11/01	0:00	76	0.0101	0	800	0.731	71	0.0125
9/11/01	1:00	75.9	0.0102	0	800	0.678	71	0.0118
9/11/01	2:00	75.9	0.0104	0	800	0.639	70	0.0120
9/11/01	3:00	75.9	0.0106	0	800	0.602	69	0.0123
9/11/01	4:00	75.8	0.0105	0	800	0.543	68	0.0118
9/11/01	5:00	75.8	0.0105	0	800	0.509	67	0.0120
9/11/01	6:00	76	0.0102	17	800	0.7	70	0.0120
9/11/01	7:00	76.2	0.0098	75	800	1.02	72	0.0115
9/11/01	8:00	76.6	0.0095	142	800	1.304	75	0.0115
9/11/01	9:00	76.8	0.0093	202	800	1.528	77	0.0118
9/11/01	10:00	77	0.0091	260	800	1.687	79	0.0114
9/11/01	11:00	77.1	0.009	288	800	1.778	81	0.0116
9/11/01	12:00	77.2	0.0089	295	800	1.809	82	0.0107
9/11/01	13:00	77.2	0.0088	282	800	1.842	82	0.0100
9/11/01	14:00	77.3	0.0086	244	800	1.856	83	0.0090
9/11/01	15:00	77.2	0.0086	179	800	1.829	82	0.0093
9/11/01	16:00	77.1	0.0086	106	800	1.729	82	0.0093
9/11/01	17:00	76.9	0.0086	39	800	1.547	81	0.0095
9/11/01	18:00	76.6	0.0088	7	800	1.316	79	0.0099
9/11/01	19:00	76.4	0.0089	0	800	1.103	76	0.0099
9/11/01	20:00	76.2	0.0091	0	800	0.973	74	0.0104
9/11/01	21:00	76.1	0.0094	0	800	0.86	72	0.0109
9/11/01	22:00	76	0.0095	0	800	0.765	71	0.0111
9/11/01	23:00	76	0.0095	0	800	0.671	69	0.0109
9/12/01	0:00	75.9	0.0096	0	800	0.607	68	0.0111
9/12/01	1:00	75.8	0.0099	0	800	0.552	67	0.0114
9/12/01	2:00	75.8	0.0099	0	800	0.489	66	0.0109
9/12/01	3:00	75.8	0.0101	0	800	0.448	66	0.0109
9/12/01	4:00	75.7	0.0103	0	800	0.413	66	0.0109
9/12/01	5:00	75.7	0.0104	0	800	0.383	66	0.0109
9/12/01	6:00	75.8	0.0103	11	800	0.477	69	0.0109
9/12/01	7:00	76.1	0.01	57	800	0.852	73	0.0113
9/12/01	8:00	76.4	0.0097	120	800	1.186	76	0.0113
9/12/01	9:00	76.7	0.0093	190	800	1.434	78	0.0109
9/12/01	10:00	77	0.0092	240	800	1.631	79	0.0114
9/12/01	11:00	77.1	0.009	269	800	1.744	81	0.0116
9/12/01	12:00	77.2	0.0089	242	800	1.823	82	0.0114
9/12/01	13:00	77.3	0.0089	257	800	1.879	83	0.0112
9/12/01	14:00	77.3	0.0089	215	800	1.91	84	0.0110
9/12/01	15:00	77.2	0.0089	165	800	1.871	82	0.0114
9/12/01	16:00	77.1	0.0091	102	800	1.77	80	0.0127
9/12/01	17:00	76.8	0.0093	29	800	1.548	78	0.0131
9/12/01	18:00	76.5	0.0094	3	800	1.274	76	0.0128
9/12/01	19:00	76.3	0.0097	0	800	1.103	74	0.0133
9/12/01	20:00	76.2	0.0098	0	800	0.967	72	0.0130
9/12/01	21:00	76.1	0.0099	0	800	0.892	72	0.0130
9/12/01	22:00	76.1	0.0099	0	800	0.816	71	0.0132
9/12/01	23:00	76	0.01	0	800	0.773	71	0.0132

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
9/13/01	0:00	76	0.01	0	800	0.714	70	0.0127
9/13/01	1:00	76	0.01	0	800	0.68	70	0.0127
9/13/01	2:00	75.9	0.0102	0	800	0.645	69	0.0130
9/13/01	3:00	75.9	0.0103	0	800	0.589	68	0.0125
9/13/01	4:00	75.8	0.0105	0	800	0.518	66	0.0123
9/13/01	5:00	75.8	0.0106	0	800	0.44	65	0.0118
9/13/01	6:00	75.8	0.0108	12	800	0.534	69	0.0123
9/13/01	7:00	76.1	0.0104	55	800	0.876	72	0.0123
9/13/01	8:00	76.5	0.0099	130	800	1.231	76	0.0121
9/13/01	9:00	76.8	0.0095	180	800	1.46	78	0.0116
9/13/01	10:00	77	0.0092	239	800	1.638	79	0.0114
9/13/01	11:00	77.1	0.009	205	800	1.704	81	0.0109
9/13/01	12:00	77.1	0.0089	182	800	1.726	82	0.0107
9/13/01	13:00	77.1	0.009	166	800	1.745	82	0.0114
9/13/01	14:00	77.1	0.009	163	800	1.756	83	0.0112
9/13/01	15:00	77	0.0089	94	800	1.643	81	0.0109
9/13/01	16:00	76.8	0.009	56	800	1.513	80	0.0112
9/13/01	17:00	76.6	0.0091	23	800	1.335	78	0.0116
9/13/01	18:00	76.4	0.0092	3	800	1.171	77	0.0119
9/13/01	19:00	76.3	0.0094	0	800	1.055	75	0.0131
9/13/01	20:00	76.2	0.0095	0	800	0.964	74	0.0133
9/13/01	21:00	76.1	0.0095	0	800	0.912	74	0.0133
9/13/01	22:00	76.1	0.0095	0	800	0.845	73	0.0135
9/13/01	23:00	76.1	0.0095	0	800	0.813	73	0.0135
9/14/01	0:00	76	0.0098	0	800	0.812	72	0.0145
9/14/01	1:00	76	0.0102	0	800	0.805	72	0.0145
9/14/01	2:00	76	0.0106	0	800	0.794	71	0.0148
9/14/01	3:00	76	0.0105	0	800	0.758	71	0.0148
9/14/01	4:00	76	0.0103	0	800	0.731	71	0.0140
9/14/01	5:00	76	0.0101	0	800	0.709	71	0.0140
9/14/01	6:00	76	0.0107	8	800	0.792	72	0.0145
9/14/01	7:00	76.1	0.0109	35	800	0.954	74	0.0148
9/14/01	8:00	76.2	0.0112	44	800	1.095	75	0.0154
9/14/01	9:00	76.4	0.0113	84	800	1.268	76	0.0160
9/14/01	10:00	76.6	0.0112	101	800	1.438	78	0.0163
9/14/01	11:00	76.6	0.0114	71	800	1.526	79	0.0170
9/14/01	12:00	76.8	0.0112	119	800	1.615	80	0.0167
9/14/01	13:00	76.9	0.0111	123	800	1.692	80	0.0168
9/14/01	14:00	76.9	0.011	107	800	1.718	81	0.0165
9/14/01	15:00	76.9	0.0111	87	800	1.696	80	0.0177
9/14/01	16:00	76.7	0.0112	56	800	1.598	78	0.0181
9/14/01	17:00	76.6	0.0114	24	800	1.462	77	0.0193
9/14/01	18:00	76.5	0.0113	4	800	1.299	77	0.0184
9/14/01	19:00	76.3	0.0114	0	800	1.179	76	0.0186
9/14/01	20:00	76.2	0.0111	0	800	1.077	76	0.0177
9/14/01	21:00	76.2	0.0114	0	800	1.058	76	0.0186
9/14/01	22:00	76.2	0.0114	0	800	1.042	77	0.0184
9/14/01	23:00	76.2	0.0114	0	800	1.03	77	0.0184
9/15/01	0:00	76.2	0.0119	0	800	1.068	77	0.0193
9/15/01	1:00	76.2	0.0123	0	800	1.124	78	0.0191
9/15/01	2:00	76.2	0.0125	0	800	1.157	78	0.0191
9/15/01	3:00	76.2	0.0125	0	800	1.168	78	0.0200
9/15/01	4:00	76.2	0.0123	0	800	1.154	78	0.0200
9/15/01	5:00	76.2	0.0118	0	800	1.108	78	0.0191
9/15/01	6:00	76.3	0.0123	11	800	1.203	78	0.0200
9/15/01	7:00	76.4	0.012	42	800	1.298	79	0.0188
9/15/01	8:00	76.5	0.0119	73	800	1.461	79	0.0188
9/15/01	9:00	76.8	0.0116	116	800	1.675	82	0.0200
9/15/01	10:00	77	0.0112	112	800	1.766	85	0.0202
9/15/01	11:00	77.1	0.0108	131	800	1.866	88	0.0205
9/15/01	12:00	77.2	0.0106	202	800	2.026	89	0.0203
9/15/01	13:00	77.4	0.0105	219	800	2.178	90	0.0211
9/15/01	14:00	77.4	0.0103	138	800	2.2	91	0.0199
9/15/01	15:00	77.4	0.0104	123	800	2.147	89	0.0203
9/15/01	16:00	77.3	0.0101	97	800	2.019	88	0.0186
9/15/01	17:00	77.1	0.0102	41	800	1.868	86	0.0191
9/15/01	18:00	76.8	0.0107	6	800	1.696	84	0.0196
9/15/01	19:00	76.6	0.0112	0	800	1.512	82	0.0200
9/15/01	20:00	76.5	0.0118	0	800	1.421	80	0.0205
9/15/01	21:00	76.4	0.0119	0	800	1.313	80	0.0205
9/15/01	22:00	76.3	0.0121	0	800	1.264	79	0.0207
9/15/01	23:00	76.3	0.012	0	800	1.202	79	0.0207

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
9/16/01	0:00	76.3	0.0119	0	800	1.16	79	0.0198
9/16/01	1:00	76.2	0.012	0	800	1.132	78	0.0200
9/16/01	2:00	76.2	0.0121	0	800	1.111	78	0.0200
9/16/01	3:00	76.2	0.0119	0	800	1.068	78	0.0200
9/16/01	4:00	76.2	0.0119	0	800	1.057	78	0.0200
9/16/01	5:00	76.2	0.0115	0	800	1.002	78	0.0191
9/16/01	6:00	76.2	0.0119	13	800	1.173	80	0.0205
9/16/01	7:00	76.6	0.0116	58	800	1.462	83	0.0207
9/16/01	8:00	76.9	0.0115	118	800	1.804	85	0.0212
9/16/01	9:00	77.1	0.0112	140	800	1.992	87	0.0208
9/16/01	10:00	77.4	0.0107	214	800	2.132	88	0.0205
9/16/01	11:00	77.5	0.0105	267	800	2.267	90	0.0201
9/16/01	12:00	77.6	0.0108	232	800	2.455	90	0.0201
9/16/01	13:00	77.7	0.0114	230	800	2.59	89	0.0213
9/16/01	14:00	77.7	0.0119	177	800	2.698	89	0.0213
9/16/01	15:00	77.6	0.0119	152	800	2.559	87	0.0218
9/16/01	16:00	77.4	0.0115	98	800	2.303	86	0.0210
9/16/01	17:00	77.2	0.0113	36	800	2.025	84	0.0215
9/16/01	18:00	76.8	0.0111	2	800	1.673	82	0.0200
9/16/01	19:00	76.6	0.0109	0	800	1.393	80	0.0195
9/16/01	20:00	76.4	0.0104	0	800	1.185	78	0.0182
9/16/01	21:00	76.3	0.0106	0	800	1.114	76	0.0178
9/16/01	22:00	76.2	0.0108	0	800	1.043	75	0.0163
9/16/01	23:00	76.2	0.011	0	800	0.997	73	0.0160
9/17/01	0:00	76.1	0.0109	0	800	0.944	73	0.0152
9/17/01	1:00	76.1	0.0111	0	800	0.903	72	0.0154
9/17/01	2:00	76	0.011	0	800	0.84	72	0.0147
9/17/01	3:00	76	0.0111	0	800	0.848	73	0.0152
9/17/01	4:00	76	0.0113	0	800	0.882	74	0.0166
9/17/01	5:00	76.1	0.0114	0	800	0.919	75	0.0172
9/17/01	6:00	76.1	0.0115	10	800	1.004	77	0.0184
9/17/01	7:00	76.3	0.011	32	800	1.106	80	0.0186
9/17/01	8:00	76.4	0.0107	38	800	1.225	82	0.0190
9/17/01	9:00	76.5	0.011	74	800	1.419	79	0.0188
9/17/01	10:00	76.6	0.0111	98	800	1.487	76	0.0178
9/17/01	11:00	76.6	0.0113	95	800	1.479	73	0.0168
9/17/01	12:00	76.6	0.0109	113	800	1.412	72	0.0154
9/17/01	13:00	76.6	0.0105	128	800	1.375	70	0.0143
9/17/01	14:00	76.6	0.0101	95	800	1.288	69	0.0131
9/17/01	15:00	76.4	0.0099	68	800	1.19	69	0.0123
9/17/01	16:00	76.3	0.01	43	800	1.092	69	0.0123
9/17/01	17:00	76.2	0.0102	21	800	0.979	69	0.0123
9/17/01	18:00	76.1	0.0104	3	800	0.833	69	0.0123
9/17/01	19:00	75.9	0.0104	0	800	0.67	68	0.0118
9/17/01	20:00	75.9	0.0102	0	800	0.568	68	0.0112
9/17/01	21:00	75.8	0.0104	0	800	0.51	67	0.0114
9/17/01	22:00	75.8	0.0105	0	800	0.457	66	0.0116
9/17/01	23:00	75.7	0.0105	0	800	0.399	65	0.0112
9/18/01	0:00	75.7	0.0106	0	800	0.363	64	0.0114
9/18/01	1:00	75.7	0.0104	0	800	0.327	64	0.0108
9/18/01	2:00	75.7	0.0103	0	800	0.292	63	0.0103
9/18/01	3:00	75.6	0.0105	0	800	0.268	62	0.0106
9/18/01	4:00	75.6	0.0106	0	800	0.258	62	0.0106
9/18/01	5:00	75.6	0.0108	0	800	0.245	61	0.0102
9/18/01	6:00	75.7	0.0101	15	800	0.39	65	0.0105
9/18/01	7:00	76.1	0.0095	75	800	0.842	69	0.0109
9/18/01	8:00	76.5	0.0091	146	800	1.207	73	0.0106
9/18/01	9:00	76.8	0.0089	210	800	1.473	76	0.0100
9/18/01	10:00	77	0.0086	260	800	1.635	78	0.0088
9/18/01	11:00	77.1	0.0084	287	800	1.728	81	0.0081
9/18/01	12:00	77.2	0.0084	294	800	1.777	82	0.0079
9/18/01	13:00	77.3	0.0085	276	800	1.845	82	0.0086
9/18/01	14:00	77.3	0.0085	239	800	1.882	83	0.0084
9/18/01	15:00	77.3	0.0085	182	800	1.853	82	0.0079
9/18/01	16:00	77.2	0.0085	113	800	1.75	80	0.0084
9/18/01	17:00	76.9	0.0085	41	800	1.545	79	0.0080
9/18/01	18:00	76.6	0.0085	5	800	1.261	76	0.0086
9/18/01	19:00	76.3	0.0086	0	800	1.014	72	0.0089
9/18/01	20:00	76.1	0.0088	0	800	0.811	69	0.0090
9/18/01	21:00	76	0.009	0	800	0.651	67	0.0094
9/18/01	22:00	75.9	0.0092	0	800	0.535	66	0.0097
9/18/01	23:00	75.8	0.0096	0	800	0.448	64	0.0101

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
9/19/01	0:00	75.7	0.0097	0	800	0.368	63	0.0097
9/19/01	1:00	75.7	0.0098	0	800	0.321	63	0.0097
9/19/01	2:00	75.6	0.0101	0	800	0.278	62	0.0100
9/19/01	3:00	75.6	0.0102	0	800	0.265	62	0.0100
9/19/01	4:00	75.6	0.0103	0	800	0.276	62	0.0100
9/19/01	5:00	75.6	0.0105	0	800	0.266	62	0.0094
9/19/01	6:00	75.7	0.0099	13	800	0.372	67	0.0107
9/19/01	7:00	76.1	0.0092	64	800	0.794	73	0.0114
9/19/01	8:00	76.5	0.0088	135	800	1.214	78	0.0116
9/19/01	9:00	76.9	0.0087	200	800	1.585	81	0.0117
9/19/01	10:00	77.2	0.0087	249	800	1.803	83	0.0112
9/19/01	11:00	77.3	0.0087	278	800	1.924	86	0.0105
9/19/01	12:00	77.4	0.0087	284	800	1.957	87	0.0103
9/19/01	13:00	77.4	0.0087	267	800	1.998	88	0.0101
9/19/01	14:00	77.5	0.0088	228	800	2.039	89	0.0106
9/19/01	15:00	77.4	0.0089	170	800	2.016	86	0.0121
9/19/01	16:00	77.2	0.0091	99	800	1.894	84	0.0126
9/19/01	17:00	77	0.0094	32	800	1.689	81	0.0140
9/19/01	18:00	76.6	0.0097	3	800	1.399	78	0.0139
9/19/01	19:00	76.4	0.01	0	800	1.164	75	0.0139
9/19/01	20:00	76.2	0.0102	0	800	1	72	0.0138
9/19/01	21:00	76.1	0.0103	0	800	0.892	72	0.0138
9/19/01	22:00	76	0.0105	0	800	0.804	71	0.0140
9/19/01	23:00	76	0.0105	0	800	0.737	71	0.0140
9/20/01	0:00	76	0.0106	0	800	0.702	71	0.0148
9/20/01	1:00	75.9	0.0107	0	800	0.697	72	0.0153
9/20/01	2:00	75.9	0.0107	0	800	0.676	72	0.0161
9/20/01	3:00	75.9	0.0107	0	800	0.662	72	0.0161
9/20/01	4:00	75.9	0.011	0	800	0.676	72	0.0161
9/20/01	5:00	75.9	0.0111	0	800	0.673	72	0.0161
9/20/01	6:00	76	0.0114	9	800	0.862	76	0.0168
9/20/01	7:00	76.3	0.0114	53	800	1.234	80	0.0185
9/20/01	8:00	76.8	0.0112	122	800	1.643	84	0.0193
9/20/01	9:00	77.2	0.0109	196	800	1.963	86	0.0189
9/20/01	10:00	77.3	0.0106	181	800	2.083	88	0.0184
9/20/01	11:00	77.5	0.0106	266	800	2.271	90	0.0189
9/20/01	12:00	77.6	0.0105	223	800	2.307	90	0.0180
9/20/01	13:00	77.6	0.0106	190	800	2.314	89	0.0182
9/20/01	14:00	77.5	0.0106	173	800	2.3	89	0.0182
9/20/01	15:00	77.4	0.0107	127	800	2.214	87	0.0187
9/20/01	16:00	77.2	0.011	43	800	2.035	85	0.0192
9/20/01	17:00	76.9	0.0112	19	800	1.809	83	0.0196
9/20/01	18:00	76.7	0.0113	2	800	1.578	82	0.0199
9/20/01	19:00	76.5	0.0114	0	800	1.399	80	0.0194
9/20/01	20:00	76.4	0.0112	0	800	1.245	79	0.0196
9/20/01	21:00	76.3	0.0111	0	800	1.169	79	0.0187
9/20/01	22:00	76.3	0.011	0	800	1.089	78	0.0189
9/20/01	23:00	76.2	0.0111	0	800	1.059	78	0.0189
9/21/01	0:00	76.2	0.0112	0	800	1.038	78	0.0189
9/21/01	1:00	76.1	0.011	0	800	0.983	77	0.0192
9/21/01	2:00	76.1	0.0111	0	800	0.963	77	0.0192
9/21/01	3:00	76.1	0.011	0	800	0.937	77	0.0183
9/21/01	4:00	76.1	0.011	0	800	0.917	76	0.0185
9/21/01	5:00	76.1	0.0109	0	800	0.885	76	0.0176
9/21/01	6:00	76.2	0.0115	12	800	1.101	79	0.0187
9/21/01	7:00	76.4	0.0118	39	800	1.349	81	0.0191
9/21/01	8:00	76.7	0.0118	92	800	1.673	84	0.0193
9/21/01	9:00	77.1	0.0112	177	800	1.912	85	0.0191
9/21/01	10:00	77.3	0.0107	181	800	1.993	86	0.0179
9/21/01	11:00	77.4	0.0104	252	800	2.078	87	0.0177
9/21/01	12:00	77.4	0.0102	214	800	2.133	88	0.0175
9/21/01	13:00	77.5	0.0102	240	800	2.208	88	0.0175
9/21/01	14:00	77.5	0.0102	192	800	2.231	89	0.0173
9/21/01	15:00	77.5	0.01	157	800	2.149	87	0.0159
9/21/01	16:00	77.3	0.01	99	800	1.994	84	0.0158
9/21/01	17:00	77.1	0.01	35	800	1.787	82	0.0154
9/21/01	18:00	76.7	0.0102	2	800	1.495	80	0.0158
9/21/01	19:00	76.5	0.0101	0	800	1.253	78	0.0155
9/21/01	20:00	76.3	0.01	0	800	1.085	76	0.0159
9/21/01	21:00	76.2	0.0103	0	800	1.021	76	0.0168
9/21/01	22:00	76.2	0.0107	0	800	1.02	77	0.0174
9/21/01	23:00	76.2	0.011	0	800	1.013	77	0.0182

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
9/22/01	0:00	76.1	0.0113	0	800	1.024	77	0.0182
9/22/01	1:00	76.1	0.0114	0	800	1.011	77	0.0182
9/22/01	2:00	76.1	0.0117	0	800	1.023	77	0.0182
9/22/01	3:00	76.1	0.0115	0	800	0.995	77	0.0182
9/22/01	4:00	76.1	0.0111	0	800	0.954	77	0.0174
9/22/01	5:00	76.1	0.0107	0	800	0.909	77	0.0165
9/22/01	6:00	76.1	0.0113	9	800	1.029	77	0.0174
9/22/01	7:00	76.4	0.0115	52	800	1.309	78	0.0180
9/22/01	8:00	76.7	0.0115	107	800	1.57	78	0.0180
9/22/01	9:00	77	0.0112	147	800	1.781	82	0.0179
9/22/01	10:00	77.2	0.0108	207	800	1.974	85	0.0181
9/22/01	11:00	77.4	0.0106	191	800	2.113	89	0.0181
9/22/01	12:00	77.4	0.0104	223	800	2.167	89	0.0172
9/22/01	13:00	77.5	0.0105	231	800	2.237	88	0.0175
9/22/01	14:00	77.5	0.0103	206	800	2.238	88	0.0166
9/22/01	15:00	77.4	0.0102	144	800	2.134	86	0.0170
9/22/01	16:00	77.3	0.0102	96	800	1.99	83	0.0169
9/22/01	17:00	77	0.0102	26	800	1.731	81	0.0173
9/22/01	18:00	76.7	0.0104	2	800	1.479	80	0.0176
9/22/01	19:00	76.5	0.0106	0	800	1.293	78	0.0171
9/22/01	20:00	76.3	0.0107	0	800	1.162	77	0.0174
9/22/01	21:00	76.2	0.0108	0	800	1.071	76	0.0168
9/22/01	22:00	76.2	0.0107	0	800	1	76	0.0168
9/22/01	23:00	76.1	0.0107	0	800	0.944	75	0.0162
9/23/01	0:00	76.1	0.0106	0	800	0.883	75	0.0162
9/23/01	1:00	76.1	0.0106	0	800	0.858	75	0.0162
9/23/01	2:00	76	0.0104	0	800	0.812	75	0.0162
9/23/01	3:00	76	0.0104	0	800	0.799	75	0.0162
9/23/01	4:00	76	0.0107	0	800	0.804	74	0.0164
9/23/01	5:00	76	0.0108	0	800	0.784	74	0.0164
9/23/01	6:00	76.1	0.0109	14	800	0.995	77	0.0165
9/23/01	7:00	76.4	0.0109	52	800	1.284	81	0.0173
9/23/01	8:00	76.8	0.0107	126	800	1.653	84	0.0174
9/23/01	9:00	77.1	0.0105	158	800	1.869	85	0.0172
9/23/01	10:00	77.4	0.0102	243	800	2.023	87	0.0159
9/23/01	11:00	77.4	0.01	236	800	2.115	88	0.0156
9/23/01	12:00	77.5	0.0099	248	800	2.123	88	0.0148
9/23/01	13:00	77.5	0.0097	252	800	2.129	88	0.0140
9/23/01	14:00	77.5	0.0096	181	800	2.118	88	0.0140
9/23/01	15:00	77.4	0.0096	147	800	2.022	86	0.0136
9/23/01	16:00	77.3	0.0096	97	800	1.934	85	0.0138
9/23/01	17:00	77	0.0098	34	800	1.759	83	0.0143
9/23/01	18:00	76.7	0.01	3	800	1.477	80	0.0150
9/23/01	19:00	76.5	0.0101	0	800	1.251	78	0.0147
9/23/01	20:00	76.3	0.0102	0	800	1.081	75	0.0154
9/23/01	21:00	76.2	0.0103	0	800	0.996	75	0.0154
9/23/01	22:00	76.1	0.0103	0	800	0.914	74	0.0156
9/23/01	23:00	76.1	0.0104	0	800	0.859	74	0.0156
9/24/01	0:00	76	0.0104	0	800	0.794	73	0.0150
9/24/01	1:00	76	0.0102	0	800	0.717	72	0.0145
9/24/01	2:00	75.9	0.0102	0	800	0.663	71	0.0140
9/24/01	3:00	75.9	0.0102	0	800	0.636	71	0.0140
9/24/01	4:00	75.9	0.0103	0	800	0.618	71	0.0140
9/24/01	5:00	75.9	0.0103	0	800	0.608	71	0.0140
9/24/01	6:00	76	0.0102	10	800	0.719	74	0.0148
9/24/01	7:00	76.3	0.01	59	800	1.086	78	0.0155
9/24/01	8:00	76.7	0.0096	132	800	1.426	81	0.0156
9/24/01	9:00	77	0.0093	190	800	1.699	83	0.0151
9/24/01	10:00	77.3	0.0091	224	800	1.873	86	0.0153
9/24/01	11:00	77.4	0.0089	234	800	1.971	88	0.0148
9/24/01	12:00	77.4	0.0089	218	800	2.024	87	0.0142
9/24/01	13:00	77.5	0.009	226	800	2.068	87	0.0142
9/24/01	14:00	77.4	0.0091	168	800	2.061	86	0.0145
9/24/01	15:00	77.4	0.0091	148	800	1.998	86	0.0136
9/24/01	16:00	77.2	0.0091	71	800	1.829	85	0.0139
9/24/01	17:00	76.9	0.0092	18	800	1.622	85	0.0139
9/24/01	18:00	76.7	0.0094	1	800	1.407	82	0.0146
9/24/01	19:00	76.4	0.0097	0	800	1.222	78	0.0147
9/24/01	20:00	76.3	0.0099	0	800	1.077	75	0.0146
9/24/01	21:00	76.2	0.0101	0	800	0.992	75	0.0146
9/24/01	22:00	76.1	0.0105	0	800	0.948	74	0.0148
9/24/01	23:00	76.1	0.0106	0	800	0.902	74	0.0148

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
9/25/01	0:00	76.1	0.0105	0	800	0.849	74	0.0148
9/25/01	1:00	76.1	0.0105	0	800	0.839	75	0.0146
9/25/01	2:00	76	0.0103	0	800	0.81	75	0.0146
9/25/01	3:00	76	0.0105	0	800	0.827	75	0.0146
9/25/01	4:00	76	0.0109	0	800	0.852	74	0.0148
9/25/01	5:00	76	0.0111	0	800	0.873	74	0.0148
9/25/01	6:00	76.1	0.011	3	800	0.903	75	0.0146
9/25/01	7:00	76.2	0.0109	21	800	0.991	76	0.0151
9/25/01	8:00	76.3	0.0106	56	800	1.117	77	0.0149
9/25/01	9:00	76.6	0.0103	117	800	1.366	79	0.0152
9/25/01	10:00	76.9	0.01	191	800	1.644	82	0.0154
9/25/01	11:00	77.1	0.0098	223	800	1.835	84	0.0158
9/25/01	12:00	77.3	0.0099	224	800	1.972	85	0.0155
9/25/01	13:00	77.4	0.0099	212	800	2.044	86	0.0153
9/25/01	14:00	77.5	0.0099	216	800	2.143	87	0.0151
9/25/01	15:00	77.4	0.0098	147	800	2.044	85	0.0139
9/25/01	16:00	77.2	0.0099	88	800	1.91	83	0.0144
9/25/01	17:00	76.9	0.01	26	800	1.678	81	0.0140
9/25/01	18:00	76.6	0.0102	1	800	1.413	79	0.0137
9/25/01	19:00	76.4	0.0103	0	800	1.219	77	0.0134
9/25/01	20:00	76.3	0.0105	0	800	1.076	75	0.0131
9/25/01	21:00	76.2	0.0103	0	800	0.957	74	0.0125
9/25/01	22:00	76.1	0.0105	0	800	0.872	72	0.0130
9/25/01	23:00	76	0.0103	0	800	0.756	71	0.0125
9/26/01	0:00	75.9	0.0104	0	800	0.67	70	0.0120
9/26/01	1:00	75.9	0.0103	0	800	0.599	70	0.0113
9/26/01	2:00	75.8	0.0103	0	800	0.524	69	0.0109
9/26/01	3:00	75.8	0.0105	0	800	0.478	68	0.0111
9/26/01	4:00	75.8	0.0103	0	800	0.416	67	0.0107
9/26/01	5:00	75.7	0.0102	0	800	0.349	66	0.0103
9/26/01	6:00	75.8	0.0099	10	800	0.48	69	0.0102
9/26/01	7:00	76.1	0.0096	62	800	0.869	71	0.0104
9/26/01	8:00	76.5	0.0092	133	800	1.18	74	0.0097
9/26/01	9:00	76.8	0.0088	196	800	1.43	77	0.0090
9/26/01	10:00	77	0.0084	245	800	1.57	79	0.0079
9/26/01	11:00	77.1	0.0078	274	800	1.682	82	0.0072
9/26/01	12:00	77.2	0.0083	279	800	1.739	83	0.0077
9/26/01	13:00	77.2	0.0081	262	800	1.799	84	0.0075
9/26/01	14:00	77.3	0.0084	221	800	1.845	85	0.0079
9/26/01	15:00	77.2	0.0085	163	800	1.809	83	0.0084
9/26/01	16:00	77.1	0.0084	93	800	1.673	82	0.0079
9/26/01	17:00	76.8	0.0084	26	800	1.437	80	0.0077
9/26/01	18:00	76.5	0.0085	1	800	1.209	78	0.0088
9/26/01	19:00	76.3	0.0086	0	800	1.015	76	0.0086
9/26/01	20:00	76.1	0.0089	0	800	0.908	74	0.0097
9/26/01	21:00	76	0.0092	0	800	0.786	72	0.0102
9/26/01	22:00	76	0.0093	0	800	0.697	71	0.0104
9/26/01	23:00	75.9	0.0096	0	800	0.62	69	0.0109
9/27/01	0:00	75.8	0.0097	0	800	0.531	67	0.0107
9/27/01	1:00	75.8	0.0097	0	800	0.466	66	0.0103
9/27/01	2:00	75.7	0.0098	0	800	0.391	64	0.0101
9/27/01	3:00	75.7	0.01	0	800	0.335	63	0.0103
9/27/01	4:00	75.6	0.01	0	800	0.268	63	0.0097
9/27/01	5:00	75.6	0.0099	0	800	0.221	62	0.0093
9/27/01	6:00	75.7	0.0097	13	800	0.37	66	0.0096
9/27/01	7:00	76.1	0.0092	65	800	0.819	71	0.0097
9/27/01	8:00	76.5	0.0089	136	800	1.198	75	0.0095
9/27/01	9:00	76.8	0.0087	200	800	1.463	77	0.0090
9/27/01	10:00	77	0.0086	248	800	1.664	80	0.0090
9/27/01	11:00	77.2	0.0085	276	800	1.761	82	0.0086
9/27/01	12:00	77.2	0.0085	280	800	1.81	83	0.0083
9/27/01	13:00	77.3	0.0085	261	800	1.876	84	0.0088
9/27/01	14:00	77.4	0.0086	221	800	1.929	85	0.0093
9/27/01	15:00	77.3	0.0086	163	800	1.885	84	0.0095
9/27/01	16:00	77.1	0.0087	93	800	1.769	83	0.0098
9/27/01	17:00	76.9	0.0087	26	800	1.554	82	0.0100
9/27/01	18:00	76.5	0.0089	1	800	1.258	77	0.0104
9/27/01	19:00	76.3	0.009	0	800	1.033	73	0.0107
9/27/01	20:00	76.1	0.0092	0	800	0.819	68	0.0105
9/27/01	21:00	76	0.0093	0	800	0.677	68	0.0105
9/27/01	22:00	75.9	0.0094	0	800	0.612	69	0.0109
9/27/01	23:00	75.9	0.0095	0	800	0.562	69	0.0109

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
9/28/01	0:00	75.8	0.0096	0	800	0.512	68	0.0105
9/28/01	1:00	75.8	0.0097	0	800	0.481	68	0.0105
9/28/01	2:00	75.8	0.0097	0	800	0.445	67	0.0101
9/28/01	3:00	75.8	0.0098	0	800	0.417	66	0.0103
9/28/01	4:00	75.7	0.0098	0	800	0.363	65	0.0099
9/28/01	5:00	75.7	0.01	0	800	0.332	64	0.0101
9/28/01	6:00	75.7	0.0099	7	800	0.408	69	0.0102
9/28/01	7:00	76	0.0098	45	800	0.762	73	0.0113
9/28/01	8:00	76.4	0.0094	100	800	1.117	78	0.0109
9/28/01	9:00	76.6	0.0092	133	800	1.353	80	0.0111
9/28/01	10:00	76.9	0.009	184	800	1.555	83	0.0104
9/28/01	11:00	77.1	0.0088	201	800	1.693	85	0.0100
9/28/01	12:00	77.2	0.0087	227	800	1.793	85	0.0100
9/28/01	13:00	77.2	0.0087	205	800	1.853	85	0.0100
9/28/01	14:00	77.2	0.0088	134	800	1.81	85	0.0100
9/28/01	15:00	77	0.0088	86	800	1.673	83	0.0105
9/28/01	16:00	76.8	0.0089	59	800	1.509	80	0.0112
9/28/01	17:00	76.6	0.009	14	800	1.299	78	0.0116
9/28/01	18:00	76.4	0.0091	0	800	1.136	77	0.0118
9/28/01	19:00	76.2	0.0092	0	800	1.008	75	0.0116
9/28/01	20:00	76.2	0.0093	0	800	0.929	74	0.0118
9/28/01	21:00	76.1	0.0094	0	800	0.832	73	0.0113
9/28/01	22:00	76	0.0096	0	800	0.752	71	0.0118
9/28/01	23:00	76	0.0096	0	800	0.667	70	0.0113
9/29/01	0:00	75.9	0.0099	0	800	0.611	69	0.0116
9/29/01	1:00	75.9	0.0101	0	800	0.559	68	0.0118
9/29/01	2:00	75.8	0.0104	0	800	0.508	67	0.0120
9/29/01	3:00	75.8	0.0103	0	800	0.455	67	0.0113
9/29/01	4:00	75.7	0.0106	0	800	0.413	66	0.0116
9/29/01	5:00	75.7	0.0105	0	800	0.366	66	0.0109
9/29/01	6:00	75.8	0.0103	11	800	0.515	70	0.0113
9/29/01	7:00	76.2	0.0098	60	800	0.949	74	0.0118
9/29/01	8:00	76.6	0.0095	130	800	1.312	78	0.0123
9/29/01	9:00	76.9	0.0092	193	800	1.597	81	0.0116
9/29/01	10:00	77.2	0.009	240	800	1.791	84	0.0109
9/29/01	11:00	77.3	0.0087	269	800	1.879	87	0.0095
9/29/01	12:00	77.4	0.0086	272	800	1.929	87	0.0095
9/29/01	13:00	77.4	0.0087	255	800	2.001	88	0.0100
9/29/01	14:00	77.4	0.0087	214	800	2.023	88	0.0100
9/29/01	15:00	77.4	0.0087	156	800	1.959	86	0.0105
9/29/01	16:00	77.2	0.0087	82	800	1.804	85	0.0100
9/29/01	17:00	76.9	0.0087	21	800	1.554	83	0.0104
9/29/01	18:00	76.6	0.0088	0	800	1.277	80	0.0111
9/29/01	19:00	76.3	0.0089	0	800	1.076	76	0.0120
9/29/01	20:00	76.2	0.0088	0	800	0.907	73	0.0120
9/29/01	21:00	76.1	0.0089	0	800	0.798	73	0.0120
9/29/01	22:00	76	0.0092	0	800	0.726	72	0.0122
9/29/01	23:00	75.9	0.0094	0	800	0.67	72	0.0115
9/30/01	0:00	75.9	0.0097	0	800	0.632	71	0.0117
9/30/01	1:00	75.9	0.0098	0	800	0.581	70	0.0113
9/30/01	2:00	75.8	0.0098	0	800	0.528	69	0.0108
9/30/01	3:00	75.8	0.0101	0	800	0.49	68	0.0111
9/30/01	4:00	75.8	0.0099	0	800	0.44	68	0.0104
9/30/01	5:00	75.7	0.0099	0	800	0.387	67	0.0100
9/30/01	6:00	75.9	0.0097	12	800	0.562	71	0.0103
9/30/01	7:00	76.2	0.0094	58	800	0.971	75	0.0108
9/30/01	8:00	76.6	0.0092	126	800	1.321	79	0.0113
9/30/01	9:00	76.9	0.009	171	800	1.564	82	0.0106
9/30/01	10:00	77.1	0.0088	219	800	1.739	84	0.0101
9/30/01	11:00	77.2	0.0088	256	800	1.866	87	0.0102
9/30/01	12:00	77.3	0.0086	271	800	1.899	88	0.0092
9/30/01	13:00	77.4	0.0085	226	800	1.941	88	0.0092
9/30/01	14:00	77.4	0.0085	170	800	1.927	89	0.0090
9/30/01	15:00	77.3	0.0085	131	800	1.884	87	0.0095
9/30/01	16:00	77.1	0.0086	83	800	1.775	84	0.0102
9/30/01	17:00	76.9	0.0086	21	800	1.535	82	0.0099
9/30/01	18:00	76.5	0.0087	0	800	1.254	78	0.0101
9/30/01	19:00	76.3	0.0088	0	800	1.036	74	0.0097
9/30/01	20:00	76.1	0.009	0	800	0.858	70	0.0100
9/30/01	21:00	76	0.0091	0	800	0.712	68	0.0104
9/30/01	22:00	75.9	0.0093	0	800	0.59	66	0.0102
9/30/01	23:00	75.8	0.0093	0	800	0.501	65	0.0098

B.2.4 Winter Season: (December)

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
12/1/01	0:00	72	0.0085	0	800	0	50	0.0071
12/1/01	1:00	71.7	0.0088	0	800	0	51	0.0074
12/1/01	2:00	71.4	0.0097	0	800	0	49	0.0073
12/1/01	3:00	71	0.0082	0	800	0	49	0.0068
12/1/01	4:00	70.7	0.0087	0	800	0	49	0.0069
12/1/01	5:00	70.6	0.0144	0	800	0	48	0.0071
12/1/01	6:00	70.5	0.0097	0	800	0	51	0.0079
12/1/01	7:00	70.5	0.0102	10	800	0.085	54	0.0089
12/1/01	8:00	71.1	0.0119	23	800	0	59	0.0101
12/1/01	9:00	72.9	0.0136	91	800	0	64	0.0121
12/1/01	10:00	74.8	0.0132	97	800	0	68	0.0125
12/1/01	11:00	76.1	0.0128	200	800	0	73	0.0121
12/1/01	12:00	76.5	0.0102	149	800	1.146	75	0.0117
12/1/01	13:00	76.6	0.0095	114	800	1.281	78	0.0117
12/1/01	14:00	76.7	0.0093	133	800	1.435	77	0.0112
12/1/01	15:00	76.7	0.0093	81	800	1.399	76	0.0107
12/1/01	16:00	76.5	0.0093	29	800	1.218	74	0.0112
12/1/01	17:00	76.2	0.0098	4	800	0.981	70	0.0121
12/1/01	18:00	76	0.0105	0	800	0.711	68	0.0126
12/1/01	19:00	75.8	0.0109	0	800	0.542	67	0.0128
12/1/01	20:00	75.7	0.0119	0	800	0.45	67	0.0135
12/1/01	21:00	75.7	0.0125	0	800	0.419	68	0.0140
12/1/01	22:00	75.7	0.0125	0	800	0.402	68	0.0140
12/1/01	23:00	75.7	0.0123	0	800	0.405	68	0.0140
12/2/01	0:00	75.7	0.0123	0	800	0.405	68	0.0140
12/2/01	1:00	75.7	0.0123	0	800	0.404	68	0.0140
12/2/01	2:00	75.7	0.0122	0	800	0.418	69	0.0138
12/2/01	3:00	75.7	0.0122	0	800	0.411	68	0.0140
12/2/01	4:00	75.7	0.0127	0	800	0.432	69	0.0146
12/2/01	5:00	75.8	0.0123	0	800	0.476	70	0.0151
12/2/01	6:00	75.8	0.0124	0	800	0.491	70	0.0151
12/2/01	7:00	75.8	0.012	6	800	0.542	70	0.0151
12/2/01	8:00	76	0.0121	35	800	0.833	74	0.0174
12/2/01	9:00	76.2	0.0121	42	800	1.087	78	0.0173
12/2/01	10:00	76.4	0.0117	60	800	1.233	80	0.0177
12/2/01	11:00	76.5	0.0115	81	800	1.414	81	0.0166
12/2/01	12:00	76.7	0.0117	83	800	1.574	82	0.0173
12/2/01	13:00	76.7	0.011	78	800	1.455	81	0.0166
12/2/01	14:00	76.7	0.0112	62	800	1.518	81	0.0166
12/2/01	15:00	76.6	0.0113	30	800	1.424	80	0.0169
12/2/01	16:00	76.4	0.0115	19	800	1.313	78	0.0173
12/2/01	17:00	76.3	0.0118	2	800	1.199	77	0.0167
12/2/01	18:00	76.2	0.0121	0	800	1.143	77	0.0167
12/2/01	19:00	76.2	0.0122	0	800	1.104	77	0.0167
12/2/01	20:00	76.2	0.0126	0	800	1.087	76	0.0178
12/2/01	21:00	76.1	0.0127	0	800	1.067	76	0.0178
12/2/01	22:00	76.1	0.0129	0	800	1.069	76	0.0178
12/2/01	23:00	76.1	0.0134	0	800	1.068	75	0.0180
12/3/01	0:00	76.1	0.0129	0	800	1.034	76	0.0178
12/3/01	1:00	76.1	0.013	0	800	1.023	75	0.0180
12/3/01	2:00	76.1	0.0133	0	800	1.036	75	0.0180
12/3/01	3:00	76.1	0.0127	0	800	0.981	75	0.0180
12/3/01	4:00	76.1	0.0123	0	800	0.945	75	0.0172
12/3/01	5:00	76.1	0.0127	0	800	0.98	75	0.0172
12/3/01	6:00	76.1	0.0121	0	800	0.923	75	0.0172
12/3/01	7:00	76.1	0.0126	10	800	1.001	75	0.0172
12/3/01	8:00	76.2	0.0122	38	800	1.071	75	0.0172
12/3/01	9:00	76.3	0.0119	58	800	1.191	76	0.0178
12/3/01	10:00	76.5	0.0115	87	800	1.326	77	0.0176
12/3/01	11:00	76	0.0087	55	800	0.536	53	0.0081
12/3/01	12:00	75.6	0.007	56	800	0.187	47	0.0064
12/3/01	13:00	75.3	0.0071	56	800	0	45	0.0064
12/3/01	14:00	74.5	0.0065	45	800	0	43	0.0059
12/3/01	15:00	73.7	0.0065	45	800	0	43	0.0059
12/3/01	16:00	72.5	0.0064	20	800	0	43	0.0059
12/3/01	17:00	72.1	0.0063	3	800	0	43	0.0054
12/3/01	18:00	71.3	0.006	0	800	0	42	0.0052
12/3/01	19:00	70.5	0.0051	0	800	0	41	0.0045
12/3/01	20:00	70.4	0.005	0	8159.93	0	42	0.0043
12/3/01	21:00	70.4	0.0052	0	8322.75	0	42	0.0043
12/3/01	22:00	70.4	0.0045	0	10778.797	0	41	0.0038
12/3/01	23:00	70.3	0.0039	0	13185.881	0	40	0.0034

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
12/4/01	0:00	70.4	0.0041	0	11624.545	0	40	0.0034
12/4/01	1:00	70.4	0.004	0	11868.775	0	40	0.0033
12/4/01	2:00	70.3	0.0038	0	12930.859	0	39	0.0031
12/4/01	3:00	70.3	0.0041	0	13633.937	0	36	0.0034
12/4/01	4:00	70.4	0.0053	0	11269.064	0	35	0.0039
12/4/01	5:00	70.3	0.005	0	13688.444	0	34	0.0041
12/4/01	6:00	70.3	0.0053	0	12798.415	0	34	0.0041
12/4/01	7:00	70.3	0.0051	6	12552.114	0	35	0.0039
12/4/01	8:00	70.4	0.0054	21	11807.673	0	35	0.0042
12/4/01	9:00	70.4	0.0047	62	11309.232	0	36	0.0040
12/4/01	10:00	70.5	0.0049	126	800	0.082	40	0.0039
12/4/01	11:00	71.8	0.0053	184	800	0	44	0.0043
12/4/01	12:00	73.5	0.0051	203	800	0	48	0.0042
12/4/01	13:00	75.3	0.0047	184	800	0	52	0.0038
12/4/01	14:00	75.8	0.0049	146	800	0.562	53	0.0040
12/4/01	15:00	76.1	0.0054	95	800	0.774	53	0.0036
12/4/01	16:00	75.9	0.0066	35	800	0.504	46	0.0051
12/4/01	17:00	75.5	0.007	4	4131.796	0	42	0.0052
12/4/01	18:00	74.9	0.005	0	800	0	39	0.0050
12/4/01	19:00	73.9	0.0046	0	800	0	37	0.0046
12/4/01	20:00	72.9	0.0044	0	800	0	36	0.0044
12/4/01	21:00	71.9	0.0043	0	800	0	35	0.0043
12/4/01	22:00	70.5	0.0057	0	800	0	35	0.0043
12/4/01	23:00	70.5	0.0043	0	6635.122	0	35	0.0043
12/5/01	0:00	70.4	0.0058	0	11017.306	0	36	0.0044
12/5/01	1:00	70.4	0.0043	0	8791.328	0	35	0.0043
12/5/01	2:00	70.4	0.0059	0	12062.826	0	34	0.0041
12/5/01	3:00	70.4	0.0041	0	9927.438	0	34	0.0041
12/5/01	4:00	70.4	0.0041	0	10318.594	0	34	0.0041
12/5/01	5:00	70.3	0.0059	0	13184.452	0	34	0.0041
12/5/01	6:00	70.3	0.0061	0	13065.389	0	35	0.0043
12/5/01	7:00	70.4	0.0068	17	8454.844	0	39	0.0050
12/5/01	8:00	71.3	0.0078	72	800	0	51	0.0064
12/5/01	9:00	73.4	0.0079	128	800	0	58	0.0069
12/5/01	10:00	75.5	0.0073	172	800	0	63	0.0068
12/5/01	11:00	76	0.0075	198	800	0.758	67	0.0070
12/5/01	12:00	76.3	0.0075	202	800	1.014	68	0.0068
12/5/01	13:00	76.5	0.0076	185	800	1.159	70	0.0070
12/5/01	14:00	76.6	0.0074	148	800	1.254	71	0.0067
12/5/01	15:00	76.5	0.0075	96	800	1.211	70	0.0070
12/5/01	16:00	76.4	0.0081	36	800	1.045	66	0.0073
12/5/01	17:00	76	0.0084	5	800	0.646	62	0.0077
12/5/01	18:00	75.7	0.009	0	800	0.365	60	0.0087
12/5/01	19:00	75.6	0.0102	0	800	0.13	59	0.0095
12/5/01	20:00	75.3	0.0103	0	800	0	58	0.0092
12/5/01	21:00	75	0.0116	0	800	0	60	0.0105
12/5/01	22:00	74.7	0.0112	0	800	0	57	0.0100
12/5/01	23:00	74.8	0.0124	0	800	0	61	0.0109
12/6/01	0:00	74.8	0.0123	0	800	0	60	0.0105
12/6/01	1:00	74.8	0.0121	0	800	0	61	0.0109
12/6/01	2:00	74.9	0.0125	0	800	0	62	0.0113
12/6/01	3:00	75	0.0131	0	800	0	62	0.0113
12/6/01	4:00	75	0.0125	0	800	0	62	0.0113
12/6/01	5:00	75.1	0.0133	0	800	0	65	0.0126
12/6/01	6:00	75.3	0.0142	0	800	0	66	0.0131
12/6/01	7:00	75.6	0.0142	7	800	0	68	0.0133
12/6/01	8:00	75.7	0.0118	28	800	0.411	68	0.0133
12/6/01	9:00	75.9	0.0114	46	800	0.63	70	0.0136
12/6/01	10:00	76	0.0114	65	800	0.864	72	0.0139
12/6/01	11:00	76.2	0.0112	77	800	1.013	73	0.0144
12/6/01	12:00	76.2	0.0119	57	800	1.156	75	0.0155
12/6/01	13:00	76.3	0.012	72	800	1.16	73	0.0160
12/6/01	14:00	76.3	0.0118	61	800	1.189	75	0.0156
12/6/01	15:00	76.2	0.0121	25	800	1.104	73	0.0160
12/6/01	16:00	76.1	0.0121	17	800	1.014	72	0.0163
12/6/01	17:00	76	0.0124	1	800	0.867	71	0.0157
12/6/01	18:00	76	0.0123	0	800	0.8	72	0.0163
12/6/01	19:00	75.8	0.0107	0	800	0.423	62	0.0113
12/6/01	20:00	75.6	0.0109	0	800	0.263	60	0.0111
12/6/01	21:00	75.6	0.011	0	800	0.144	58	0.0103
12/6/01	22:00	75.4	0.0108	0	800	0	56	0.0096
12/6/01	23:00	75	0.01	0	800	0	54	0.0089

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
12/7/01	0:00	74.6	0.0098	0	800	0	53	0.0086
12/7/01	1:00	74.3	0.0101	0	800	0	53	0.0086
12/7/01	2:00	74.1	0.0104	0	800	0	53	0.0086
12/7/01	3:00	74.1	0.0117	0	800	0	55	0.0093
12/7/01	4:00	74	0.0117	0	800	0	55	0.0093
12/7/01	5:00	73.8	0.0111	0	800	0	55	0.0093
12/7/01	6:00	73.3	0.0101	0	800	0	55	0.0093
12/7/01	7:00	73	0.0099	8	800	0	55	0.0092
12/7/01	8:00	73.4	0.0101	40	800	0	54	0.0089
12/7/01	9:00	73.8	0.0101	52	800	0	54	0.0089
12/7/01	10:00	74.2	0.0099	61	800	0	54	0.0089
12/7/01	11:00	74.7	0.0095	80	800	0	53	0.0086
12/7/01	12:00	75	0.0094	78	800	0	53	0.0086
12/7/01	13:00	75.4	0.0092	79	800	0	52	0.0083
12/7/01	14:00	75.6	0.0095	69	800	0	52	0.0083
12/7/01	15:00	75.6	0.0091	48	800	0.204	51	0.0080
12/7/01	16:00	75	0.0082	12	800	0	49	0.0074
12/7/01	17:00	73.7	0.0077	2	800	0	48	0.0071
12/7/01	18:00	73.2	0.0081	0	800	0	48	0.0071
12/7/01	19:00	72.3	0.0075	0	800	0	47	0.0068
12/7/01	20:00	71.8	0.0078	0	800	0	47	0.0068
12/7/01	21:00	71	0.0071	0	800	0	45	0.0063
12/7/01	22:00	70.5	0.0071	0	800	0	44	0.0061
12/7/01	23:00	70.4	0.007	0	7068.873	0	44	0.0061
12/8/01	0:00	70.4	0.0066	0	8722.994	0	43	0.0058
12/8/01	1:00	70.4	0.007	0	7644.859	0	42	0.0056
12/8/01	2:00	70.3	0.006	0	12380.833	0	41	0.0054
12/8/01	3:00	70.3	0.0058	0	13311.614	0	40	0.0052
12/8/01	4:00	70.3	0.005	0	17039.832	0	37	0.0046
12/8/01	5:00	70.3	0.005	0	15297.011	0	36	0.0044
12/8/01	6:00	70.3	0.0049	0	16647.457	0	35	0.0043
12/8/01	7:00	70.3	0.0048	6	15965.365	0	34	0.0041
12/8/01	8:00	70.3	0.0049	23	14180.767	0	34	0.0041
12/8/01	9:00	70.3	0.0045	35	15499.312	0	35	0.0039
12/8/01	10:00	70.4	0.005	83	11256.861	0	35	0.0043
12/8/01	11:00	70.4	0.0049	85	11492.021	0	35	0.0043
12/8/01	12:00	70.4	0.0045	100	10360.412	0	35	0.0039
12/8/01	13:00	70.4	0.0044	93	9630.523	0	34	0.0038
12/8/01	14:00	70.3	0.0041	43	13084.106	0	33	0.0036
12/8/01	15:00	70.3	0.0042	26	14248.271	0	32	0.0036
12/8/01	16:00	70.3	0.0044	20	16286.521	0	32	0.0038
12/8/01	17:00	70.3	0.0044	3	17112.094	0	32	0.0038
12/8/01	18:00	70.2	0.0042	0	22520.34	0	32	0.0038
12/8/01	19:00	70.2	0.0041	0	19832.709	0	31	0.0036
12/8/01	20:00	70.2	0.0039	0	20443	0	32	0.0034
12/8/01	21:00	70.2	0.0039	0	21237.02	0	32	0.0034
12/8/01	22:00	70.2	0.0035	0	22015.721	0	32	0.0031
12/8/01	23:00	70.2	0.0035	0	20226.631	0	32	0.0030
12/9/01	0:00	70.2	0.0033	0	19968.688	0	33	0.0028
12/9/01	1:00	70.2	0.003	0	21098.402	0	32	0.0025
12/9/01	2:00	70.2	0.0029	0	19790.951	0	31	0.0023
12/9/01	3:00	70.2	0.0027	0	22007.457	0	31	0.0022
12/9/01	4:00	70.2	0.0026	0	21955.234	0	30	0.0021
12/9/01	5:00	70.2	0.0029	0	18993.219	0	29	0.0020
12/9/01	6:00	70.2	0.0024	0	21551.859	0	28	0.0018
12/9/01	7:00	70.2	0.0023	12	20179.588	0	30	0.0017
12/9/01	8:00	70.3	0.0022	62	14460.332	0	33	0.0017
12/9/01	9:00	70.4	0.0022	120	8375.411	0	35	0.0017
12/9/01	10:00	70.5	0.0022	165	800	0.083	39	0.0017
12/9/01	11:00	71.1	0.0022	193	800	0	40	0.0017
12/9/01	12:00	72.1	0.0024	198	800	0	41	0.0017
12/9/01	13:00	73	0.0023	181	800	0	42	0.0017
12/9/01	14:00	74	0.0025	144	800	0	43	0.0017
12/9/01	15:00	74.5	0.0026	90	800	0	42	0.0017
12/9/01	16:00	73.5	0.0023	32	800	0	39	0.0017
12/9/01	17:00	72.1	0.0026	3	800	0	36	0.0017
12/9/01	18:00	70.8	0.0031	0	800	0	33	0.0017
12/9/01	19:00	70.4	0.0032	0	800	0	29	0.0020
12/9/01	20:00	70.3	0.0035	0	13265.183	0	28	0.0021
12/9/01	21:00	70.3	0.0035	0	14857.687	0	28	0.0021
12/9/01	22:00	70.3	0.0044	0	14422.552	0	27	0.0021
12/9/01	23:00	70.3	0.0044	0	15253.825	0	26	0.0021

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
12/10/01	0:00	70.3	0.004	0	16767.203	0	25	0.0022
12/10/01	1:00	70.2	0.0029	0	20376.715	0	25	0.0020
12/10/01	2:00	70.3	0.0039	0	17850.984	0	23	0.0021
12/10/01	3:00	70.3	0.0021	0	14778.2	0	23	0.0021
12/10/01	4:00	70.3	0.0021	0	15309.287	0	22	0.0021
12/10/01	5:00	70.3	0.0021	0	15713.358	0	22	0.0021
12/10/01	6:00	70.3	0.002	0	16101.359	0	21	0.0020
12/10/01	7:00	70.3	0.0041	16	15872.104	0	25	0.0023
12/10/01	8:00	70.4	0.0041	68	7728.511	0	32	0.0023
12/10/01	9:00	70.8	0.0031	126	800	0	37	0.0021
12/10/01	10:00	72.4	0.0027	172	800	0	47	0.0018
12/10/01	11:00	74.1	0.0036	198	800	0	43	0.0018
12/10/01	12:00	75.4	0.0029	189	800	0	45	0.0017
12/10/01	13:00	75.8	0.0035	158	800	0.539	47	0.0017
12/10/01	14:00	75.8	0.0031	80	800	0.395	45	0.0017
12/10/01	15:00	75.6	0.0031	41	800	0.111	45	0.0017
12/10/01	16:00	75.1	0.0038	22	800	0	44	0.0020
12/10/01	17:00	73.8	0.0035	2	800	0	42	0.0023
12/10/01	18:00	72.5	0.0035	0	800	0	40	0.0023
12/10/01	19:00	71.1	0.0033	0	800	0	39	0.0023
12/10/01	20:00	70.5	0.0041	0	800	0	37	0.0029
12/10/01	21:00	70.4	0.0056	0	7949.169	0	36	0.0032
12/10/01	22:00	70.4	0.0059	0	9315.022	0	36	0.0035
12/10/01	23:00	70.3	0.0046	0	13280.164	0	36	0.0037
12/11/01	0:00	70.4	0.0048	0	11489.936	0	38	0.0034
12/11/01	1:00	70.4	0.0032	0	9237.228	0	34	0.0032
12/11/01	2:00	70.4	0.0034	0	10098.502	0	32	0.0034
12/11/01	3:00	70.4	0.0032	0	10861.026	0	31	0.0032
12/11/01	4:00	70.3	0.0052	0	13605.663	0	34	0.0034
12/11/01	5:00	70.3	0.0048	0	14157.613	0	34	0.0034
12/11/01	6:00	70.3	0.0048	0	13762.985	0	35	0.0034
12/11/01	7:00	70.3	0.0046	9	12944.971	0	36	0.0032
12/11/01	8:00	70.4	0.0043	28	11617.573	0	39	0.0031
12/11/01	9:00	70.4	0.0039	50	9412.209	0	42	0.0029
12/11/01	10:00	70.5	0.0037	90	5968.83	0	45	0.0028
12/11/01	11:00	70.9	0.0045	88	800	0	45	0.0027
12/11/01	12:00	71.7	0.0063	76	800	0	47	0.0028
12/11/01	13:00	72.5	0.004	111	800	0	51	0.0028
12/11/01	14:00	74.1	0.0044	130	800	0	52	0.0026
12/11/01	15:00	75.1	0.0034	81	800	0	52	0.0024
12/11/01	16:00	75.2	0.0058	26	800	0	46	0.0034
12/11/01	17:00	74.1	0.0055	3	800	0	40	0.0037
12/11/01	18:00	72.9	0.0061	0	800	0	37	0.0037
12/11/01	19:00	72.1	0.0037	0	800	0	36	0.0037
12/11/01	20:00	71	0.0035	0	800	0	33	0.0035
12/11/01	21:00	70.5	0.0032	0	800	0	31	0.0032
12/11/01	22:00	70.4	0.0031	0	9681.135	0	29	0.0031
12/11/01	23:00	70.4	0.0031	0	11153.436	0	29	0.0031
12/12/01	0:00	70.4	0.0029	0	12052.389	0	29	0.0029
12/12/01	1:00	70.4	0.0031	0	12602.044	0	29	0.0031
12/12/01	2:00	70.3	0.0029	0	12964.022	0	29	0.0029
12/12/01	3:00	70.3	0.0047	0	16122.138	0	29	0.0029
12/12/01	4:00	70.3	0.0053	0	15372.102	0	29	0.0029
12/12/01	5:00	70.3	0.0028	0	13463.991	0	27	0.0028
12/12/01	6:00	70.3	0.0027	0	13811.231	0	27	0.0027
12/12/01	7:00	70.3	0.0053	15	12929.377	0	29	0.0029
12/12/01	8:00	70.5	0.0072	65	800	0.08	39	0.0037
12/12/01	9:00	71.3	0.0045	113	800	0	46	0.0037
12/12/01	10:00	72.8	0.0039	149	800	0	52	0.0031
12/12/01	11:00	74.4	0.0036	160	800	0	55	0.0026
12/12/01	12:00	75.6	0.0035	175	800	0	55	0.0026
12/12/01	13:00	76	0.0039	171	800	0.716	58	0.0027
12/12/01	14:00	76.2	0.0039	135	800	0.891	58	0.0027
12/12/01	15:00	76.1	0.0036	88	800	0.846	58	0.0027
12/12/01	16:00	75.9	0.0036	29	800	0.463	54	0.0027
12/12/01	17:00	75.5	0.0043	4	4615.33	0	50	0.0034
12/12/01	18:00	74.6	0.0049	0	800	0	48	0.0037
12/12/01	19:00	73.7	0.0054	0	800	0	48	0.0042
12/12/01	20:00	72.8	0.0054	0	800	0	47	0.0044
12/12/01	21:00	72.1	0.006	0	800	0	47	0.0048
12/12/01	22:00	71.6	0.0069	0	800	0	46	0.0051
12/12/01	23:00	71	0.0069	0	800	0	44	0.0051

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
12/13/01	0:00	70.8	0.0053	0	800	0	43	0.0053
12/13/01	1:00	70.5	0.0049	0	800	0	41	0.0049
12/13/01	2:00	70.4	0.0073	0	8350.893	0	41	0.0049
12/13/01	3:00	70.4	0.0073	0	9151.736	0	41	0.0049
12/13/01	4:00	70.4	0.0073	0	9451.824	0	41	0.0049
12/13/01	5:00	70.4	0.0073	0	9301.778	0	44	0.0055
12/13/01	6:00	70.4	0.0069	0	8936.848	0	46	0.0055
12/13/01	7:00	70.4	0.0069	6	7852.415	0	48	0.0055
12/13/01	8:00	70.5	0.0076	22	5919.933	0	49	0.0058
12/13/01	9:00	70.7	0.0081	49	800	0	53	0.0063
12/13/01	10:00	71.4	0.0079	71	800	0	56	0.0067
12/13/01	11:00	72.5	0.009	88	800	0	56	0.0072
12/13/01	12:00	73.7	0.0109	72	800	0	58	0.0073
12/13/01	13:00	74.5	0.0087	73	800	0	58	0.0073
12/13/01	14:00	74.9	0.0083	60	800	0	58	0.0073
12/13/01	15:00	75.4	0.0085	27	800	0	55	0.0085
12/13/01	16:00	75.2	0.0103	12	800	0	55	0.0085
12/13/01	17:00	74.8	0.0109	3	800	0	55	0.0091
12/13/01	18:00	74.5	0.0115	0	800	0	55	0.0091
12/13/01	19:00	74.4	0.0085	0	800	0	55	0.0085
12/13/01	20:00	73.9	0.0105	0	800	0	54	0.0087
12/13/01	21:00	73.6	0.0103	0	800	0	55	0.0085
12/13/01	22:00	73.3	0.0097	0	800	0	55	0.0079
12/13/01	23:00	72.8	0.008	0	800	0	53	0.0068
12/14/01	0:00	72.3	0.0073	0	800	0	51	0.0063
12/14/01	1:00	71.6	0.0066	0	800	0	51	0.0058
12/14/01	2:00	71.1	0.0066	0	800	0	51	0.0058
12/14/01	3:00	70.7	0.0061	0	800	0	51	0.0053
12/14/01	4:00	70.5	0.0059	0	800	0	50	0.0051
12/14/01	5:00	70.5	0.0054	0	6377.046	0	50	0.0046
12/14/01	6:00	70.4	0.0043	0	7623.991	0	50	0.0037
12/14/01	7:00	70.4	0.0044	9	7552.793	0	49	0.0037
12/14/01	8:00	70.5	0.0044	35	6028.513	0	49	0.0036
12/14/01	9:00	70.5	0.0045	63	800	0.092	49	0.0036
12/14/01	10:00	70.9	0.0045	75	800	0	49	0.0036
12/14/01	11:00	71.3	0.0043	91	800	0	49	0.0036
12/14/01	12:00	71.9	0.0043	91	800	0	50	0.0034
12/14/01	13:00	72.6	0.0048	85	800	0	51	0.0036
12/14/01	14:00	72.8	0.0067	43	800	0	47	0.0053
12/14/01	15:00	72.2	0.0064	28	800	0	46	0.0055
12/14/01	16:00	71.8	0.0072	14	800	0	45	0.0058
12/14/01	17:00	71.1	0.0068	2	800	0	44	0.0056
12/14/01	18:00	70.5	0.0072	0	800	0	44	0.0060
12/14/01	19:00	70.5	0.0074	0	6695.672	0	44	0.0060
12/14/01	20:00	70.4	0.0074	0	7593.527	0	44	0.0060
12/14/01	21:00	70.4	0.0074	0	8089.165	0	44	0.0060
12/14/01	22:00	70.4	0.0072	0	8169.76	0	45	0.0058
12/14/01	23:00	70.4	0.0081	0	7797.098	0	45	0.0063
12/15/01	0:00	70.4	0.0081	0	7857.142	0	45	0.0063
12/15/01	1:00	70.4	0.0087	0	7453.376	0	45	0.0063
12/15/01	2:00	70.4	0.0081	0	7969.986	0	45	0.0063
12/15/01	3:00	70.4	0.0077	0	8491.104	0	45	0.0063
12/15/01	4:00	70.4	0.0075	0	8330.518	0	46	0.0061
12/15/01	5:00	70.4	0.0079	0	8276.683	0	46	0.0065
12/15/01	6:00	70.4	0.0079	0	8255.42	0	46	0.0065
12/15/01	7:00	70.4	0.0081	8	7279.286	0	47	0.0063
12/15/01	8:00	70.5	0.0082	28	6431.263	0	47	0.0068
12/15/01	9:00	70.5	0.0087	55	800	0.083	49	0.0073
12/15/01	10:00	71.1	0.0094	74	800	0	50	0.0076
12/15/01	11:00	72.1	0.01	94	800	0	52	0.0082
12/15/01	12:00	73.5	0.0088	86	800	0	54	0.0088
12/15/01	13:00	74.3	0.0107	80	800	0	55	0.0092
12/15/01	14:00	74.9	0.0107	66	800	0	54	0.0089
12/15/01	15:00	74.2	0.0094	45	800	0	54	0.0089
12/15/01	16:00	74.5	0.011	17	800	0	55	0.0086
12/15/01	17:00	74.2	0.0101	3	800	0	55	0.0086
12/15/01	18:00	73.7	0.0098	0	800	0	55	0.0086
12/15/01	19:00	73.4	0.0102	0	800	0	56	0.0090
12/15/01	20:00	73	0.0102	0	800	0	57	0.0093
12/15/01	21:00	72.8	0.0098	0	800	0	55	0.0086
12/15/01	22:00	72.6	0.0105	0	800	0	56	0.0090
12/15/01	23:00	72.6	0.0111	0	800	0	58	0.0096

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
12/16/01	0:00	72.5	0.0103	0	800	0	58	0.0091
12/16/01	1:00	72.4	0.0105	0	800	0	57	0.0093
12/16/01	2:00	72.3	0.0102	0	800	0	57	0.0087
12/16/01	3:00	72.4	0.0105	0	800	0	57	0.0087
12/16/01	4:00	72.3	0.011	0	800	0	55	0.0086
12/16/01	5:00	72.4	0.0086	0	800	0	55	0.0086
12/16/01	6:00	72.4	0.0085	0	800	0	53	0.0085
12/16/01	7:00	72.3	0.008	5	800	0	53	0.0080
12/16/01	8:00	73	0.01	45	800	0	60	0.0086
12/16/01	9:00	73.8	0.0106	44	800	0	63	0.0091
12/16/01	10:00	75.6	0.0102	139	800	0	67	0.0094
12/16/01	11:00	76	0.0093	112	800	0.728	70	0.0093
12/16/01	12:00	76.3	0.0092	176	800	1.081	72	0.0102
12/16/01	13:00	76.5	0.0089	172	800	1.234	74	0.0091
12/16/01	14:00	76.7	0.0086	141	800	1.334	74	0.0084
12/16/01	15:00	76.6	0.0084	84	800	1.278	72	0.0076
12/16/01	16:00	76.3	0.0081	30	800	1.02	66	0.0072
12/16/01	17:00	76	0.0082	3	800	0.6	63	0.0073
12/16/01	18:00	75.7	0.0082	0	800	0.274	60	0.0074
12/16/01	19:00	75.1	0.0078	0	800	0	58	0.0073
12/16/01	20:00	74.7	0.0077	0	800	0	55	0.0069
12/16/01	21:00	74.1	0.0079	0	800	0	54	0.0071
12/16/01	22:00	73.6	0.0078	0	800	0	53	0.0068
12/16/01	23:00	73	0.008	0	800	0	52	0.0071
12/17/01	0:00	72.3	0.0076	0	800	0	49	0.0067
12/17/01	1:00	71.7	0.0073	0	800	0	49	0.0063
12/17/01	2:00	71.2	0.0072	0	800	0	49	0.0062
12/17/01	3:00	70.5	0.0067	0	800	0	47	0.0058
12/17/01	4:00	70.4	0.0058	0	8022.315	0	46	0.0051
12/17/01	5:00	70.4	0.0054	0	8072.919	0	45	0.0044
12/17/01	6:00	70.4	0.0049	0	10380.26	0	44	0.0042
12/17/01	7:00	70.4	0.0051	12	7971.342	0	44	0.0042
12/17/01	8:00	70.5	0.0046	56	4397.562	0	48	0.0041
12/17/01	9:00	71.8	0.0043	107	800	0	52	0.0037
12/17/01	10:00	73.5	0.004	152	800	0	55	0.0034
12/17/01	11:00	75.5	0.0044	162	800	0	58	0.0032
12/17/01	12:00	75.9	0.0042	184	800	0.668	60	0.0034
12/17/01	13:00	76.2	0.0041	165	800	0.908	61	0.0032
12/17/01	14:00	76.3	0.0044	136	800	1.042	62	0.0032
12/17/01	15:00	76.2	0.0042	71	800	0.953	62	0.0032
12/17/01	16:00	76	0.0049	32	800	0.614	56	0.0037
12/17/01	17:00	75.8	0.0051	3	800	0.354	48	0.0051
12/17/01	18:00	75.2	0.0073	0	800	0	45	0.0049
12/17/01	19:00	74	0.0063	0	800	0	43	0.0049
12/17/01	20:00	72.9	0.0063	0	800	0	44	0.0051
12/17/01	21:00	72.4	0.006	0	800	0	50	0.0046
12/17/01	22:00	71.9	0.0067	0	800	0	45	0.0049
12/17/01	23:00	71.2	0.0071	0	800	0	43	0.0053
12/18/01	0:00	70.5	0.0069	0	800	0	42	0.0051
12/18/01	1:00	70.5	0.0049	0	5168.494	0	41	0.0049
12/18/01	2:00	70.4	0.0069	0	8342.562	0	42	0.0051
12/18/01	3:00	70.4	0.0068	0	9401.578	0	44	0.0056
12/18/01	4:00	70.4	0.0074	0	8541.977	0	44	0.0056
12/18/01	5:00	70.4	0.007	0	9070.858	0	44	0.0056
12/18/01	6:00	70.4	0.0074	0	8636.336	0	44	0.0056
12/18/01	7:00	70.4	0.0074	10	7346.587	0	46	0.0056
12/18/01	8:00	70.7	0.0076	41	800	0	53	0.0064
12/18/01	9:00	71.8	0.0103	65	800	0	62	0.0093
12/18/01	10:00	73	0.0114	53	800	0	68	0.0104
12/18/01	11:00	74.4	0.0125	72	800	0	70	0.0113
12/18/01	12:00	75.6	0.0124	77	800	0	72	0.0115
12/18/01	13:00	76	0.0107	92	800	0.76	74	0.0125
12/18/01	14:00	76.1	0.0106	70	800	0.948	74	0.0133
12/18/01	15:00	76.1	0.0106	46	800	0.949	74	0.0133
12/18/01	16:00	76	0.0106	20	800	0.821	72	0.0130
12/18/01	17:00	75.9	0.0111	4	800	0.675	70	0.0135
12/18/01	18:00	75.8	0.0116	0	800	0.518	69	0.0137
12/18/01	19:00	75.7	0.0126	0	800	0.397	68	0.0140
12/18/01	20:00	75.7	0.0125	0	800	0.316	67	0.0135
12/18/01	21:00	75.6	0.0129	0	800	0.25	67	0.0134
12/18/01	22:00	75.6	0.0119	0	800	0.257	66	0.0123
12/18/01	23:00	75.6	0.0126	0	800	0.229	66	0.0130

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
12/19/01	0:00	75.6	0.0125	0	800	0.232	67	0.0128
12/19/01	1:00	75.6	0.0122	0	800	0.267	67	0.0128
12/19/01	2:00	75.6	0.0121	0	800	0.286	67	0.0128
12/19/01	3:00	75.6	0.012	0	800	0.291	67	0.0128
12/19/01	4:00	75.6	0.0124	0	800	0.259	66	0.0130
12/19/01	5:00	75.6	0.0127	0	800	0.285	67	0.0135
12/19/01	6:00	75.6	0.0125	0	800	0.303	67	0.0135
12/19/01	7:00	75.6	0.0121	8	800	0.31	66	0.0130
12/19/01	8:00	75.8	0.0119	34	800	0.503	68	0.0140
12/19/01	9:00	75.9	0.0115	54	800	0.725	71	0.0140
12/19/01	10:00	76.1	0.0113	77	800	0.917	71	0.0140
12/19/01	11:00	76.4	0.0105	119	800	1.143	75	0.0138
12/19/01	12:00	76.6	0.0103	143	800	1.381	77	0.0134
12/19/01	13:00	76.8	0.0101	135	800	1.503	79	0.0130
12/19/01	14:00	76.9	0.01	119	800	1.609	81	0.0133
12/19/01	15:00	76.9	0.0099	86	800	1.607	80	0.0127
12/19/01	16:00	76.7	0.0099	33	800	1.392	76	0.0122
12/19/01	17:00	76.4	0.0099	5	800	1.112	74	0.0126
12/19/01	18:00	76.1	0.0105	0	800	0.934	72	0.0131
12/19/01	19:00	76	0.011	0	800	0.742	70	0.0136
12/19/01	20:00	75.9	0.0115	0	800	0.611	69	0.0138
12/19/01	21:00	75.8	0.0125	0	800	0.548	69	0.0145
12/19/01	22:00	75.7	0.013	0	800	0.488	69	0.0145
12/19/01	23:00	75.8	0.013	0	800	0.535	70	0.0151
12/20/01	0:00	75.8	0.0127	0	800	0.494	69	0.0146
12/20/01	1:00	75.8	0.0124	0	800	0.5	69	0.0146
12/20/01	2:00	75.7	0.0129	0	800	0.481	69	0.0146
12/20/01	3:00	75.8	0.0122	0	800	0.491	69	0.0146
12/20/01	4:00	75.7	0.0127	0	800	0.475	69	0.0146
12/20/01	5:00	75.7	0.012	0	800	0.453	69	0.0138
12/20/01	6:00	75.8	0.0115	0	800	0.459	69	0.0138
12/20/01	7:00	75.8	0.0118	10	800	0.491	68	0.0141
12/20/01	8:00	75.8	0.0121	17	800	0.57	70	0.0143
12/20/01	9:00	76	0.0117	56	800	0.856	73	0.0144
12/20/01	10:00	76.1	0.0114	64	800	1.001	74	0.0142
12/20/01	11:00	76.4	0.0113	85	800	1.226	78	0.0140
12/20/01	12:00	76.4	0.0109	71	800	1.202	77	0.0135
12/20/01	13:00	76.4	0.0107	74	800	1.212	76	0.0137
12/20/01	14:00	76.4	0.0107	64	800	1.175	74	0.0142
12/20/01	15:00	76.3	0.0107	43	800	1.138	75	0.0140
12/20/01	16:00	76.3	0.0105	26	800	1.062	74	0.0142
12/20/01	17:00	76.1	0.0103	2	800	0.89	72	0.0139
12/20/01	18:00	75.9	0.0106	0	800	0.688	68	0.0133
12/20/01	19:00	75.8	0.0108	0	800	0.537	67	0.0128
12/20/01	20:00	75.7	0.0094	0	800	0.31	67	0.0088
12/20/01	21:00	75.7	0.0074	0	800	0.248	65	0.0064
12/20/01	22:00	75.6	0.0066	0	800	0.13	61	0.0056
12/20/01	23:00	75.5	0.0048	0	800	0.076	65	0.0042
12/21/01	0:00	75.1	0.0054	0	800	0	60	0.0048
12/21/01	1:00	74.4	0.0051	0	800	0	55	0.0045
12/21/01	2:00	73.7	0.0049	0	800	0	52	0.0042
12/21/01	3:00	73	0.0053	0	800	0	49	0.0045
12/21/01	4:00	72.3	0.0054	0	800	0	47	0.0045
12/21/01	5:00	71.5	0.0049	0	800	0	45	0.0040
12/21/01	6:00	70.8	0.0048	0	800	0	44	0.0038
12/21/01	7:00	70.5	0.0044	11	800	0	43	0.0034
12/21/01	8:00	71	0.004	56	800	0	47	0.0034
12/21/01	9:00	72.7	0.0035	119	800	0	51	0.0028
12/21/01	10:00	74.6	0.0031	162	800	0	54	0.0025
12/21/01	11:00	75.8	0.0032	194	800	0	57	0.0025
12/21/01	12:00	76	0.0031	201	800	0.75	57	0.0024
12/21/01	13:00	76.2	0.0028	185	800	0.875	58	0.0022
12/21/01	14:00	76.2	0.0031	151	800	0.97	59	0.0025
12/21/01	15:00	76.3	0.0033	99	800	0.975	56	0.0024
12/21/01	16:00	76.1	0.004	40	800	0.834	53	0.0026
12/21/01	17:00	75.9	0.0041	6	800	0.477	43	0.0041
12/21/01	18:00	75.5	0.0039	0	800	0.077	40	0.0039
12/21/01	19:00	74.7	0.0038	0	800	0	37	0.0038
12/21/01	20:00	73.6	0.0038	0	800	0	36	0.0038
12/21/01	21:00	72.1	0.0062	0	800	0	33	0.0038
12/21/01	22:00	70.7	0.0054	0	800	0	32	0.0036
12/21/01	23:00	70.4	0.006	0	800	0	32	0.0036

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
12/22/01	0:00	70.4	0.0034	0	8204.772	0	31	0.0034
12/22/01	1:00	70.4	0.0033	0	9785.6	0	29	0.0033
12/22/01	2:00	70.4	0.0034	0	10685.512	0	30	0.0034
12/22/01	3:00	70.3	0.0058	0	13404.992	0	30	0.0034
12/22/01	4:00	70.4	0.0031	0	11782.664	0	28	0.0031
12/22/01	5:00	70.3	0.0055	0	14482.196	0	28	0.0031
12/22/01	6:00	70.3	0.0028	0	12535.787	0	28	0.0028
12/22/01	7:00	70.4	0.0034	15	9156.974	0	30	0.0034
12/22/01	8:00	70.5	0.0063	56	4022.819	0	41	0.0045
12/22/01	9:00	72.1	0.0056	113	800	0	51	0.0044
12/22/01	10:00	73.8	0.004	134	800	0	56	0.0031
12/22/01	11:00	75.6	0.0042	178	800	0	58	0.0030
12/22/01	12:00	76.1	0.0031	146	800	0.844	61	0.0031
12/22/01	13:00	76.2	0.0048	144	800	0.974	62	0.0034
12/22/01	14:00	76.3	0.0046	104	800	0.978	62	0.0034
12/22/01	15:00	76.1	0.0043	59	800	0.803	61	0.0033
12/22/01	16:00	75.9	0.0043	32	800	0.582	57	0.0033
12/22/01	17:00	75.7	0.0048	6	800	0.231	54	0.0038
12/22/01	18:00	75.1	0.0053	0	800	0	48	0.0038
12/22/01	19:00	74.2	0.0057	0	800	0	46	0.0042
12/22/01	20:00	72.9	0.0053	0	800	0	45	0.0045
12/22/01	21:00	72.3	0.0069	0	800	0	43	0.0045
12/22/01	22:00	71.7	0.0074	0	800	0	46	0.0056
12/22/01	23:00	71.2	0.0074	0	800	0	46	0.0056
12/23/01	0:00	70.6	0.0068	0	800	0	48	0.0056
12/23/01	1:00	70.5	0.0072	0	800	0	45	0.0058
12/23/01	2:00	70.5	0.0078	0	6483.867	0	43	0.0054
12/23/01	3:00	70.4	0.009	0	6890.839	0	43	0.0054
12/23/01	4:00	70.5	0.0052	0	6668.172	0	42	0.0052
12/23/01	5:00	70.4	0.0048	0	7485.039	0	40	0.0048
12/23/01	6:00	70.4	0.0068	0	9944.513	0	41	0.0050
12/23/01	7:00	70.4	0.0075	11	8405.367	0	46	0.0061
12/23/01	8:00	70.5	0.0081	35	5016.75	0	49	0.0069
12/23/01	9:00	70.9	0.0092	53	800	0	53	0.0080
12/23/01	10:00	71.7	0.0097	60	800	0	58	0.0085
12/23/01	11:00	73.2	0.0105	96	800	0	65	0.0093
12/23/01	12:00	74.8	0.0107	90	800	0	67	0.0095
12/23/01	13:00	75.7	0.0106	81	800	0	69	0.0097
12/23/01	14:00	75.8	0.0101	60	800	0.534	68	0.0106
12/23/01	15:00	75.9	0.0099	55	800	0.6	68	0.0106
12/23/01	16:00	75.8	0.01	23	800	0.48	65	0.0106
12/23/01	17:00	75.7	0.0104	2	800	0.313	62	0.0107
12/23/01	18:00	75.6	0.0109	0	800	0.21	60	0.0105
12/23/01	19:00	75.4	0.0117	0	4219.553	0	60	0.0105
12/23/01	20:00	75.3	0.0126	0	800	0	59	0.0107
12/23/01	21:00	75.2	0.0126	0	800	0	59	0.0107
12/23/01	22:00	75.1	0.0132	0	800	0	59	0.0107
12/23/01	23:00	75.2	0.0108	0	800	0	59	0.0108
12/24/01	0:00	74.9	0.0118	0	800	0	57	0.0100
12/24/01	1:00	74.5	0.0105	0	800	0	55	0.0093
12/24/01	2:00	73.6	0.0099	0	800	0	55	0.0093
12/24/01	3:00	72.4	0.0072	0	800	0	48	0.0066
12/24/01	4:00	71.9	0.0076	0	800	0	48	0.0066
12/24/01	5:00	71.1	0.0049	0	800	0	47	0.0040
12/24/01	6:00	70.5	0.0045	0	800	0	47	0.0038
12/24/01	7:00	70.5	0.0047	12	4649.334	0	47	0.0038
12/24/01	8:00	70.9	0.0045	57	800	0	49	0.0040
12/24/01	9:00	72.4	0.0047	116	800	0	52	0.0042
12/24/01	10:00	74.2	0.0046	162	800	0	53	0.0040
12/24/01	11:00	75.6	0.0045	191	800	0	56	0.0038
12/24/01	12:00	76	0.0045	198	800	0.712	57	0.0038
12/24/01	13:00	76.1	0.0041	185	800	0.842	59	0.0036
12/24/01	14:00	76.3	0.0043	151	800	1.033	60	0.0034
12/24/01	15:00	76.3	0.0039	100	800	0.997	58	0.0031
12/24/01	16:00	76.2	0.0038	41	800	0.858	56	0.0026
12/24/01	17:00	75.8	0.0056	6	800	0.355	46	0.0038
12/24/01	18:00	75.2	0.0063	0	800	0	40	0.0039
12/24/01	19:00	74.1	0.0062	0	800	0	38	0.0038
12/24/01	20:00	73.3	0.0038	0	800	0	36	0.0038
12/24/01	21:00	71.9	0.0062	0	800	0	35	0.0038
12/24/01	22:00	71.2	0.0036	0	800	0	33	0.0036
12/24/01	23:00	70.5	0.006	0	800	0	33	0.0036

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
12/25/01	0:00	70.4	0.0034	0	8214.295	0	31	0.0034
12/25/01	1:00	70.3	0.0052	0	12566.595	0	30	0.0034
12/25/01	2:00	70.4	0.0034	0	10553.634	0	30	0.0034
12/25/01	3:00	70.4	0.0036	0	11055.502	0	31	0.0036
12/25/01	4:00	70.4	0.0033	0	11596.71	0	30	0.0033
12/25/01	5:00	70.3	0.0052	0	14798.344	0	30	0.0034
12/25/01	6:00	70.3	0.0052	0	14554.914	0	32	0.0034
12/25/01	7:00	70.4	0.0046	14	12079.848	0	37	0.0036
12/25/01	8:00	70.5	0.005	61	4511.188	0	43	0.0041
12/25/01	9:00	71.9	0.0045	120	800	0	52	0.0038
12/25/01	10:00	73.8	0.0051	166	800	0	57	0.0045
12/25/01	11:00	75.6	0.0055	194	800	0	62	0.0049
12/25/01	12:00	76	0.0056	201	800	0.751	64	0.0049
12/25/01	13:00	76.2	0.0066	167	800	0.971	65	0.0058
12/25/01	14:00	76.4	0.0068	140	800	1.065	66	0.0061
12/25/01	15:00	76.3	0.0072	101	800	1.025	64	0.0066
12/25/01	16:00	76.1	0.0075	43	800	0.826	60	0.0069
12/25/01	17:00	75.8	0.0078	8	800	0.409	57	0.0071
12/25/01	18:00	75.5	0.0077	0	800	0.097	54	0.0067
12/25/01	19:00	74.9	0.0079	0	800	0	53	0.0069
12/25/01	20:00	74.2	0.0074	0	800	0	51	0.0064
12/25/01	21:00	73.3	0.0077	0	800	0	49	0.0068
12/25/01	22:00	72.7	0.0083	0	800	0	50	0.0071
12/25/01	23:00	72.1	0.008	0	800	0	49	0.0068
12/26/01	0:00	71.5	0.0078	0	800	0	48	0.0066
12/26/01	1:00	71	0.0077	0	800	0	47	0.0063
12/26/01	2:00	70.5	0.0077	0	800	0	47	0.0063
12/26/01	3:00	70.5	0.009	0	800	0	46	0.0066
12/26/01	4:00	70.5	0.008	0	6397.834	0	48	0.0066
12/26/01	5:00	70.5	0.0085	0	6175.353	0	50	0.0071
12/26/01	6:00	70.5	0.0083	0	6441.474	0	50	0.0071
12/26/01	7:00	70.5	0.0086	9	5372.951	0	53	0.0074
12/26/01	8:00	71.2	0.0093	44	800	0	55	0.0081
12/26/01	9:00	72.4	0.0091	67	800	0	61	0.0083
12/26/01	10:00	74.5	0.0096	123	800	0	67	0.0088
12/26/01	11:00	75.7	0.0092	115	800	0	68	0.0085
12/26/01	12:00	76	0.0089	112	800	0.746	69	0.0089
12/26/01	13:00	76.1	0.0091	93	800	0.854	68	0.0098
12/26/01	14:00	76.1	0.0091	74	800	0.855	68	0.0098
12/26/01	15:00	76	0.0091	36	800	0.729	67	0.0094
12/26/01	16:00	75.9	0.0091	14	800	0.559	65	0.0092
12/26/01	17:00	75.8	0.0094	3	800	0.422	64	0.0095
12/26/01	18:00	75.7	0.0098	0	800	0.273	61	0.0095
12/26/01	19:00	75.5	0.0107	0	800	0.118	60	0.0098
12/26/01	20:00	75.3	0.0091	0	800	0	59	0.0082
12/26/01	21:00	74.6	0.0074	0	800	0	56	0.0067
12/26/01	22:00	74	0.0074	0	800	0	54	0.0067
12/26/01	23:00	73.6	0.007	0	800	0	54	0.0062
12/27/01	0:00	73.4	0.0068	0	800	0	54	0.0056
12/27/01	1:00	72.8	0.006	0	800	0	52	0.0051
12/27/01	2:00	72.3	0.0063	0	800	0	51	0.0054
12/27/01	3:00	71.8	0.0057	0	800	0	51	0.0049
12/27/01	4:00	71.5	0.0057	0	800	0	50	0.0047
12/27/01	5:00	71	0.0053	0	800	0	49	0.0044
12/27/01	6:00	70.5	0.0045	0	800	0	47	0.0036
12/27/01	7:00	70.5	0.0043	7	6383.614	0	47	0.0034
12/27/01	8:00	70.5	0.0041	24	6228.902	0	48	0.0033
12/27/01	9:00	70.5	0.0042	46	4179.996	0	51	0.0034
12/27/01	10:00	71	0.0043	63	800	0	53	0.0034
12/27/01	11:00	71.8	0.0043	92	800	0	53	0.0034
12/27/01	12:00	72.7	0.0046	105	800	0	55	0.0038
12/27/01	13:00	74.2	0.0045	154	800	0	58	0.0038
12/27/01	14:00	75.1	0.0047	74	800	0	58	0.0038
12/27/01	15:00	75.5	0.0048	55	800	0	59	0.0040
12/27/01	16:00	75.4	0.005	23	800	0	55	0.0040
12/27/01	17:00	74.9	0.0052	3	800	0	54	0.0042
12/27/01	18:00	74.3	0.0052	0	800	0	53	0.0040
12/27/01	19:00	73.7	0.006	0	800	0	48	0.0042
12/27/01	20:00	72.7	0.0057	0	800	0	45	0.0045
12/27/01	21:00	71.8	0.005	0	800	0	46	0.0038
12/27/01	22:00	71.2	0.0056	0	800	0	44	0.0038
12/27/01	23:00	70.5	0.0056	0	800	0	42	0.0038

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
12/28/01	0:00	70.5	0.0041	0	5675.512	0	39	0.0041
12/28/01	1:00	70.4	0.0059	0	9422.43	0	39	0.0041
12/28/01	2:00	70.4	0.0054	0	10959.334	0	38	0.0040
12/28/01	3:00	70.4	0.0054	0	11437.661	0	38	0.0040
12/28/01	4:00	70.3	0.005	0	12551.942	0	37	0.0038
12/28/01	5:00	70.3	0.005	0	12860.836	0	37	0.0038
12/28/01	6:00	70.3	0.0052	0	12727.89	0	36	0.0038
12/28/01	7:00	70.4	0.005	13	11116.125	0	41	0.0041
12/28/01	8:00	70.5	0.0052	57	5020.141	0	45	0.0045
12/28/01	9:00	71.5	0.006	87	800	0	52	0.0052
12/28/01	10:00	72	0.0065	53	800	0	54	0.0057
12/28/01	11:00	73.3	0.0074	123	800	0	59	0.0066
12/28/01	12:00	74.4	0.0079	110	800	0	63	0.0073
12/28/01	13:00	75.6	0.0079	109	800	0	66	0.0072
12/28/01	14:00	75.7	0.0083	74	800	0.37	64	0.0077
12/28/01	15:00	75.7	0.0084	42	800	0.34	63	0.0079
12/28/01	16:00	75.5	0.0086	23	800	0.112	60	0.0081
12/28/01	17:00	75.2	0.0089	5	800	0	59	0.0083
12/28/01	18:00	74.7	0.008	0	800	0	58	0.0074
12/28/01	19:00	74.1	0.008	0	800	0	58	0.0074
12/28/01	20:00	73.6	0.009	0	800	0	56	0.0084
12/28/01	21:00	72.8	0.0086	0	800	0	55	0.0081
12/28/01	22:00	72.5	0.0093	0	800	0	55	0.0086
12/28/01	23:00	72.1	0.009	0	800	0	56	0.0084
12/29/01	0:00	71.9	0.0091	0	800	0	56	0.0084
12/29/01	1:00	71.7	0.0093	0	800	0	57	0.0087
12/29/01	2:00	71.3	0.0095	0	800	0	56	0.0090
12/29/01	3:00	71.2	0.0097	0	800	0	56	0.0090
12/29/01	4:00	70.9	0.0101	0	800	0	56	0.0096
12/29/01	5:00	70.9	0.0103	0	800	0	56	0.0096
12/29/01	6:00	70.8	0.0109	0	800	0	58	0.0103
12/29/01	7:00	71	0.0114	4	800	0	59	0.0107
12/29/01	8:00	71.3	0.0122	13	800	0	61	0.0115
12/29/01	9:00	72.1	0.0127	45	800	0	64	0.0121
12/29/01	10:00	72.8	0.013	43	800	0	65	0.0125
12/29/01	11:00	73.6	0.0132	47	800	0	65	0.0126
12/29/01	12:00	74.2	0.0128	53	800	0	66	0.0123
12/29/01	13:00	75.2	0.0145	49	800	0	66	0.0130
12/29/01	14:00	75.7	0.0148	43	800	0	66	0.0130
12/29/01	15:00	75.8	0.0116	31	800	0.424	66	0.0130
12/29/01	16:00	75.8	0.0109	22	800	0.459	66	0.0130
12/29/01	17:00	75.7	0.0117	3	800	0.373	65	0.0133
12/29/01	18:00	75.6	0.0122	0	800	0.295	65	0.0133
12/29/01	19:00	75.6	0.0122	0	800	0.267	66	0.0130
12/29/01	20:00	75.6	0.013	0	800	0.251	66	0.0137
12/29/01	21:00	75.6	0.0127	0	800	0.218	66	0.0130
12/29/01	22:00	75.6	0.0125	0	800	0.184	65	0.0125
12/29/01	23:00	75.6	0.0124	0	800	0.162	64	0.0121
12/30/01	0:00	75.6	0.0122	0	800	0.19	64	0.0121
12/30/01	1:00	75.6	0.012	0	800	0.204	64	0.0120
12/30/01	2:00	75.6	0.012	0	800	0.203	64	0.0121
12/30/01	3:00	75.6	0.012	0	800	0.202	64	0.0121
12/30/01	4:00	75.6	0.0122	0	800	0.182	64	0.0121
12/30/01	5:00	75.5	0.0122	0	800	0.157	63	0.0117
12/30/01	6:00	75.5	0.0122	0	800	0.146	63	0.0116
12/30/01	7:00	75.5	0.0122	7	800	0.121	63	0.0116
12/30/01	8:00	75.6	0.0116	26	800	0.268	64	0.0121
12/30/01	9:00	75.8	0.011	51	800	0.461	65	0.0125
12/30/01	10:00	75.9	0.0106	70	800	0.625	65	0.0125
12/30/01	11:00	76.1	0.0099	93	800	0.842	66	0.0130
12/30/01	12:00	76.1	0.01	58	800	0.94	68	0.0140
12/30/01	13:00	76.2	0.01	90	800	1.032	70	0.0142
12/30/01	14:00	76.3	0.0099	67	800	1.051	70	0.0142
12/30/01	15:00	76.2	0.0106	51	800	1.043	69	0.0145
12/30/01	16:00	76.1	0.0104	21	800	0.894	69	0.0145
12/30/01	17:00	76	0.0108	5	800	0.765	69	0.0145
12/30/01	18:00	75.9	0.011	0	800	0.622	68	0.0140
12/30/01	19:00	75.7	0.0104	0	800	0.293	60	0.0104
12/30/01	20:00	75.6	0.0108	0	800	0.263	60	0.0110
12/30/01	21:00	75.6	0.0115	0	800	0.24	62	0.0119
12/30/01	22:00	75.7	0.0106	0	800	0.285	62	0.0119
12/30/01	23:00	75.6	0.0118	0	800	0.181	61	0.0115

Date	Time	Indoor Tdb (F)	Indoor W (lbw/lbda)	GBH (Btu/ft²)	Heating Power (Btu/hr)	Cooling Power (kW)	Outdoor Tdb (F)	Outdoor W (lbw/lbda)
12/31/01	0:00	75.5	0.0121	0	800	0.078	59	0.0107
12/31/01	1:00	74.9	0.0098	0	800	0	54	0.0089
12/31/01	2:00	74.6	0.0097	0	800	0	52	0.0082
12/31/01	3:00	74.1	0.0094	0	800	0	51	0.0079
12/31/01	4:00	73.8	0.0095	0	800	0	50	0.0077
12/31/01	5:00	73.2	0.0089	0	800	0	50	0.0077
12/31/01	6:00	72.1	0.0073	0	800	0	46	0.0066
12/31/01	7:00	70.4	0.0057	4	800	0	41	0.0054
12/31/01	8:00	70.5	0.0068	16	4961.597	0	42	0.0056
12/31/01	9:00	70.6	0.0084	34	800	0	46	0.0066
12/31/01	10:00	70.8	0.0075	45	800	0	47	0.0063
12/31/01	11:00	71.3	0.0075	95	800	0	48	0.0066
12/31/01	12:00	71.4	0.0075	52	800	0	46	0.0066
12/31/01	13:00	71.3	0.007	52	800	0	44	0.0061
12/31/01	14:00	71.1	0.0065	72	800	0	43	0.0058
12/31/01	15:00	70.7	0.0066	30	800	0	43	0.0058
12/31/01	16:00	70.4	0.0063	14	800	0	42	0.0056
12/31/01	17:00	70.4	0.0061	3	9293.478	0	41	0.0054
12/31/01	18:00	70.4	0.0059	0	10977.076	0	40	0.0052
12/31/01	19:00	70.4	0.0057	0	12158.379	0	39	0.0050
12/31/01	20:00	70.3	0.0057	0	12762.289	0	39	0.0050
12/31/01	21:00	70.3	0.0053	0	15628.193	0	38	0.0048
12/31/01	22:00	70.3	0.0053	0	14770.743	0	37	0.0046
12/31/01	23:00	70.3	0.0053	0	13603.497	0	36	0.0044

B.3 DOE-2 BEPS REPORTS

The Building Energy Performance Summary (BEPS) reports of the prototype models in Section 5.2 are presented:

B.3.1 Lightweight (Base Case)

B.3.1.1 Lightweight (base case): Bangkok (Thailand)

ENERGY TYPE:	ELECTRICITY	NATURAL-GAS
UNITS: MBTU		
CATEGORY OF USE	-----------	-----------
AREA LIGHTS	13.2	0.0
MISC EQUIPMT	13.2	0.0
SPACE HEAT	0.0	7.0
SPACE COOL	42.3	0.0
HEAT REJECT	6.0	0.0
PUMPS & MISC	2.7	0.0
VENT FANS	23.4	0.0
DOMHOT WATER	0.0	8.2
	-----------	-----------
TOTAL	100.8	15.2

B.3.1.2 Lightweight (base case): Houston (Texas)

ENERGY TYPE:	ELECTRICITY	NATURAL-GAS
UNITS: MBTU		
CATEGORY OF USE	-----------	-----------
AREA LIGHTS	13.2	0.0
MISC EQUIPMT	13.2	0.0
SPACE HEAT	0.0	14.6
SPACE COOL	25.3	0.0
HEAT REJECT	4.4	0.0
PUMPS & MISC	2.4	0.0
VENT FANS	23.4	0.0
DOMHOT WATER	0.0	11.6
	-----------	-----------
TOTAL	81.9	26.2

B.3.1.3 Lightweight (base case): San Francisco (California)

ENERGY TYPE:	ELECTRICITY	NATURAL-GAS
UNITS: MBTU		
CATEGORY OF USE	-----------	-----------
AREA LIGHTS	13.2	0.0
MISC EQUIPMT	13.2	0.0
SPACE HEAT	0.0	31.5
SPACE COOL	1.7	0.0
HEAT REJECT	0.3	0.0
PUMPS & MISC	0.2	0.0
VENT FANS	23.4	0.0
DOMHOT WATER	0.0	14.4
	-----------	-----------
TOTAL	52.0	45.9

B.3.1.4 Lightweight (base case): Phoenix (Arizona)

ENERGY TYPE:	ELECTRICITY	NATURAL-GAS
UNITS: MBTU		
CATEGORY OF USE	-----------	-----------
AREA LIGHTS	13.2	0.0
MISC EQUIPMT	13.2	0.0
SPACE HEAT	0.0	8.2
SPACE COOL	25.6	0.0
HEAT REJECT	3.6	0.0
PUMPS & MISC	2.2	0.0
VENT FANS	23.4	0.0
DOMHOT WATER	0.0	10.6
	-----------	-----------
TOTAL	81.2	18.8

B.3.1.5 Lightweight (base case): Chicago (Illinois)

ENERGY TYPE:	ELECTRICITY	NATURAL-GAS
UNITS: MBTU		
CATEGORY OF USE	-----------	-----------
AREA LIGHTS	13.2	0.0
MISC EQUIPMT	13.2	0.0
SPACE HEAT	0.0	100.6
SPACE COOL	6.0	0.0
HEAT REJECT	1.0	0.0
PUMPS & MISC	0.6	0.0
VENT FANS	23.4	0.0
DOMHOT WATER	0.0	15.8
	-----------	-----------
TOTAL	57.4	116.4

B.3.1.6 Lightweight (base case): Boston (Massachusetts)

ENERGY TYPE:	ELECTRICITY	NATURAL-GAS
UNITS: MBTU		
CATEGORY OF USE	-----------	-----------
AREA LIGHTS	13.2	0.0
MISC EQUIPMT	13.2	0.0
SPACE HEAT	0.0	102.9
SPACE COOL	4.8	0.0
HEAT REJECT	0.8	0.0
PUMPS & MISC	0.5	0.0
VENT FANS	23.4	0.0
DOMHOT WATER	0.0	15.6
	-----------	-----------
TOTAL	55.9	118.5

B.3.1.5 Lightweight (base case): Boise (Idaho)

ENERGY TYPE:	ELECTRICITY	NATURAL-GAS
UNITS: MBTU		
CATEGORY OF USE	-----------	-----------
AREA LIGHTS	13.2	0.0
MISC EQUIPMT	13.2	0.0
SPACE HEAT	0.0	76.2
SPACE COOL	5.7	0.0
HEAT REJECT	0.8	0.0
PUMPS & MISC	0.5	0.0
VENT FANS	23.4	0.0
DOMHOT WATER	0.0	15.6
	-----------	-----------
TOTAL	56.8	91.8

B.3.2 Lightweight without Internal Loads

B.3.2.1 Lightweight without internal load: Houston (Texas)

ENERGY TYPE:	ELECTRICITY	NATURAL-GAS
UNITS: MBTU		
CATEGORY OF USE	-----------	-----------
AREA LIGHTS	0.0	0.0
MISC EQUIPMT	0.0	0.0
SPACE HEAT	0.0	23.3
SPACE COOL	17.0	0.0
HEAT REJECT	3.1	0.0
PUMPS & MISC	1.7	0.0
VENT FANS	23.4	0.0
DOMHOT WATER	0.0	11.6
	-----------	-----------
TOTAL	45.2	34.9

B.3.3 High Thermal Mass

B.3.3.1 High thermal mass: Houston (Texas)

ENERGY TYPE:	ELECTRICITY	NATURAL-GAS
UNITS: MBTU		
CATEGORY OF USE	-----------	-----------
AREA LIGHTS	13.2	0.0
MISC EQUIPMT	13.2	0.0
SPACE HEAT	0.0	13.8
SPACE COOL	20.5	0.0
HEAT REJECT	3.3	0.0
PUMPS & MISC	1.8	0.0
VENT FANS	23.4	0.0
DOMHOT WATER	0.0	11.6
	-----------	-----------
TOTAL	75.4	25.4

B.3.3.2 High thermal mass: Phoenix (Arizona)

ENERGY TYPE:	ELECTRICITY	NATURAL-GAS
UNITS: MBTU		
CATEGORY OF USE	-----------	-----------
AREA LIGHTS	13.2	0.0
MISC EQUIPMT	13.2	0.0
SPACE HEAT	0.0	8.0
SPACE COOL	25.9	0.0
HEAT REJECT	3.7	0.0
PUMPS & MISC	2.2	0.0
VENT FANS	23.4	0.0
DOMHOT WATER	0.0	10.6
	-----------	-----------
TOTAL	81.6	18.6

B.3.4 Lightweight with an Economizer

B.3.4.1 Lightweight with an economizer: Houston (Texas)

ENERGY TYPE:	ELECTRICITY	NATURAL-GAS
UNITS: MBTU		
CATEGORY OF USE	-----------	-----------
AREA LIGHTS	13.2	0.0
MISC EQUIPMT	13.2	0.0
SPACE HEAT	0.0	16.7
SPACE COOL	25.2	0.0
HEAT REJECT	4.1	0.0
PUMPS & MISC	2.2	0.0
VENT FANS	23.4	0.0
DOMHOT WATER	0.0	11.6
	-----------	-----------
TOTAL	81.3	28.3

B.3.4.2 Lightweight with an economizer: San Francisco (California)

ENERGY TYPE:	ELECTRICITY	NATURAL-GAS
UNITS: MBTU		
CATEGORY OF USE	-----------	-----------
AREA LIGHTS	13.2	0.0
MISC EQUIPMT	13.2	0.0
SPACE HEAT	0.0	36.3
SPACE COOL	1.3	0.0
HEAT REJECT	0.2	0.0
PUMPS & MISC	0.1	0.0
VENT FANS	23.4	0.0
DOMHOT WATER	0.0	14.4
	-----------	-----------
TOTAL	51.4	50.7

APPENDIX C

BIOCLIMATIC ANALYSIS CHARTS

A psychrometric chart was developed and used in this study to display the thermal properties of weather data as well as other corresponding data points. In order to evaluate indoor comfort conditions and to verify the Givoni-Milne bioclimatic chart (1979), the ASHRAE comfort chart (1992), and the G-M design strategy boundaries (1979) were combined onto the psychrometric chart using the Microsoft Excel spreadsheet package (Microsoft Office, 2003). The equations used to develop each variable in this study were described in Section 4.3.1.1. Appendix C.1 through C.3 show the data spreadsheets used to develop the psychrometric chart, the ASHRAE comfort zone (1992), and the design strategy boundaries of the G-M bioclimatic chart (1979).

C.1 DATA SPREADSHEETS FOR THE PSYCHROMETRIC CHART

	B	C	D	E	F
3	Tdb	20	25	30	35
4	R	480	485	490	495
5	K	3.340513	3.334906	3.329388	3.323959
6	Psat	0.054552	0.067346	0.082739	0.101174
7	Elev., H (ft) =		108		P =
8	0.1	0.000232	0.000286	0.000352	0.000430
9	0.2	0.000464	0.000573	0.000704	0.000861
10	0.3	0.000696	0.000860	0.001056	0.001292
11	0.4	0.000928	0.001147	0.001409	0.001724
12	0.5	0.001161	0.001434	0.001763	0.002157
13	0.6	0.001394	0.001721	0.002116	0.002590
14	0.7	0.001627	0.002009	0.002470	0.003023
15	0.8	0.001860	0.002297	0.002825	0.003458
16	0.9	0.002093	0.002586	0.003180	0.003893
17	1	0.002326	0.002874	0.003535	0.004328

Q	R	S	T	U
90	95	100	105	110
550	555	560	565	570
3.269901	3.265484	3.261148	3.256890	3.252712
0.705240	0.823439	0.958426	1.112135	1.286668
0.003011	0.003518	0.004099	0.004761	0.005515
0.006051	0.007076	0.008252	0.009595	0.011128
0.009120	0.010675	0.012460	0.014505	0.016843
0.012220	0.014315	0.016725	0.019491	0.022662
0.015350	0.017998	0.021048	0.024557	0.028587
0.018512	0.021723	0.025429	0.029702	0.034623
0.021705	0.025492	0.029871	0.034931	0.040772
0.024930	0.029305	0.034374	0.040244	0.047037
0.028187	0.033163	0.038940	0.045643	0.053422
0.031478	0.037068	0.043570	0.051132	0.059929

Figure C.1 *The data spreadsheet used to calculate and create relative humidity ratio lines of a psychrometric chart for the hot-humid climate, Houston, Texas.*

Dry Bulb Lines		Wet Bulb Lines		Humidity Ratio Lines	
Tdb	W	Tdb	W	Tdb	W
20	0.002326	**20**	0.002326	**38.95**	0.005000
20	0	**30.49**	0	**110**	0.005000
25	0.002874	**25**	0.002874	**57.23**	0.010000
25	0	**37.92**	0	**110**	0.010000
30	0.003535	**30**	0.003535	**68.50**	0.015000
30	0	**45.85**	0	**110**	0.015000
35	0.004328	**35**	0.004328	**76.77**	0.020000
35	0	**54.36**	0	**110**	0.020000
40	0.005277	**40**	0.005277	**83.34**	0.025000
40	0	**63.54**	0	**110**	0.025000
45	0.006406	**45**	0.006406	**88.80**	0.030000
45	0	**73.51**	0	**110**	0.030000
50	0.007747	**50**	0.007747		
50	0	**84.39**	0		
55	0.009334	**55**	0.009334		
55	0	**96.32**	0		
60	0.011206	**60**	0.011206		
60	0	**109.48**	0		
65	0.013408	**65**	0.013408		
65	0	**124.04**	0		
70	0.015992	**70**	0.015992		
70	0	**140.24**	0		
75	0.019017	**75**	0.019017		
75	0	**158.30**	0		
80	0.022551	**80**	0.022551		
80	0	**178.52**	0		
85	0.026674	**85**	0.026674		
85	0	**201.23**	0		
90	0.030000	**88.971**	0.030099		
90	0	**226.79**	0		
95	0.030000	**95**	0.037068		
95	0	**255.65**	0		
100	0.030000	**100**	0.043570		
100	0	**288.33**	0		
105	0.030000	**105**	0.051132		
105	0	**325.43**	0		
110	0.030000	**110**	0.059929		
110	0	**367.66**	0		

Figure C.2 *The data spreadsheet used to create dry-bulb temperature, wet-bulb temperature, and humidity ratio lines of a psychrometric chart for the hot-humid climate, Houston, Texas.*

Specific Volumn Lines						
V	12.5		13.0		15.0	
	W	Tdb	W	Tdb	W	Td
	0.000000	34.3	0.000000	54.1	0.025232	110.0
	0.003736	31.4	0.007228	48.2	0.030000	105.8

Figure C.3 *The data spreadsheet used to create specific volume lines of a psychrometric chart for the hot-humid climate, Houston, Texas.*

A psychrometric chart is plotted as an x-y plot where the x axis represents the dry-bulb temperature (*Tdb*) and the y axis represents the humidity ratio (*W*). Figure C.1 shows a dataspread sheet in USCS (U.S. Customary System or IP) units, which was used to calculate humidity ratio values for any given dry-bulb temperature and its corresponding relative humidity. The data from the calculation would then be used to create relative humidity lines as well as dry-bulb temperature lines, web bulb temperature lines, and humidity ratio lines (Figure C.2) of a psychometric chart for the normal temperature range (Houston, Texas). Figure C.3 shows a data spreadsheet used to create the specific volume lines of the psychrometric chart. The dry-bulb temperature and its corresponding humidity ratio at each specific volume value were calculated and plotted onto the psychrometirc chart. (see equations in Section 4.3.1.1).

Since the atmospheric pressure affects the properties of the air and the atmospheric pressure changes as the altitude of a location changes. Therefore, a psychrometric chart for the locations with different altitudes was also developed using equations, which were described in the Section 4.3.1.1. The data from the calculations used for drawing each line of the psychrometric chart (i.e., dry-bulb temperature, wet-bulb temperature, humidity ratio, relative humidity, and specific volume lines), as well as the ASHRAE comfort zone (1992), and the Givoni-Milne bioclimatic design strategy boundaries (1979), were then adjusted as the altitude of each location changed.

C.2 DATA SPREADSHEET FOR THE ASHRAE COMFORT CHART (1992)

The ASHRAE comfort zone (1992), which was used to evaluate indoor comfort conditions in this research, was overlaid onto the psychrometric chart. Figure C.4 shows the data spreadsheet used to develop the ASHRAE comfort zone. The coordinates of the ASHRAE comfort zone (1992) were defined in Section 4.3.1.2.

ASHRAE's Comfort Zone									
Point	1	2	3	4	5	6	7	8	1
Tdb	69	74	76	81.0	78.2	74	73.05	68.0	69
R					538.2	534	533.05	528.00	529
K					3.280646	3.284580	3.285478	3.290302	3.289340
Psat					0.482909	0.420074	0.406894	0.342719	0.354673
RH					0.60	0.60	0.60	0.60	
W	0.00454	0.00454	0.00454	0.00454	0.01256	0.01090	0.01055	0.00886	0.00454

Figure C.4 *The data spreadsheet used to draw the ASHRAE comfort chart (1992).*

Active Solar		
Point	A	B
Tdb	35	35
W	0.000000	0.004328

Passive Solar		
Point	A	B
Tdb	44.5	44.5
W	0.000000	0.006284

Givoni's Comfort Zone						
Point	A	B	C	D	E	A
Tdb	68	68	80	80	75	68
W	0.011825	0.002915	0.004367	0.011033	0.015063	0.011825

High Thermal Mass								
Point	B	C	D	E	F	G	H	B
Tdb	68	80	80	75	92	96	96	68
W	0.002915	0.004367	0.011033	0.015063	0.014965673	0.010971	0.002915	0.002915

High Thermal Mass with Nighttime Ventilation							
Point	F	G	H	I	J	K	F
Tdb	92	96	96	110	110	106	92
W	0.01496567	0.010971	0.002915	0.002915	0.011086	0.014965673	0.014965673

Ventilation											
Point	C	D	E	A	L	M1	M2	M3	N	O	C
Tdb	80	80	75	68	68	70	75	81	90	90.0	80
W	0.004367	0.011033	0.015063	0.011825	0.014852	0.015930446	0.018943431	0.023235	0.015291	0.006028	0.004367

Evaporative Cooling									
Point	B	C	D	E	P	Q	R	S	B
Tdb	68	80	80	75	100	105	105	80	68
W	0.002915	0.004367	0.011033	0.015063	0.009472	0.005700225	0.000000	0.000000	0.002915

Figure C.5 *The data spreadsheet used to delineate the design strategy boundaries of the Givoni-Milne bioclimatic chart (1979).*

C.3 DATA SPREADSHEET FOR THE GIVONI_MILNE BIOCLIMATIC CHART (1979)

The Givoni-Milne bioclimatic chart (1979), which has been verified in this study, was also overlaid onto the psychrometric chart. The “Climatic Design” by Watson and Labs (1983, p. 206; see Figure 2.10 and Table 2.1) contains the detailed description for drawing the design strategy boundaries of the G-M chart (1979) used in this research.

Figure C.5 shows a spreadsheet used to delineate the design strategy boundaries of the G-M Chart (1979). The design strategies in the chart include: conventional heating, active solar, passive solar, internal gains, humidification, comfort zone, dehumidification, ventilation, evaporative cooling, high thermal mass, high thermal mass with night ventilation, air-conditioning, and air-conditioning with conventional dehumidification (see Equations 4.1 through 4.12, Section 4.3.1.1) The detailed descriptions used for overlaying each design strategy region onto the chart were described in the Section 4.3.1.3.

APPENDIX D

THE DOE-2 SIMULATION BASE-CASE RESULTS

D.1 LIGHTWEIGHT (BASE CASE): VERY HOT-HUMID CLIMATE (BANGKOK, THAILAND)

The results of the lightweight house (base case) in the representative very hot-humid climate of Bangkok, Thailand, are presented in Figure D.1 and D.2. In a similar fashion as Figures 5.16 and 5.17, Figure D.1 consists of three plots and a bar chart (Figures D.1a through D.1d). Figure D.2 consists of three plots and a table (Figures D.2a through D.2d).

Figure D.1a shows a significant narrow range of the outdoor temperatures for one year of data, which is in the temperature range of 60 to 100 °F. The range of the outdoor temperatures during mid of May through mid of November, in the range of 75 to 95 °F; are narrower than the outdoor temperatures range during the other periods of the year. The outdoor temperatures are higher during March through mid of May and lower during mid of November through February. As expected, the cooling system is continuously activated for the whole year. This results in the indoor temperature being very well maintained near the cooling temperature setpoint (78 °F). The cooling energy use for the lightweight house (base case) in Bangkok is significantly large and occurs for the whole year. With the exception of the constant heating load of the energy used by a pilot light, which is shown in red line at the bottom part of the figure, there is no heating energy used for space heating in any periods of the year.

Figure D.1b shows variation of the outdoor relative humidity for one year of data, which is mostly in the range of 40 to 100%. There is a small portion of the time during February through April and in December when the outdoor relative humidity goes below 40% relative humidity. The indoor relative humidity for the whole year is well maintained between 40 to 60% range.

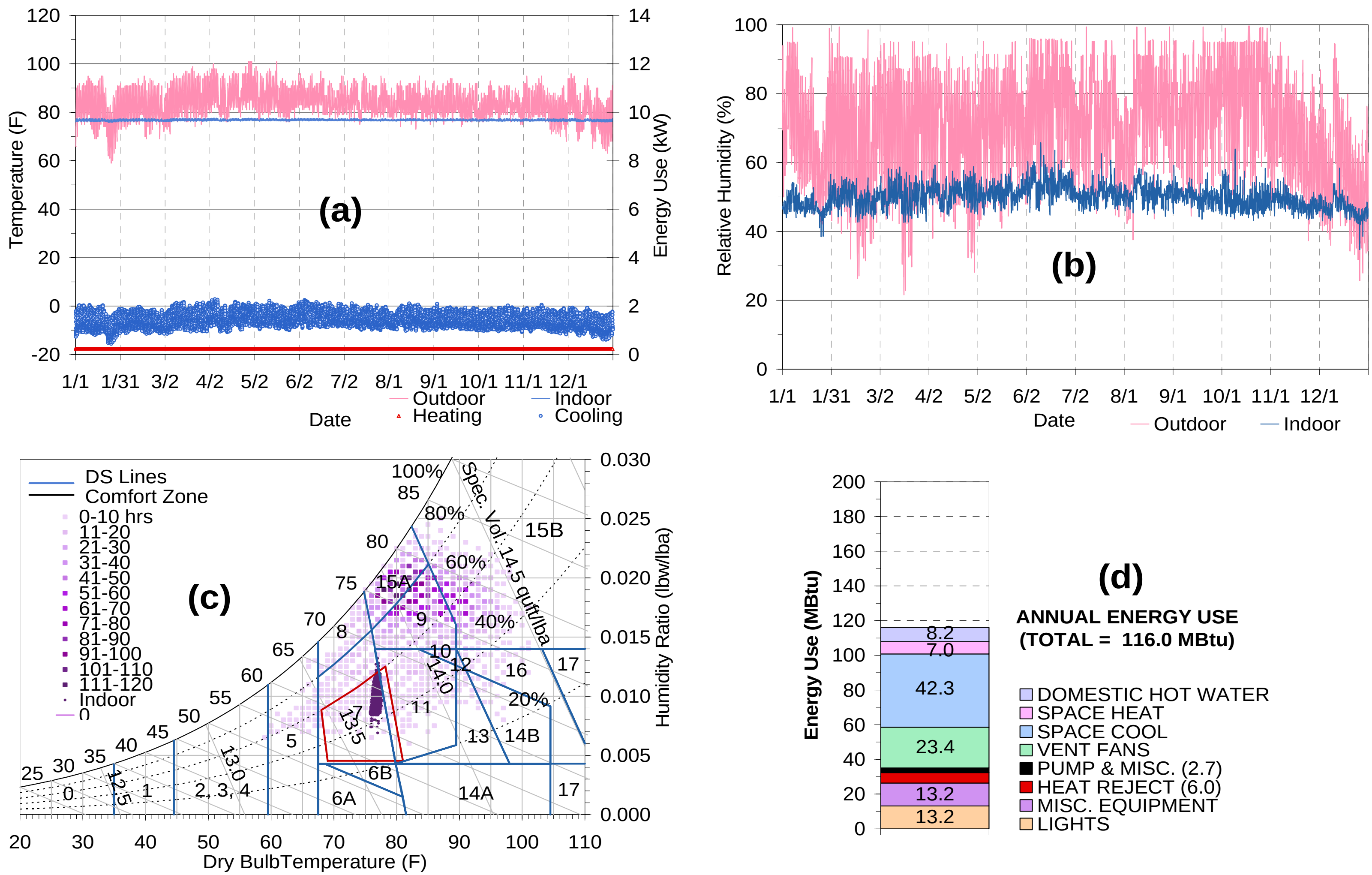
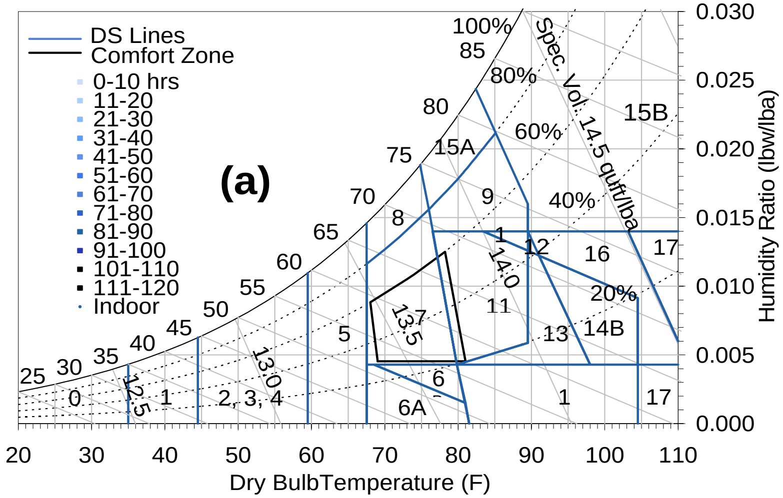
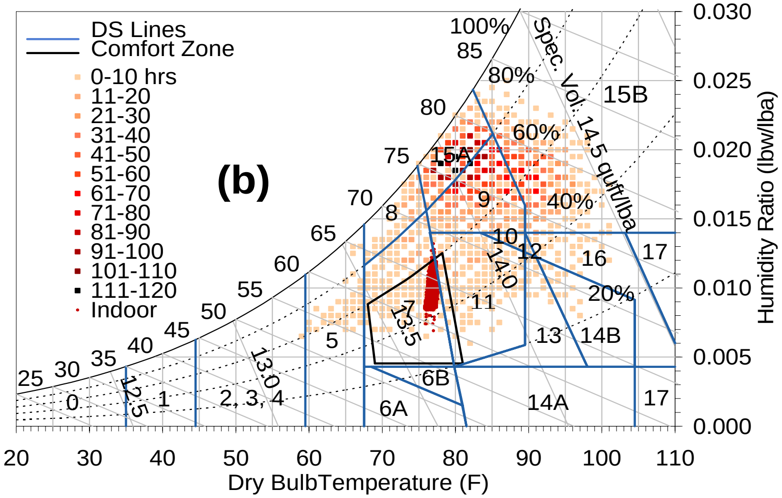
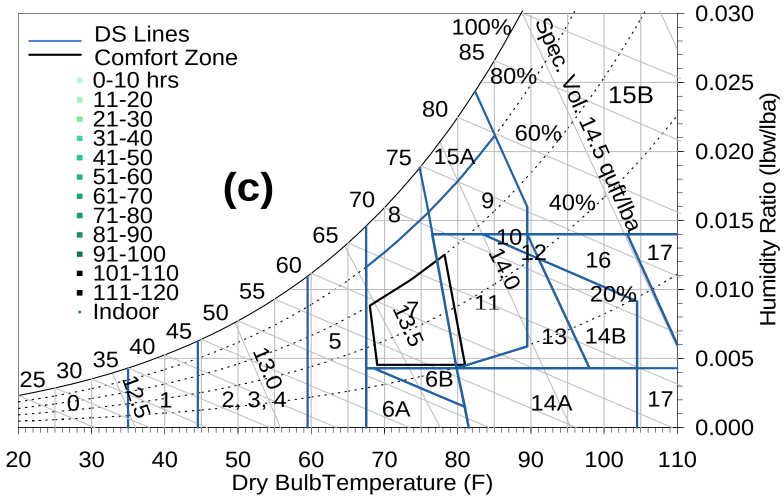


Figure D.1 *Annual hourly indoor and outdoor conditions and energy use of the lightweight house (base case) in the very hot-humid climate, Bangkok, Thailand. (a) Indoor and outdoor dry-bulb temperatures and energy use of gas and electricity, (b) Indoor and outdoor relative humidity, (c) Indoor and outdoor conditions on the G-M Chart, and (d) Energy use of each category.*







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(d)

Design Strategies	Regions	G-M Bio-Chart (%)	DOE-2 Simulation HTG (%)	CLG (%)	N-H-C (%)
Conventional Heating	0	0.00	0.00	0.00	0.00
Active Solar	1	0.00	0.00	0.00	0.00
Passive Solar	2,3,4	0.01	0.00	0.01	0.00
Internal Gains	5	0.90	0.00	0.90	0.00
Humidification	6A, 6B	0.00	0.00	0.00	0.00
Comfort Zone	7	5.09	0.00	5.09	0.00
Dehumidification	8	2.34	0.00	2.34	0.00
Ventilation	9,10,11	41.08	0.00	41.08	0.00
Evaporative Cooling	6B,11,13,14A,14B	6.00	0.00	6.00	0.00
High Thermal Mass	10,11,12,13	6.68	0.00	6.68	0.00
High Thermal Mass with Night Ventilation	16, 14B	0.90	0.00	0.90	0.00
Air-Conditioning	17	0.00	0.00	0.00	0.00
Air-Conditioning & Dehumidification	15A,15B	49.11	0.00	49.11	0.00
Number of Hours/Year		8760	0	8760	0
Percentage of Hours/Year		100.00	0.00	100.00	0.00

Region	0	1	2	3	4	5	6A	6B	7	8	9	10	11	12	13	14A	14B	15A	15B	16	17	Total
Hours	0	0	0	0	1	79	0	0	446	205	3063	61	475	17	32	0	19	2332	1970	60	0	8760
G-M (%)	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	5.1	2.3	35.0	0.7	5.4	0.2	0.4	0.0	0.2	26.6	22.5	0.7	0.0	100.00
DOE-2 (%)	0.00		6.00							94.00												100.00

Figure D.2 *Daytime and nighttime annual hourly indoor and outdoor conditions of the lightweight house (base case) in the very hot-humid, Bangkok, Thailand, on the G-M Chart. (a) Heating period, (b) Cooling period, (c) Non-heating-cooling period, and (d) Comparison of the results from the G-M Chart vs. the DOE-2 simulation.*

Figure D.1c shows that the outdoor conditions for the whole year are spread-out above the 40°F dewpoint line covering the upper part of the comfort zone and the areas to the right and the left of the comfort zone. The majority of the hours cover the areas to the upper right of the comfort zone. The frequency of occurrence is higher at higher temperatures, in the temperature range of 75 to 95 °F; which are the G-M areas of ventilation and air-conditioning with dehumidification (regions 9 and 15). The indoor temperatures for the whole year falls within the comfort zone and stays close to the cooling temperature setpoints (78 ºF). There are only a few hours-per-year when the indoor conditions fall above the humidity constraints of the comfort zone (i.e., above 60 % relative humidity line).

Figure D.1d shows that the total annual energy use is 116.0 MBtu. The energy use includes: domestic hot water (8.2 MBtu), space heating (i.e., pilot light, 7.0 MBtu), space cooling (42.3 MBtu), ventilation fans (23.4 MBtu), pump and miscellaneous (2.7 MBtu), heat rejection (6.0 MBtu), miscellaneous equipment (13.2 MBtu), and lights (13.2 MBtu). The results show that the energy use for space cooling is significantly high and the energy use for space heating is not required. Therefore, only the design strategies for cooling should be considered. Furthermore, since the heating is never used, the pilot light could probably be turned-off, which would reduce the total energy use.

As expected, Figure D.2a shows no hours for the whole year in the heating period, which correspond to the results in Figures D.1a and D.1d. Figure D.2b shows that the outdoor conditions during the cooling period or for the whole year fall into the comfort zone and are spread-out to the right and the left of the comfort zone. The cooling data covers the heating design strategy regions, which are passive solar and internal gains (regions 4 and 5); the G-M comfort zone (region 7); and the cooling design strategy regions, which include dehumidification, ventilation, evaporative cooling, high thermal mass with and without night ventilation and air-conditioning with dehumidification design strategies (regions 8 to 16). The frequency of occurrence is high in the areas of the G-M comfort zone, dehumidification, evaporative cooling and high thermal mass (regions 7 to 8 and 11) and highest in the areas of ventilation and air-conditioning with dehumidification (regions 9 to 11 and 15). Most indoor temperatures fall into the area of comfort zone and stay close to the cooling temperature setpoint of 78 °F. Figure D.2b shows that there is a small portion of the hours-per-year that the indoor conditions fall above the humidity constraints of the comfort zone (i.e., below 36 °F dewpoint). In a similar fashion to Figure D.2a, Figure D.2c also shows no hours for the whole year in non-heating-cooling period.

Figure D.2d compares the results from the DOE-2 simulation to the results from the G-M bioclimatic chart. The criteria used to identify the effective design strategies for heating, cooling, and non-heating-cooling periods in the G-M Chart analysis are described in Section 5.2.1.1 (see the last paragraph of p. 149). In the heating period, DOE-2 shows that the heating system does not activate for the whole year, which corresponds to results from the G-M Chart showing no hours in conventional heating and active solar design strategies (regions 0 and 1).

In the cooling period (Figure D.2d), the DOE-2 simulation calculates 8,760 hours-per-year (100.00%) when the cooling system is activated. Basically, the heating hours are the data for whole year, where the data falls into many regions as explained in Figure D.1c. The results from the G-M Chart analysis show 8,234 hours-per-year (94.00%) in the heating period, which is less than the results from the DOE-2 simulation. The results from the DOE-2 simulation in the regions 8 to 16; which include the G-M design strategy regions for dehumidification (2.34%), ventilation (41.08%), evaporative cooling (6.00%), high thermal mass (6.68%), high thermal mass with night ventilation (0.90%) and air-conditioning with dehumidification (49.11%) correspond to the results from the G-M Chart analysis. However, the differences are in regions 4, 5, and 7; where the DOE-2 shows a portion of the time in regions 4 (passive solar, 0.01%), 5 (internal gains, 0.90%), and 7 (the G-M comfort zone, 5.09%).

In the non-heating-cooling period (Figure D.2d), DOE-2 shows zero hours-per-year (0.00%). However, the G-M Chart analysis show 526 hours-per-year (6.00%) in the non-heating-cooling period; which includes regions 4 (passive solar, 0.01%), 5 (internal gains, 0.90%), and 7 (the G-M comfort zone, 5.09%).

Summary and discussion: A lightweight house (base case) was simulated using the TMY2 weather data for Bangkok, Thailand (very hot-humid climate). The results showed a significant narrow range of the outdoor temperature (60 to 100 °F) and relative humidity (40 to 100%). The whole year was in the cooling period. The indoor temperature and relative humidity were very well maintained for the whole year. The indoor temperature stayed close to the cooling setpoint (78 °F) and the relative humidity floated between 40 to 60% range. There was a small portion of the hours in the year that the indoor relative humidity fell above the humidity constraints of the comfort zone (i.e., above 60% relative humidity line). The total annual energy use for the lightweight house (base case) in Bankok, Thailand, was 116.0 MBtu. There was no energy use for heating except the energy use by a pilot light, which could actually be eliminated. The cooling energy use was significantly high (42.3 MBtu). Therefore, only the design strategies for cooling should be considered.

The DOE-2 simulation results showed no hours for the whole year in the heating or non-heating-cooling period. The results showed the whole year data (i.e., in the cooling period) covered several regions from 4, 5, and 7 to 16; which included passive solar, internal gains, the G-M comfort zone, dehumidification, ventilation, evaporative cooling, high thermal mass with and without night ventilation, and air-conditioning with dehumidification. The frequency of occurrences were highest in regions 9 to 11 (ventilation) and 15 (air-conditioning with dehumidification).

In the cooling period, the DOE-2 simulation yielded 100.00% of the hours-per-year, which was more than the G-M Chart results showing 94.00% of the hours-per-year. For the regions 8 to 16; which were dehumidification, ventilation, evaporative cooling, high thermal mass with and without night ventilation, and air-conditioning with dehumidification design strategies; the results from the DOE-2 simulation corresponded to the results from the G-M Chart analysis. However, the differences were in regions 4, 5, and 7; where DOE-2 showed a portion of the cooling hours in these periods. Unfortunately, in the G-M Chart analysis, these regions were usually considered to be the non-heating-cooling period.

D.2 LIGHTWEIGHT (BASE CASE): COOL-HUMID CLIMATE (CHICAGO, ILLINOIS)

The results of the lightweight house (base case) in the representative cool-humid climate of Chicago, Illinois, are presented in Figures D.3 and D.4. In a similar fashion as Figures 5.16 and 5.17, Figure D.3 consists of three plots and a bar chart (Figures D.3a through D.3d). Figure D.4 consists of three plots and a table (Figures D.4a through D.4d). Figure D.3a shows a significant wide range of the outdoor temperatures for the whole year, which is in the temperature range of -10 to 95 °F. The range of the outdoor temperatures in the summer, 45 to 95 °F; is narrower than the range in the winter, which is in the range of -10 to 70 °F. The indoor temperatures in the cooling periods (mid-May through September) and heating periods (October through mid-May) fluctuate between heating and cooling setpoints (68 to 78 °F), which correspond to the activation of the cooling or heating systems. As expected, the cooling energy use in Chicago is small and occurs mostly in the summer, while the heating energy use is significantly large and occurs during the other periods of the year.

Figure D.3b shows variation in the outdoor relative humidity for the whole year, which varies over the range of 20 to 100%. The range of the outdoor relative humidity in the summer is as wide as the range in the winter. The indoor relative humidity in the summer (mid-May through September) is maintained between 20 to 80%. Although there are portions of the hours in the summer that the indoor relative humidity goes above 60%, it is well maintained than the other periods of the year. The indoor relative humidity in the other periods of the year fluctuates between 5 to 80%, when the cooling system is mostly inactive. During November through March, the indoor relative humidity is significantly lower.

Figure D.3c shows that the outdoor conditions for the whole year stay above the 20% relative humidity line, with the majority of the hours covering the areas to the left of the comfort zone. There are portions of the hours in the year that the outdoor conditions cover the comfort zone and the areas to the right of the comfort zone. The frequency of occurrence is highest at lower temperatures, in the temperature range of

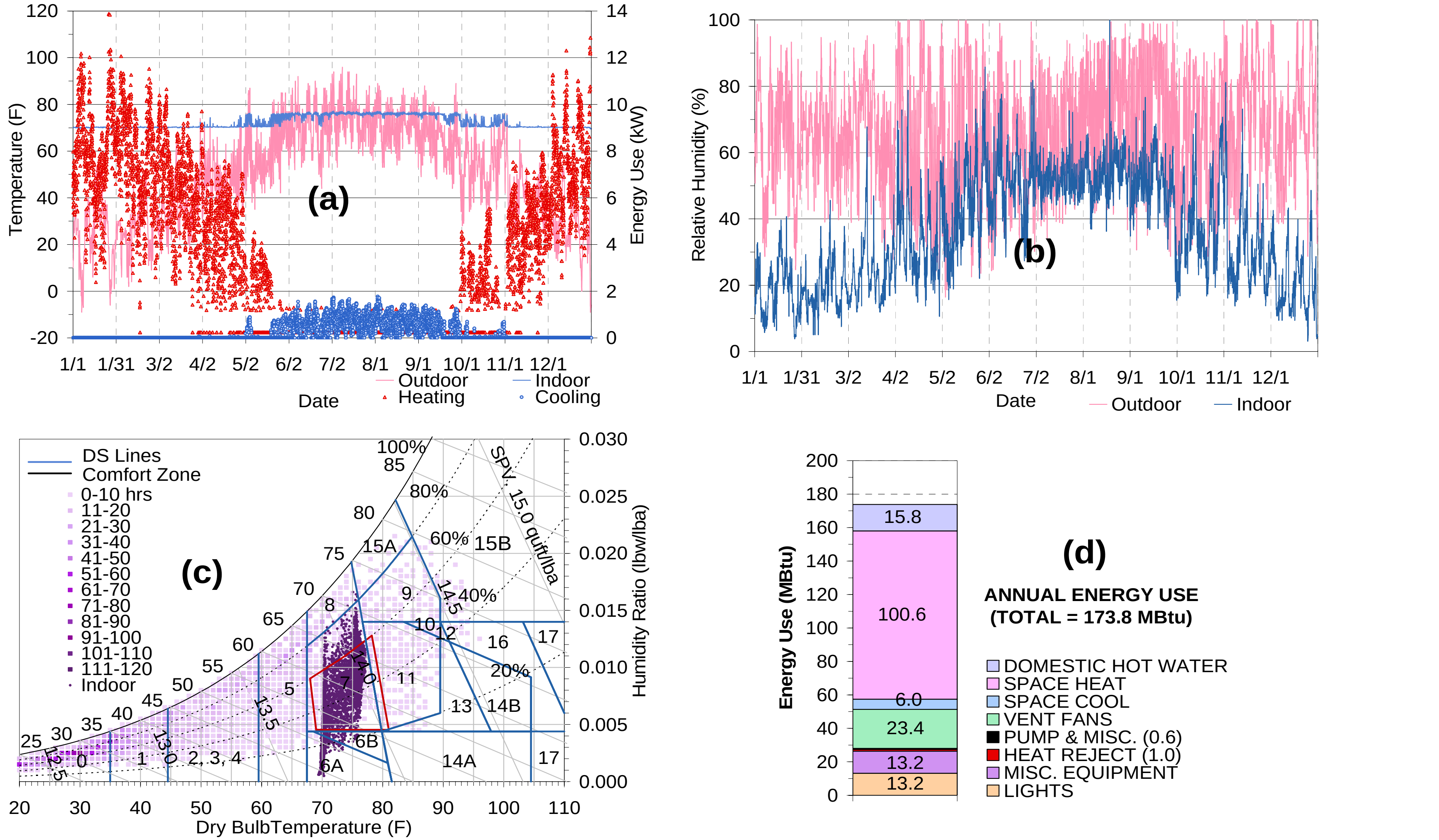
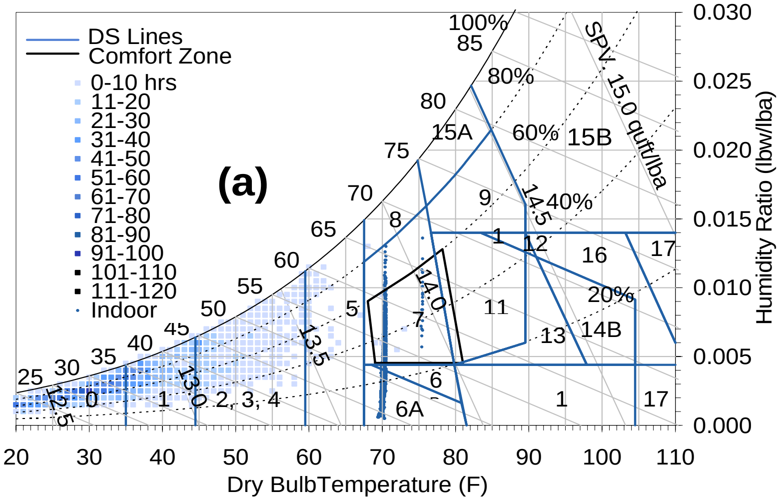
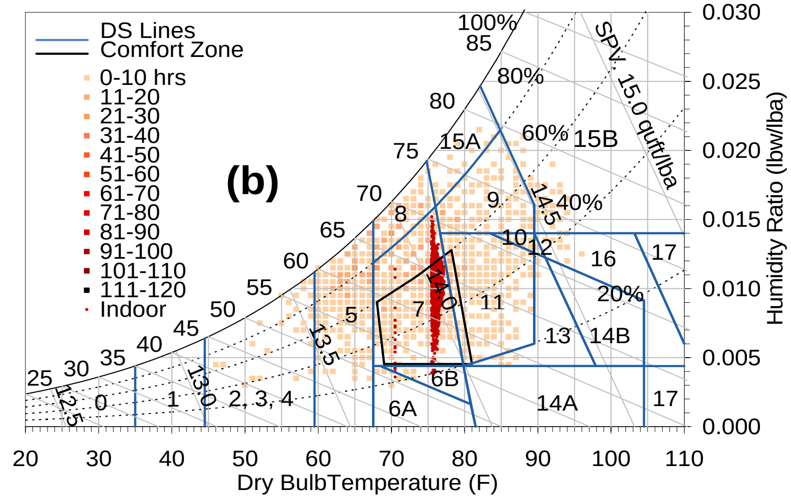
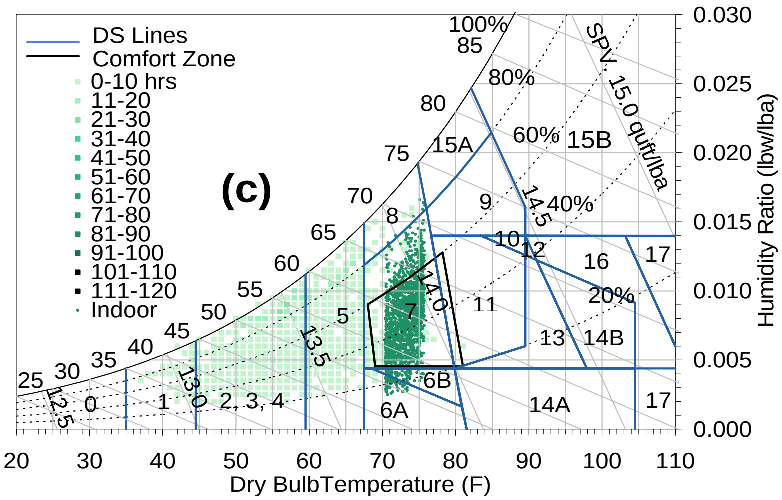


Figure D.3 *Annual hourly indoor and outdoor conditions and energy use of the lightweight house (base case) in the cool-humid climate, Chicago, Illinois. (a) Indoor and outdoor dry-bulb temperatures and energy use of gas and electricity, (b) Indoor and outdoor relative humidity, (c) Indoor and outdoor conditions on the G-M Chart, and (d) Energy use of each category.*







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(d)

Design Strategies	Regions	G-M Bio-Chart (%)	DOE-2 Simulation HTG (%)	DOE-2 Simulation CLG (%)	DOE-2 Simulation N-H-C (%)
Conventional Heating	0	26.86	26.86	0.00	0.00
Active Solar	1	15.83	15.48	0.00	0.35
Passive Solar	2,3,4	20.45	10.42	0.55	9.47
Internal Gains	5	13.22	0.50	6.06	6.66
Humidification	6A, 6B	0.24	0.00	0.15	0.09
Comfort Zone	7	11.77	0.06	10.26	1.45
Dehumidification	8	3.31	0.01	3.15	0.15
Ventilation	9,10,11	7.23	0.00	7.20	0.01
Evaporative Cooling	6B,11,13,14A,14B	5.15	0.00	5.11	0.03
High Thermal Mass	10,11,12,13	5.16	0.00	5.15	0.01
High Thermal Mass with Night Ventilation	16, 14B	0.15	0.00	0.15	0.00
Air-Conditioning	17	0.00	0.00	0.00	0.00
Air-Conditioning & Dehumidification	15A,15B	0.82	0.00	0.83	0.00
Number of Hours/Year		8760	4672	2495	1593
Percentage of Hours/Year		100.00	53.33	28.48	18.18

Region	0	1	2	3	4	5	6A	6B	7	8	9	10	11	12	13	14A	14B	15A	15B	16	17	Total
Hours	2353	1387	604	601	586	1158	12	9	1031	290	191	8	434	3	7	1	0	33	39	13	0	8760
G-M (%)	26.9	15.8	6.9	6.9	6.7	13.2	0.1	0.1	11.8	3.3	2.2	0.1	5.0	0.0	0.1	0.0	0.0	0.4	0.4	0.1	0.0	100.00
DOE-2 (%)	42.69		45.67							11.63												100.00

Figure D.4 *Daytime and nighttime annual hourly indoor and outdoor conditions of the lightweight house (base case) on the G-M Chart in the cool-humid climate, Chicago, Illinois, on the G-M Chart. (a) Heating period, (b) Cooling period, (c) Non-heating-cooling period, and (d) Comparison of the results from the G-M Chart vs. the DOE-2 simulation.*

-10 to 45 °F; which are the G-M areas of conventional heating and active solar (regions 0 and 1). During all periods, the indoor temperatures fall mostly within the comfort zone, where the temperatures stay between the heating and cooling temperature setpoints (68 to 78 ºF). However, there are many hours of the year when the indoor conditions fall above or below the humidity constraints of the comfort zone (i.e., above 60 % relative humidity line and below 36 °F dewpoint).

Figure D.3d shows that the total annual energy use is 173.8 MBtu. The energy use includes: domestic hot water (15.8 MBtu), space heating (100.6 MBtu), space cooling (6.0 MBtu), ventilation fans (23.4 MBtu), pump and miscellaneous (0.6 MBtu), heat rejection (1.0 MBtu), miscellaneous equipment (13.2 MBtu), and lights (13.2 MBtu). From the results, the energy use for space heating is the highest and significantly higher than the energy use for space cooling. Therefore, the design strategies for heating should be considered a priority.

In a similar fashion as Figure 5.17, Figures D.4 consists of Figures D.4a through D.4d, which shows the daytime and nighttime annual hourly indoor and outdoor conditions on the G-M Chart during the heating period (Figure D.4a), cooling period (Figure D.4b), non-heating period (Figure D.4c), and a comparison table of the results from the G-M Chart and the DOE-2 simulations (Figure D.4d).

Figure D.4a shows that most of the outdoor conditions during the heating period cover an area to the far left of the comfort zone. The majority of the hours involve the G-M definitions of conventional heating, active solar, and passive solar design strategies (regions 0, 1, and 2 to 4). Only a few hours fall into the internal gains strategy and the dehumidification design strategy (region 5, 7, and 8). Most of the indoor temperatures stay close to the heating temperature setpoint of 68 °F. There is a small portion of the heating hours that stay close to the cooling temperature setpoint of 78 °F. These hours occur individually right after the hours that the cooling system was continuously activated (see the DOE-2 hourly report, Appendix B). These are most likely due to the indoor temperature fluctuations that are usually found in a lightweight house. In Figure D.4a, there are many hours in this period that the indoor conditions fall above or below the humidity constraints of the ASHRAE comfort zone, which is expected for a house with a heating system that has neither humidification nor dehumidification.

Figure D.4b shows that the outdoor conditions during the cooling period fall into the comfort zone and spread-out to the right and the left of the comfort zone. The cooling data covers regions of heating design strategies, which are passive solar and internal gains (regions 2 to 4 and 5); the G-M comfort zone (region 7); and the cooling design strategy regions, which include dehumidification, ventilation, evaporative cooling, high thermal mass and air-conditioning with dehumidification (regions 8 to 15). A small portion of the cooling data falls within the areas of humidification and high thermal mass with night ventilation design strategies (regions 6A, 6B, and 16). The frequency of occurrence is high in the areas of internal gains design strategy and the G-M comfort zone (regions 5 and 7). Most indoor temperatures fall into the area of comfort zone and stay close to the cooling temperature setpoint of 78 °F. Only a few hours of the cooling periods stay close to the heating temperature setpoint of 68 °F. These hours occur right after the hours that the heating system was continuously activated (see the DOE-2 hourly report, Appendix B), which are most likely due to the indoor temperature fluctuations of a lightweight house. Figure D.4b shows that there is a portion of the hours in the cooling period that the indoor conditions fall above the 60 % relative humidity.

Figure D.4c shows that majority of the outdoor conditions during the non-heating-cooling period fall to the left of the comfort zone, which include areas of passive solar, and internal gain design strategies (regions 2 to 4 and 5). A small portion of the hours falls within the areas of active solar, humidification, the G-M comfort zone, dehumidification (regions 1, 6A and 6B, 7, and 8); with only a few hours covering the region 11 (ventilation, evaporative cooling, and high thermal mass). The frequency of occurrence is high in the area of internal gains design strategy (region 5) and highest in the area of passive solar design strategy (regions 2 to 4). The indoor temperatures mostly float between the heating and cooling temperature setpoints (68 to 78 °F), with many hours falling above or below the humidity constraints of the comfort zone (i.e., above 60% relative humidity line and below 36 °F dewpoint).

In Figure D.4d, the results from the DOE-2 simulation show that there are 4,672 hours (53.33%) of the year that the heating system is activated. The cooling system is activated for 2,495 hours (28.48%) and there are 1,593 hours (18.18%) when neither the heating nor the cooling system is activated. The results from the G-M Chart analysis show 3,740 hours (42.69%) of the year in the heating period, 1,019 hours (11.63%) in the cooling period, and 4,001 hours (45.67%) in the non-heating-cooling period. The criteria used to identify the effective design strategies for heating, cooling, and non-heating-cooling periods in the G-M Chart analysis are described in Section 5.2.1.1 (see the last paragraph of p. 149).

Figure D.4d compares the results from the DOE-2 simulation to the results from the G-M bioclimatic chart. As mentioned in the previous paragraphs, the DOE-2 simulation showed 53.33% of the time for the year in the heating period, which is more than the results from the G-M Chart (42.69%). In this period the DOE-2 simulation shows 26.86% of the time in conventional heating (region 0) and 15.48% of the time in active solar (region 1). These are very close to the results from the G-M Chart, which show 26.86% in conventional heating and 15.83% in active solar design strategy. However, the DOE-2 simulation shows that there is a significant portion of heating hours in passive solar (regions 2 to 4, 10.42%) and a small portion in internal gains (region 5, 0.50%), the G-M comfort zone (region 7, 0.06%), and dehumidification design strategies (region 8, 0.01%).

In the cooling period (Figure D.4d), the DOE-2 simulation calculated 28.48% of the hours-per-year in several regions including passive solar, internal gains, humidification, the G-M comfort zone, dehumidification, ventilation, evaporative cooling, high thermal mass with and without night ventilation, and air-conditioning with dehumidification design strategies (regions 2 to 16). The G-M Chart shows that only 11.63% of the time is in this period. In regions 8 to 16, the results from the DOE-2 simulation correspond or very close to the results from the G-M Chart analysis.

However, the differences are in regions 2 to 7. In Figure D.4d, DOE-2 shows a small portion in region 2 to 4 (passive solar, 0.55%) and region 6 (humidification, 0.15%). In addition, DOE-2 shows significant portions fall into region 5 (internal gain, 6.06%) and region 7 (the G-M comfort zone, 10.26%). Unfortunately, in the G-M Chart analysis, regions 2 to 7 are not usually considered cooling periods.

In the non-heating-cooling period (Figure D.4d), the results from the DOE-2 simulation are much different from the results from the G-M Chart. The DOE-2 simulation shows 18.18% of the hours-per-year in this period while the G-M Chart shows as much as 45.67%. The DOE-2 simulation shows a small portion occurs in region 1 (active solar, 0.35%), region 8 (dehumidification, 0.15%), and region 11 (ventilation, high thermal mass, and evaporative cooling; 0.01%). In the G-M Chart analysis, these hours are not included in the non-heating-cooling period. In regions 2 to 4 (passive solar), the results from the DOE-2 simulation (9.47%) are significantly less than the G-M Chart analysis results (20.45%). The differences are also shown in regions 5 through 7 (internal gain, humidification, and the G-M comfort zone). In these regions the DOE-2 simulation shows only 6.67% (region 5), 0.09% (region 6), and 1.45% (region 7) versus the G-M Chart showing 13.22%, 0.24%, and 11.77% in regions 5, 6, and 7; respectively.

Summary and discussion: A lightweight house (base case) was simulated using the TMY2 weather data for Chicago, Illinois (cool-humid climate). The results showed a significant wide range of the outdoor temperatures (-10 to 95 °F) and relative humidity (20 to 100%), which were narrower in the summer than in the winter. The cooling period was almost half of the heating period and occurred mostly in the summer from mid of May through September while the heating period occurred all other periods of the year. The indoor temperatures fluctuated between heating and cooling temperature setpoints (68 to 78 °F), which corresponds to the activation of heating or cooling systems. The indoor temperature during the winter was very well maintained near the 68 °F when the heating system was continuously activated (mid-November through March). The indoor relative humidity floated between 5 to 80%. The indoor relative humidity was well maintained during the cooling period than the other periods of the year. There was a significant portion of the hours in all periods of the year that the indoor relative humidity fell above or below the humidity constraints of the comfort zone (i.e., above 60% relative humidity and below 36 °F dewpoint), especially, in the heating period when the indoor relative humidity was significantly lower than the other periods of the year. The total annual energy use for the lightweight house (base case) in Chicago, Illinois, was 173.8 MBtu. The heating energy use (100.6 MBtu) was significantly higher than the cooling energy use (6.0 MBtu). Therefore, the design strategies for heating should be considered a priority.

The DOE-2 simulation results showed that the outdoor conditions during the heating period covered an area to the left of the comfort zone from regions 0 through 5 (conventional heating, active solar, passive solar, and internal gains design strategies) and regions 7 to 8 (the G-M comfort zone and humidification design strategies). The majority of the hours fell within regions 0 to 4. The outdoor conditions during the cooling period fell into the comfort zone and spread-out to the right and the left of the comfort zone; covering several regions from 2 to 16. The majority of the hours fell within the areas of internal gains (region 5), the G-M comfort zone (region 7), dehumidification (region 8), ventilation (regions 9 to 11), evaporative cooling (regions 6B, 11, and 13 to 14), and high thermal mass (regions 10 to 13). In the non-heating-cooling period, most of the hours during this period covered from regions 1 to 8 (active solar, passive solar, internal gains, humidification, the G-M comfort zone, and dehumidification), where the majority of the hours was in region 2 to 4 and 5 (passive solar and internal gains).

In the heating period, the DOE-2 simulation yielded 53.33% of the hours-per-year, which was more than the G-M Chart results (42.69%). In the conventional heating (regions 0) and active solar (region 1) design strategies, the results from DOE-2 simulation corresponded or were very close to the results from the G-M Chart. However, the DOE-2 simulation shows a significant portion of the heating hours in passive solar (regions 2 to 4) and a small portion in internal gains (region 5), the G-M comfort zone (region 7), and dehumidification (region 8). Unfortunately, in the G-M chart analysis these regions were not usually considered heating periods.

In the cooling period, the DOE-2 simulation showed 28.48% of the hours-per-year, which was significantly more than the G-M Chart results (11.63%). In regions 8 to 16, which were humidification, ventilation, evaporative cooling, high thermal mass with and without night ventilation, and air-conditioning with dehumidification design strategies, the results from the DOE-2 simulation corresponded to the results from the G-M Chart analysis. However, there were differences in the regions 2 to 7, with a significant portion falling in region 5 (internal gain) and region 7 (the G-M comfort zone); where the G-M Chart analysis does not usually consider cooling periods.

In the non-heating-cooling period, the results from the DOE-2 simulation (18.18%) were significantly less than the results from the G-M Chart (45.67%). In regions 2 to 4 (passive solar), the results from the DOE-2 simulation are significantly less than the G-M Chart analysis results. The differences are also shown in regions 5 to 7 (internal gain, humidification, and the G-M comfort zone). In addition, DOE-2 showed a small portion of the hours-per-year in the region 1 (active solar), 8 (dehumidification), and 11 (ventilation, evaporative cooling, and high thermal mass). Unfortunately, in the G-M chart analysis these regions were not usually considered non-heating-cooling period.

D.3 LIGHTWEIGHT (BASE CASE): COOL-HUMID CLIMATE (BOSTON, MASSACHUSETTS)

The results of the lightweight house (base case) in the representative cool-humid climate of Boston, Massachusetts, are presented in Figure D.5 (Figures D.5a through D.5d) and Figure D.6 (Figures D.6a through D.6d). Figure D.5a shows a significant wide range of the outdoor temperatures for the whole year, which is in the temperature range of 5 to 90 °F. The range of the outdoor temperatures in the summer, in the range of 50 to 90 °F; is narrower than the range in the winter, which is in the range of 5 to 70 °F. The indoor temperatures in the cooling periods (mid-May through September) and heating

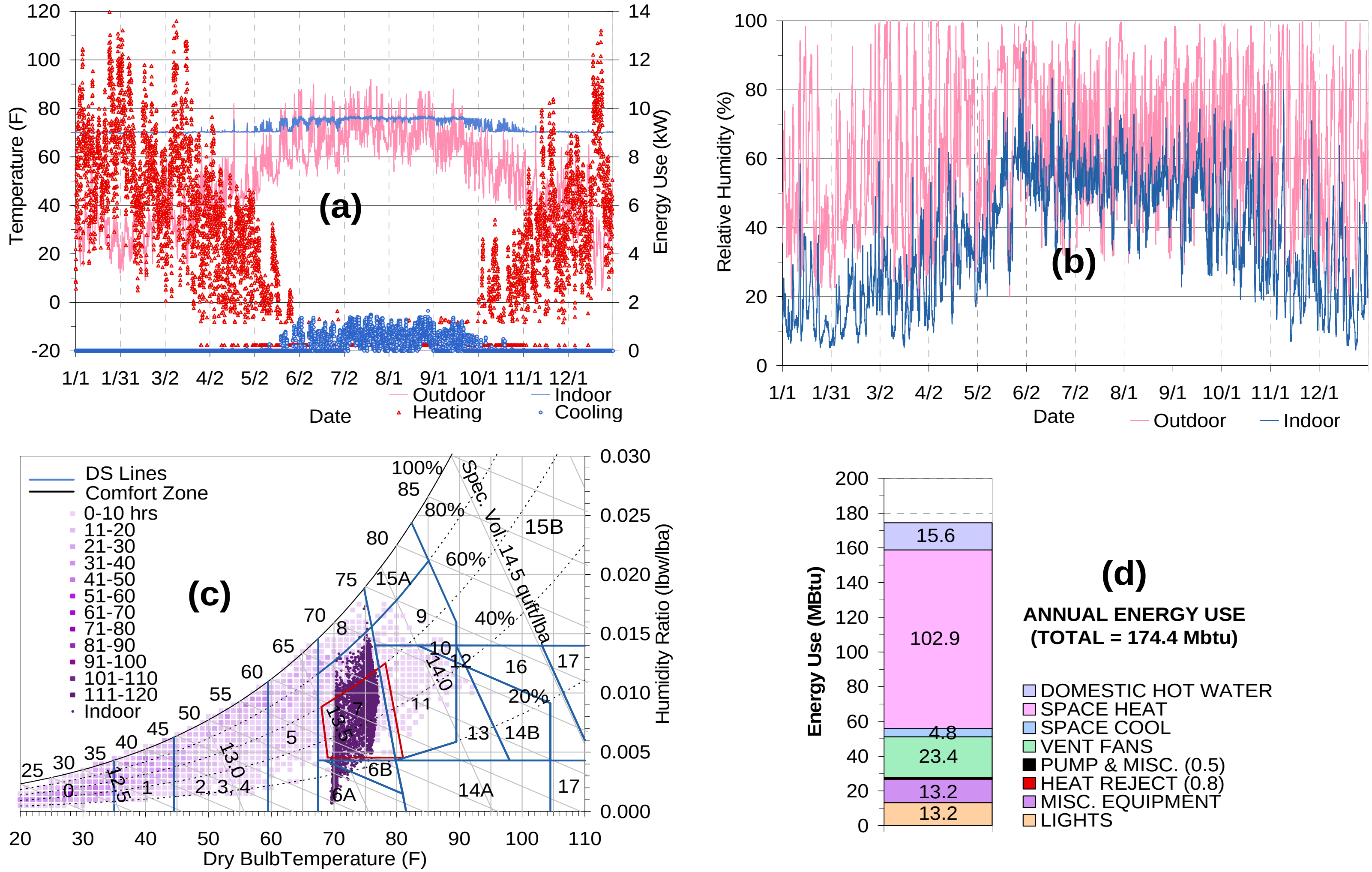
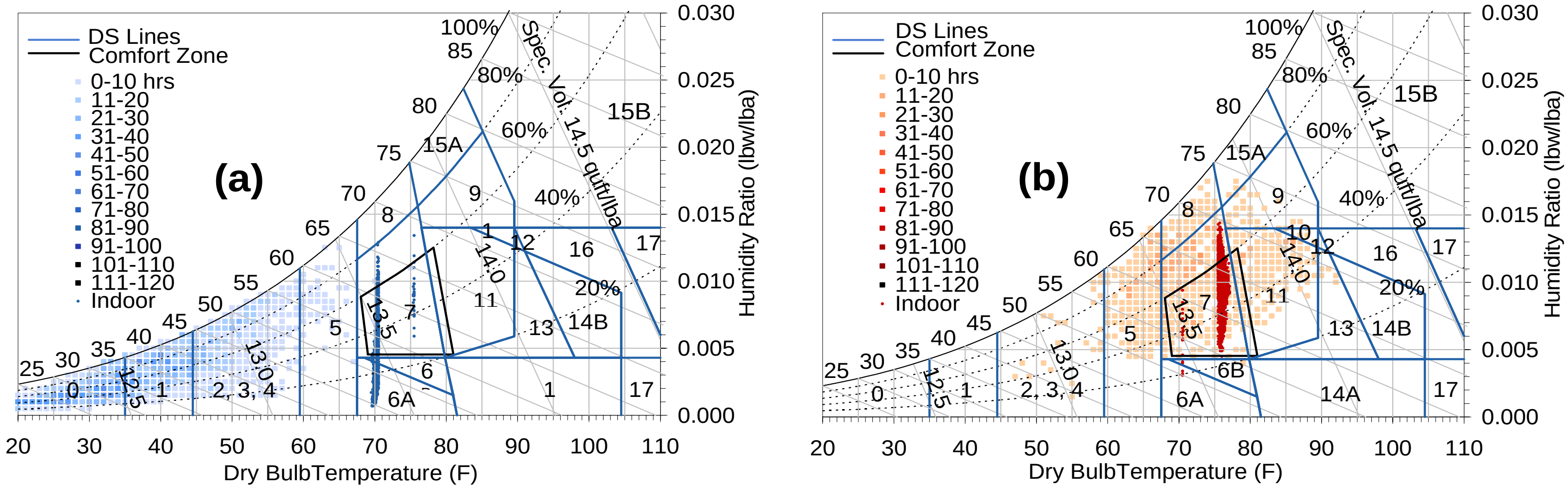
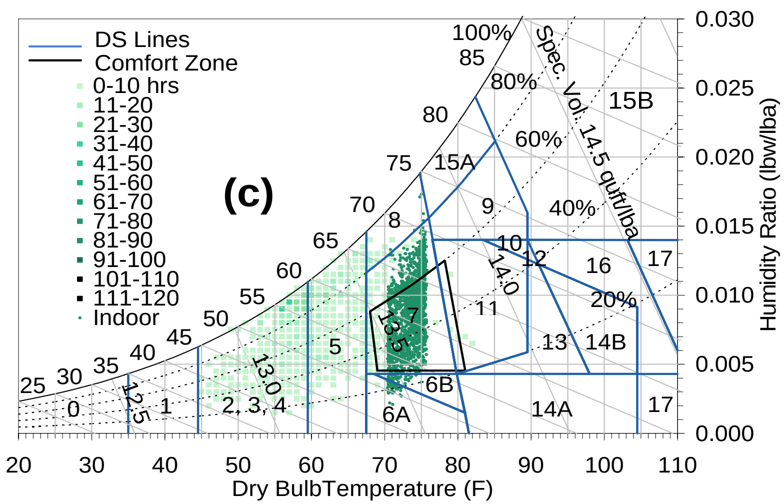


Figure D.5 *Annual hourly indoor and outdoor conditions and energy use of the lightweight house (base case) in the cool-humid climate, Boston, Massachusetts. (a) Indoor and outdoor dry-bulb temperatures and energy use of gas and electricity, (b) Indoor and outdoor relative humidity, (c) Indoor and outdoor conditions on the G-M Chart, and (d) Energy use of each category.*





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Design Strategies	Regions	G-M Bio-Chart (%)	DOE-2 Simulation HTG (%)	DOE-2 Simulation CLG (%)	DOE-2 Simulation N-H-C (%)
Conventional Heating	0	21.27	21.27	0.00	0.00
Active Solar	1	18.95	18.95	0.00	0.00
Passive Solar	2,3,4	24.49	14.77	0.32	9.39
Internal Gains	5	15.16	0.64	6.06	8.46
Humidification	6A, 6B	0.05	0.00	0.01	0.03
Comfort Zone	7	12.00	0.03	10.82	1.14
Dehumidification	8	2.77	0.00	2.48	0.30
Ventilation	9,10,11	5.19	0.00	5.13	0.07
Evaporative Cooling	6B,11,13,14A,14B	4.81	0.00	4.71	0.09
High Thermal Mass	10,11,12,13	4.84	0.00	4.77	0.07
High Thermal Mass with Night Ventilation	16, 14B	0.00	0.00	0.00	0.00
Air-Conditioning	17	0.00	0.00	0.00	0.00
Air-Conditioning & Dehumidification	15A,15B	0.05	0.00	0.05	0.00
Number of Hours/Year		8760	4876	2185	1699
Percentage of Hours/Year		100.00	55.66	24.94	19.39

Region	0	1	2	3	4	5	6A	6B	7	8	9	10	11	12	13	14A	14B	15A	15B	16	17	Total
Hours	1863	1660	689	640	816	1328	1	3	1051	243	38	6	411	0	7	0	0	4	0	0	0	8760
G-M (%)	21.3	18.9	7.9	7.3	9.3	15.2	0.0	0.0	12.0	2.8	0.4	0.1	4.7	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	100.00
DOE-2 (%)		40.22							51.69												8.09	100.00

Figure D.6 *Daytime and nighttime annual hourly indoor and outdoor conditions of the lightweight house (base case) in the cool-humid climate, Boston, Massachusetts, on the G-M Chart. (a) Heating period, (b) Cooling period, (c) Non-heating-cooling period, and (d) Comparison of the results from the G-M Chart vs. the DOE-2 simulation.*

(68 to 78 °F), which correspond to the activation of the cooling or heating systems. In a similar fashion as the lightweight house (base case) in Chicago, the cooling energy use for the lightweight house (base case) in Boston is also small and occurs mostly in the summer, while the heating energy use is significantly large and occurs most other periods of the year.

Figure D.5b shows variation in the outdoor relative humidity for the whole year, which is wide and in the relative humidity range of 20 to 100%. The range of the outdoor relative humidity in the summer, in the range of 30 to 100%; is a little narrower than the range in the winter, which is in the 20 to 100% range. The indoor relative humidity in the summer (mid-May through September) is maintained between 20 to 80% range. Although there are portions of the hours in the summer that the indoor relative humidity goes above 60%, it is well maintained than the other periods of the year. The indoor relative humidity in the other periods of the year fluctuates between 5 to 80%. The indoor relative humidity is significantly low during November through March.

Figure D.5c shows that the outdoor conditions for the whole year stay above the 20% relative humidity line. Although there are portions of the hours in the year that the outdoor conditions cover the comfort zone and the areas to the right of the comfort zone, the majority of the hours cover the areas to the left of the comfort zone. The frequency of occurrence is higher at lower temperature, in the temperature range of 5 to 45 °F; which are the G-M areas of conventional heating and active solar (regions 0 and 1). The indoor temperatures fall within the comfort zone, where the temperatures stay between the heating and cooling temperature setpoints (68 to 78 ºF). However, there are many hours of the year when the indoor conditions fall above or below the humidity constraints of the comfort zone (i.e., above 60 % relative humidity line and below 36 °F dewpoint).

Figure D.5d shows that the total annual energy use is 174.4 MBtu. The energy use includes: domestic hot water (15.6 MBtu), space heating (102.9 MBtu), space cooling (4.8 MBtu), ventilation fans (23.4 MBtu), pump and miscellaneous (0.5 MBtu), heat rejection (0.8 MBtu), miscellaneous equipment (13.2 MBtu), and lights (13.2

MBtu). The results show that the energy use for space heating is the highest and significantly higher than the energy use for space cooling. Therefore, the design strategies for heating should be considered a priority.

Figure D.6a shows that most of the outdoor conditions during the heating period cover an area to the far left of the comfort zone. The majority of the hours involve the G-M definitions of conventional heating, active solar, and passive solar design strategies (regions 0, 1, and 2 to 4). Only a few hours fall upon internal gains and the G-M comfort zone (region 5 and 7). Most of the indoor temperatures stay close to the heating temperature setpoint of 68 °F. There is a small portion of the heating hours that stay close to the cooling temperature setpoint of 78 °F. These hours occur individually right after the hours that the cooling system was continuously activated (see the DOE-2 hourly report, Appendix B). These are most likely due to the indoor temperature fluctuations of a lightweight house. Figure D.6a shows that there are many hours in this period, where the indoor conditions fall above or below the humidity constraints of the ASHRAE comfort zone.

Figure D.6b shows the outdoor conditions during the cooling period, which fall into the comfort zone and spread-out to the right and the left of the comfort zone. The cooling data covers the heating design strategy regions, which include passive solar and internal gains (regions 2 to 4 and 5); the G-M comfort zone (region 7); and the cooling design strategy regions, which are dehumidification, ventilation, evaporative cooling and high thermal mass (regions 8 to 11, 13, and 15A). A small portion of the cooling data falls within the areas of humidification and air-conditioning with dehumidification design strategies (regions 6A, 6B, and 15A). The frequency of occurrence is high in the areas of internal gains design strategy and the G-M comfort zone (regions 5 and 7). Most indoor temperatures fall into the area of comfort zone and stay close to the cooling temperature setpoint of 78 °F. There are only a few hours of the cooling periods that the indoor temperatures stay close to the heating temperature setpoint of 68 °F. These hours are usually occur individually right after the hours that the heating system was continuously activated (see the DOE-2 hourly report, Appendix B), which are most likely due to the indoor temperature fluctuations of a lightweight house. Figure D.6b shows that there is a portion of the hours in cooling period that the indoor conditions fall above the 60 % relative humidity.

Figure D.6c shows that majority of the outdoor conditions during the non-heating-cooling period fall to the left of the comfort zone, which include areas of passive solar, and internal gain design strategies (regions 2 to 4 and 5). A small portion of the hours falls within the areas of the G-M comfort zone and dehumidification (regions 7, and 8); with only a few hours covering regions 6 and 11 (humidification, ventilation, evaporative cooling, and high thermal mass). The frequency of occurrence is high in the area of internal gains design strategy (region 5) and highest in the area of passive solar design strategy (regions 2 to 4). The indoor temperatures mostly float between the heating and cooling temperature setpoints (68 to 78 °F), with many hours falling above or below the humidity constraints of the comfort zone (i.e., above 60% relative humidity line and below 36 °F dewpoint).

In Figure D.6d, the DOE-2 simulation shows that the heating system is activated for 4,876 hours-per-year (55.66%). There are 2,185 hours-per-year (24.94%) when the cooling system is activated and 1,699 hours-per-year (19.39%) when neither the heating nor cooling systems is activated. The results from the G-M Chart analysis show 3,523 hours-per-year (40.22%) in the heating period, 709 hours-per-year (8.09%) in the cooling period, and 4,528 hours-per-year (51.69%) in the non-heating-cooling period. The criteria used to identify the effective design strategies for heating, cooling, and non-heating-cooling periods in the G-M Chart analysis are described in Section 5.2.1.1 (see the last paragraph of p. 149).

Figure D.6d compares the results from the DOE-2 simulation to the results from the G-M bioclimatic chart. In heating period, the DOE-2 simulation showed 55.66% of the time for the year in the heating period, which is more than the results from the G-M Chart (40.22%). In this period the DOE-2 simulation shows 21.27% of the time in conventional heating (region 0) and 18.95% of the time in active solar (region 1). These correspond are to the results from the G-M Chart. However, the DOE-2 simulation shows that there is a significant portion of heating hours in passive solar design strategy (regions 2 to 4, 14.77%) and a small portion in internal gains (region 5, 0.64%) and the G-M comfort zone (region 7, 0.03%).

In the cooling period (Figure D.6d), the DOE-2 simulation calculated 24.94% of the hours-per-year in several regions including passive solar, internal gains, humidification, the G-M comfort zone, dehumidification, ventilation, evaporative cooling, high thermal mass, and air-conditioning with dehumidification design strategies (regions 2 to 11, 13, and 15A). The G-M Chart shows only 8.09% of the time in this period. In regions 8 to 11, 13, and 15A, the results from the DOE-2 simulation correspond or very close to the results from the G-M Chart analysis. However, the differences are in regions 2 to 7, where the DOE-2 shows a portion of the time in regions 2 to 4 and 6 (passive solar, 0.32%; and humidification, 0.01%) and a significant portion of the time in regions 5 and 7 (internal gain, 6.06%; the G-M comfort zone, 10.82%). Unfortunately, in the G-M Chart analysis, regions 2 to 7 are not usually considered cooling periods.

In the non-heating-cooling period (Figure D.6d), the results from the DOE-2 simulation are significantly different from the results from the G-M Chart. The DOE-2 simulation shows 19.39% of the hours-per-year in this period while the G-M Chart shows as much as 51.69%. In regions 2 to 4 (passive solar), the results from the DOE-2 simulation (9.39%) are significantly less than the G-M Chart analysis results (24.49%). The differences are also shown in regions 5 through 7 (internal gain, humidification, and the G-M comfort zone). In these regions the DOE-2 simulation shows only 8.46% (region 5), 0.03% (region 6), and 1.14% (region 7) versus the G-M Chart showing 15.16%, 0.05%, and 12.00%; respectively. In addition, the DOE-2 simulation shows a small portion occurs in regions 1 (active solar, 0.35%), 8 (dehumidification, 0.15%), and 11 (ventilation, high thermal mass, and evaporative cooling; 0.01%); where in the G-M Chart analysis these regions are not included in the non-heating-cooling period.

Summary and discussion: A lightweight house (base case) was simulated using the TMY2 weather data for Boston, Massachusetts (cool-humid climate). The results showed a significant wide range of the outdoor temperatures (5 to 90 °F) and relative humidity (20 to 100%), which were narrower in the summer than in the winter. The cooling period was almost half of the heating period and occurred mostly in the summer from mid of May through September while the heating period occurred in the other periods of the year. The indoor temperatures fluctuated between heating and cooling temperature setpoints (68 to 78 °F), which corresponds to the activation of heating or cooling systems. The indoor temperatures during the winter were very well maintained near 68 °F when the heating system was continuously activated (mid-November through March). The indoor relative humidity floated between 5 to 80%, which was well maintained during the cooling period than the other periods of the year. There was a significant portion of the hours in all periods of the year that the indoor relative humidity fell above or below the humidity constraints of the comfort zone (i.e., above 60% relative humidity and below 36 °F dewpoint). Especially, in the heating period when the indoor relative humidity was significantly lower than the other periods of the year. The total annual energy use for the lightweight house (base case) in Boston, Massachusetts, was 174.4 MBtu, The heating energy use (102.9 MBtu) was significantly higher than the cooling energy use (4.8 MBtu). Therefore, the design strategies for heating should be considered a priority.

The DOE-2 simulation results showed that the outdoor conditions during the heating period covered an area to the left of the comfort zone from regions 0 through 5 and 7 (conventional heating, active solar, passive solar, internal gains, and the G-M comfort zone). The majority of the hours fell within regions 0 to 4. The outdoor conditions during the cooling period fell into the comfort zone and spread-out to the right and the left of the comfort zone; covering several regions from 2 to 11, 13, and 15A. The majority of the hours fell within the areas of internal gains (region 5), the G-M comfort zone (region 7), dehumidification (region 8), ventilation (regions 9 to 11), evaporative cooling (regions 6B, 11, and 13), and high thermal mass (regions 10 to 11, and 13). In the non-heating-cooling period, most of the hours during this period covered from regions 2 to 8 (i.e., active solar, passive solar, internal gains, humidification, the G-M comfort zone, and dehumidification), where the majority of the hours were in regions 2 to 4 and 5 (passive solar and internal gains).

In the heating period, the DOE-2 simulation yielded 55.66% of the hours-per-year, which was more than the G-M Chart results (40.22%). In the conventional heating (regions 0) and active solar (region 1) design strategies, the results from the DOE-2 simulation corresponded to the results from the G-M Chart. However, the DOE-2 simulation shows a significant portion of the heating hours in passive solar (regions 2 to 4) and a small portion in internal gains (region 5) and the G-M comfort zone (region 7). Unfortunately, in the G-M chart analysis these regions are not considered heating periods.

In the cooling period, the DOE-2 simulation showed 24.94% of the hours-per-year, which was more than the G-M Chart results (8.09%). In regions 8 to 11, 13, and 15A; which were humidification, ventilation, evaporative cooling, high thermal mass and air-conditioning with dehumidification design strategies; the results from the DOE-2 simulation corresponded or were very close to the results from the G-M Chart analysis. However, the differences were in regions 2 to 7, with a significant portion falling in region 5 (internal gain) and region 7 (the G-M comfort zone); where in the G-M Chart analysis were not usually considered cooling periods.

In the non-heating-cooling period, the results from the DOE-2 simulation (19.39%) were significantly less than the results from the G-M Chart (51.69%). In regions 2 to 4 (passive solar), the results from the DOE-2 simulation are significantly less than the G-M Chart analysis results. The differences are also shown in regions 5 to 7 (internal gain, humidification, and the G-M comfort zone). In addition, DOE-2 showed a small portion of the hours-per-year in the regions 8 (dehumidification) and 11 (ventilation, evaporative cooling, and high thermal mass). Unfortunately, in the G-M chart analysis these regions were not usually considered non-heating-cooling period.

D.4 LIGHTWEIGHT (BASE CASE): COOL-DRY CLIMATE (BOISE, IDAHO)

The results of the lightweight house (base case) in the representative cool-dry climate of Boise, Idaho, are presented in Figure D.7 (Figures D.7a through D.7d) and Figure D.2 (Figures D.2a through D.2d). Figure D.7a shows a significant wide range of the outdoor temperatures for the whole year, which is in the temperature range of 0 to 100 °F. The range of the outdoor temperatures in the summer, 40 to 100 °F; is a little narrower than the range in the winter, which is in the range of 0 to 70 °F. The indoor temperature in the cooling periods (mid-May through mid-October) and heating periods (mid-October through mid-May) fluctuates between heating and cooling setpoints (68 to 78 °F), which correspond to the activation of the cooling or heating systems. The cooling energy use for the lightweight house (base case) in Boise is small and occurs mostly in the summer, while the heating energy use is significantly large and occurs during all other periods of the year.

Figure D.7b shows variation in the outdoor relative humidity for the whole year, which is significantly wide and in the range of 5 to 100%. The range of the outdoor relative humidity in the summer, in the range of 5 to 100%; is a little wider than the range in the winter, which is in the 15 to 100% range. The indoor relative humidity in the summer (mid-May through mid-October) is maintained between 20 to 60% range. Although there are portions of the hours in the summer when the indoor relative humidity goes below 20%, it is well maintained than the other periods of the year. The indoor relative humidity in the other periods of the year fluctuates between 5 to 70%. The indoor relative humidity is significantly low during mid-October through April.

Figure D.7c shows that the outdoor conditions for the whole year are widely spread-out under the 63°F dewpoint line covering the comfort zone and the areas to the right and the left of the comfort zone, with majority of the hours cover the areas to the left of the comfort zone. The frequency of occurrence is higher at lower temperatures, in the temperature range of 0 to 45 °F; which are the G-M areas of conventional heating and active solar (regions 0 and 1). The indoor temperature for the whole year falls within the comfort zone and stays between the heating and cooling temperature setpoints (68 to

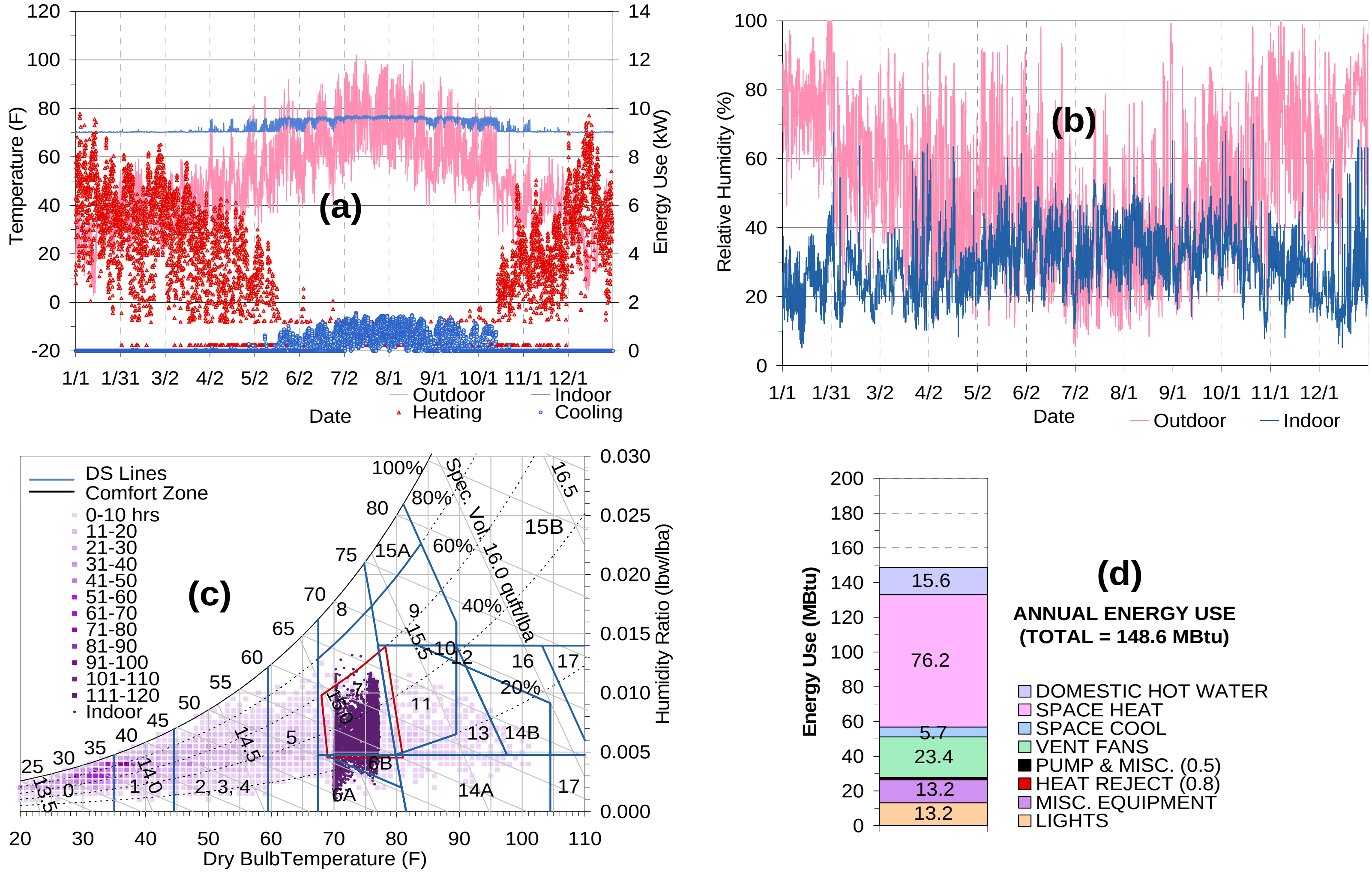
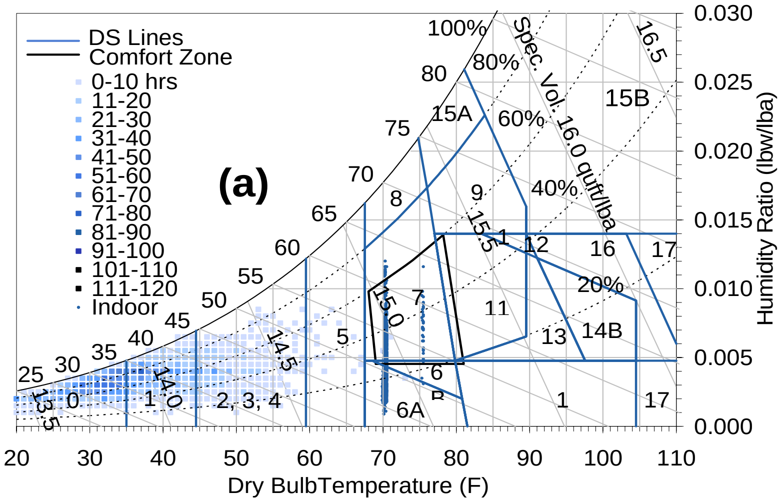
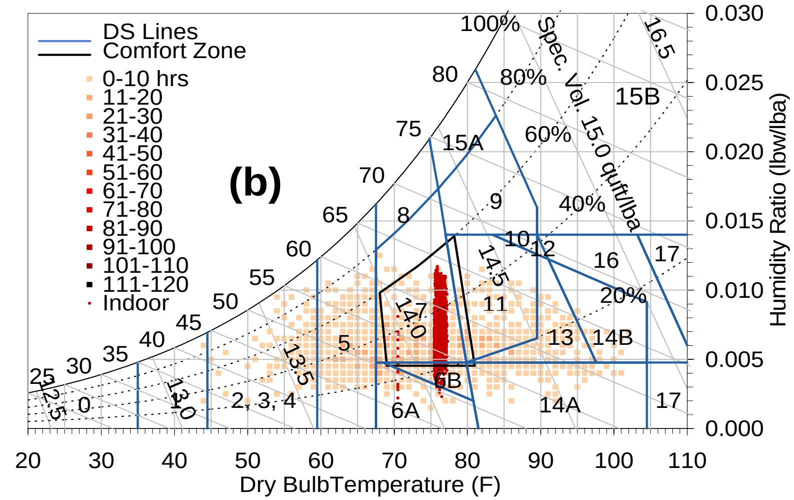
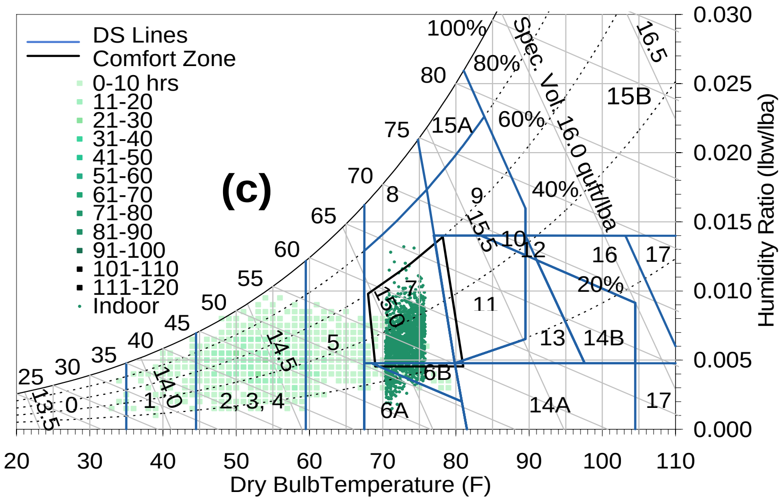


Figure D.7 *Annual hourly indoor and outdoor conditions and energy use of the lightweight house (base case) in the cool-dry climate, Boise, Idaho. (a) Indoor and outdoor dry-bulb temperatures and energy use of gas and electricity, (b) Indoor and outdoor relative humidity, (c) Indoor and outdoor conditions on the G-M Chart, and (d) Energy use of each category.*







BOISE (DT & NT) 6LIspvzd

(d)

Design Strategies	Regions	G-M Bio-Chart (%)	DOE-2 Simulation HTG (%)	DOE-2 Simulation CLG (%)	DOE-2 Simulation N-H-C (%)
Conventional Heating	0	21.79	21.76	0.00	0.03
Active Solar	1	20.02	18.74	0.02	1.26
Passive Solar	2,3,4	27.16	9.85	1.62	15.68
Internal Gains	5	11.26	0.22	6.82	4.22
Humidification	6A, 6B	3.09	0.01	2.57	0.51
Comfort Zone	7	9.25	0.02	8.92	0.31
Dehumidification	8	0.00	0.00	0.00	0.00
Ventilation	9,10,11	3.24	0.00	3.24	0.00
Evaporative Cooling	6B,11,13,14A,14B	8.33	0.00	8.25	0.08
High Thermal Mass	10,11,12,13	5.92	0.00	5.92	0.00
High Thermal Mass with Night Ventilation	16, 14B	0.22	0.00	0.22	0.00
Air-Conditioning	17	0.00	0.00	0.00	0.00
Air-Conditioning & Dehumidification	15A,15B	0.00	0.00	0.00	0.00
Number of Hours/Year		8760	4433	2398	1929
Percentage of Hours/Year		100.00	50.61	27.37	22.02

Region	0	1	2	3	4	5	6A	6B	7	8	9	10	11	12	13	14A	14B	15A	15B	16	17	Total
Hours	1909	1754	842	840	697	986	192	79	810	0	0	0	284	0	235	113	19	0	0	0	0	8760
G-M (%)	21.8	20.0	9.6	9.6	8.0	11.3	2.2	0.9	9.2	0.0	0.0	0.0	3.2	0.0	2.7	1.3	0.2	0.0	0.0	0.0	0.0	100.00
DOE-2 (%)		41.82							50.75												7.43	100.00

Figure D.8 *Daytime and nighttime annual hourly indoor and outdoor conditions of the lightweight house (base case) on the G-M Chart (cool-dry climate, Boise, Idaho). (a) Heating period, (b) Cooling period, (c) Non-heating-cooling period, and (d) Comparison of the results from the G-M Chart vs. the DOE-2 simulation..*

78 ºF). However, there are many hours-per-year when the indoor conditions fall below the humidity constraints of the comfort zone (i.e., below 36 °F dewpoint temperature), which indicates the need for humidification.

Figure D.7d shows that the total annual energy use is 148.6 MBtu. The energy use includes: domestic hot water (15.6 MBtu), space heating (76.2 MBtu), space cooling (5.7 MBtu), ventilation fans (23.4 MBtu), pump and miscellaneous (0.5 MBtu), heat rejection (0.8 MBtu), miscellaneous equipment (13.2 MBtu), and lights (13.2 MBtu). The results show that the energy use for space heating is the highest and significantly higher than the energy use for space cooling. Therefore, the design strategies for heating should be considered a priority.

Figure D.8a shows that most of the outdoor conditions during the heating period cover an area to the far left of the comfort zone. The majority of the hours involve the G-M definitions of conventional heating, active solar, and passive solar design strategies (regions 0, 1, and 2 to 4). Only a few hours fall into internal gains, humidification, and the G-M comfort zone (region 5 to 7). Most of the indoor temperatures stay close to the heating temperature setpoint of 68 °F. A small portion of the heating hours, which stay close to the cooling temperature setpoint of 78 °F, occur individually right after the hours that the cooling system was continuously activated (see the DOE-2 hourly report, Appendix B). These are most likely due to the indoor temperature fluctuations of a lightweight house. Figure D.8a shows that there are portions of the hours in this period, when the indoor conditions fall above or below the humidity constraints of the ASHRAE comfort zone (i.e., above 60 % relative humidity line and below 36 °F dewpoint).

Figure D.8b shows that the outdoor conditions during the cooling period fall into the comfort zone and are spread-out to the right and the left of the comfort zone. The cooling data covers the heating design strategy regions, which include passive solar, internal gains, and humidification (regions 2 to 4, 5, and 6); the G-M comfort zone (region 7); and the cooling design strategy regions, which are ventilation, evaporative cooling, and high thermal mass (regions 6B, 11, 13, and 14). A small portion of the cooling data falls within the areas of active solar and high thermal mass with night ventilation design strategies (regions 1 and 14B). The frequency of occurrence is high in the areas of internal gains design strategy and the G-M comfort zone (regions 5 and 7). Most indoor temperatures fall into the area of comfort zone and stay close to the cooling temperature setpoint of 78 °F. There are only a few hours of the cooling periods when the indoor temperatures stay close to the heating temperature setpoint of 68 °F. These hours usually occur individually right after the hours that the heating system was continuously activated (see the DOE-2 hourly report, Appendix B), which are most likely due to the indoor temperature fluctuations of a lightweight house. Figure D.8b shows that there is a portion of the hours in cooling period that the indoor conditions fall below the humidity constraints of the comfort zone (i.e., below 36 °F dewpoint).

Figure D.8c shows that majority of the outdoor conditions during the non-heating-cooling period fall to the left of the comfort zone, which include the areas of active solar, passive solar, and internal gain design strategies (regions 1, 2 to 4, and 5). A small portion of the hours falls within the areas of conventional heating, humidification, the G-M comfort zone, and evaporative cooling (regions 0, 6, and 7). The frequency of occurrence is high in the area of internal gains design strategy (region 5) and highest in the area of passive solar design strategy (regions 2 to 4). The indoor temperatures mostly float between the heating and cooling temperature setpoints (68 to 78 °F), with many hours falling below the humidity constraints of the comfort zone.

In Figure D.8d, the DOE-2 simulation shows that the heating system is activated for 4,433 hours-per-year (50.61%). There are 2,398 hours-per-year (27.37%) when the cooling system is activated and 1,929 hours-per-year (22.02%) when neither the heating nor cooling systems is activated. The results from the G-M Chart analysis show 3,663 hours-per-year (41.82%) in the heating period, 651 hours-per-year (7.43%) in the cooling period, and 4,446 hours-per-year (50.75%) in the non-heating-cooling period. The criteria used to identify the effective design strategies for heating, cooling, and non-heating-cooling periods in the G-M Chart analysis are described in Section 5.2.1.1 (see the last paragraph of p. 149).

Figure D.8d shows comparison of the results from the DOE-2 simulation and the results from the G-M bioclimatic chart. As mentioned in the previous paragraph, the DOE-2 simulation showed 50.61% of the hours-per-year in the heating period, which is more than the results from the G-M Chart (41.82%). In this period DOE-2 shows 21.76% of the time in conventional heating (region 0) and 18.74% of the time in active solar (region 1), which are a little less than the results from the G-M Chart showing 21.79% in conventional heating (region 0) and 20.02% in active solar (region 1). However, the DOE-2 simulation shows a significant portions of heating hours in passive solar design strategy (regions 2 to 4, 14.77%) and a small portion in internal gains (region 5, 0.22%), humidification (region 6A, 0.01%), and the G-M comfort zone (region 7, 0.02%).

In the cooling period (Figure D.8d), the DOE-2 simulation calculated 27.37% of the hours-per-year in many regions including active solar, passive solar, internal gains, humidification, the G-M comfort zone, ventilation, evaporative cooling, and high thermal mass with and without night ventilation design strategies (regions 1 to 7, 11, and 13 to 14). The G-M Chart shows only 7.43% of the hours-per-year in cooling period. The results from the DOE-2 simulation in 11 and 13 to 14; which include ventilation (3.24%), evaporative cooling (8.25%), high thermal mass with and without night ventilation (5.92% and 0.22%) correspond to the results from the G-M Chart analysis; respectively. However, the differences are in regions 1 to 7, where the DOE-2 shows a portion of the time in regions 1, 2 to 4, and 6 (active solar, 0.02%; passive solar, 1.62%; and humidification, 2.57%) and a significant portion of the time in regions 5 and 7 (internal gain, 6.82%; the G-M comfort zone, 8.92%). Unfortunately, in the G-M Chart analysis, regions 2 to 7 are not considered cooling periods.

In the non-heating-cooling period (Figure D.8d), the results from the DOE-2 simulation are significantly different from the results from the G-M Chart. The DOE-2 simulation shows 22.02% of the hours-per-year in this period while the G-M Chart shows as much as 50.75%. In regions 2 to 4 (passive solar), the results from the DOE-2 simulation (15.68%) are significantly less than the G-M Chart analysis results (27.16%).

The differences are also shown in regions 5 through 7 (internal gain, humidification, and the G-M comfort zone). In these regions DOE-2 shows only 4.22% (region 5), 0.51% (region 6), and 0.31% (region 7) versus the G-M Chart showing 11.26%, 3.09%, and 9.25%; respectively. In addition, the DOE-2 simulation shows a small portion of the hours falls into regions 0 (conventional heating, 0.03%) and 1 (active solar, 1.26%); where in the G-M Chart analysis are not included in the non-heating-cooling period.

Summary and discussion: A lightweight house (base case) was simulated using the TMY2 weather data for Boise, Idaho (cool-dry climate). The results showed a significant wide range of the outdoor temperatures (0 to 100 °F) and relative humidity (5 to 100%). The cooling period was almost half of the heating period and occurred mostly in the summer from mid of May through mid of October while the heating period occurred in the other periods of the year. The indoor temperatures fluctuated between heating and cooling temperature setpoints (68 to 78 °F), which corresponds to the activation of heating or cooling systems. The indoor temperatures during the winter were very well maintained near the 68 °F when the heating system was continuously activated (mid-November through March). The indoor relative humidity (RH) floated between 5 to 70%, which was well maintained during the cooling period than the other periods of the year. There was a significant portion of the hours in all periods of the year, especially in the heating period, that the indoor relative humidity fell below the humidity constraints of the comfort zone (i.e., below 36 °F dewpoint). The total annual energy use for the lightweight house (base case) in Boise, Idaho, was 148.6 MBtu, The heating energy use (76.2 MBtu) was significantly higher than the cooling energy use (5.7 MBtu). Therefore, the design strategies for heating should be considered a priority.

The DOE-2 simulation results showed that the outdoor conditions during the heating period covered an area to the left of the comfort zone from regions 0 through 7 (conventional heating, active solar, passive solar, internal gains, humidification, and the G-M comfort zone). The majority of the hours fell within regions 0 to 4. The outdoor conditions during the cooling period fell into the comfort zone and spread-out to the right and the left of the comfort zone; covering several regions from 1 to 7, 11, 13, and

14. The majority of the hours fell within the areas of passive solar (regions 2 to 4), internal gains (region 5), humidification (region 6), the G-M comfort zone (region 7), ventilation (region 11), evaporative cooling (regions 6B, 11, 13, and 14), and high thermal mass (regions 11 and 13). In the non-heating-cooling period, most of the hours during this period covered from regions 0 to 7, where the majority of the hours was in regions 1, 2 to 4, and 5 (active solar, passive solar, and internal gains).

In the heating period, the DOE-2 simulation yielded 50.61% of the hours-per-year, which was more than the G-M Chart results (41.82%). In the conventional heating (regions 0) and active solar (region 1), the results from the DOE-2 simulation were close to the results from the G-M Chart. However, DOE-2 showed a significant portion of the hours in passive solar (regions 2 to 4) and a small portion in internal gains (region 5), humidification (region 6), and the G-M comfort zone (region 7). Unfortunately, in the G-M chart analysis these regions were not considered heating periods.

In the cooling period, the DOE-2 simulation showed 27.37% of the hours-per-year, which was more than the G-M Chart results (7.43%). In regions 11, 13, and 14; which were ventilation, evaporative cooling, high thermal mass with and without night ventilation design strategies; the results from the DOE-2 simulation corresponded or were very close to the results from the G-M Chart analysis. However, the differences were in regions 1 to 7, with a significant portion falling in region 5 (internal gain) and region 7 (the G-M comfort zone); where in the G-M Chart analysis were not usually considered cooling periods.

In the non-heating-cooling period, the results from the DOE-2 simulation (22.02%) were significantly less than the results from the G-M Chart (50.75%). In regions 2 to 4 (passive solar), the results from the DOE-2 simulation are significantly less than the G-M Chart analysis results. The differences are also shown in regions 5 to 7 (internal gain, humidification, and the G-M comfort zone). In addition, DOE-2 showed a small portion of the hours-per-year in the regions 0 (conventional heating) and 1 (active solar), where in the G-M chart analysis these regions were not included in the non-heating-cooling period.

APPENDIX E

SOLAR DATA FOR THE SEVEN SELECTED CLIMATES

The monthly global horizontal (GBH) solar radiation for each selected climate was extracted from the TMY2 weather data using DOE-2 simulation program. Table E.1 shows comparison of the monthly global horizontal solar radiation as well as the total global horizontal solar radiation for the whole year of the seven representative cities (i.e., Bangkok, Houston, Phoenix, San Francisco, Chicago, Boston, and Boise). Figure E.1 shows a time-series plot of the monthly global horizontal solar radiation of the seven representative cities and Figure E.2 show comparison of the annual global horizontal solar radiation of the seven representative cities in a bar chart.

Table E.1 *Comparison of the monthly global horizontal solar radiation of the seven selected climates.*

Seven Selected Climates							
Month	**Bangkok** (Btu/ft²-month)	**Houston** (Btu/ft²-month)	**Phoenix** (Btu/ft²-month)	**San Francisco** (Btu/ft²-month)	**Chicago** (Btu/ft²-month)	**Boston** (Btu/ft²-month)	**Boise** (Btu/ft²-month)
1	46,252	26,603	31,952	21,703	17,335	18,196	16,558
2	46,021	29,749	38,181	28,051	23,032	24,647	23,022
3	57,693	41,970	54,061	40,891	34,891	37,261	37,869
4	53,165	46,752	68,532	54,229	45,654	43,692	50,122
5	49,611	55,174	79,809	65,788	58,718	54,767	63,238
6	48,354	58,213	78,748	68,100	59,856	57,343	68,760
7	47,028	57,829	76,908	74,417	62,687	59,272	75,218
8	42,639	54,318	70,516	64,244	50,713	53,450	65,110
9	43,850	46,604	59,808	52,820	39,868	40,494	48,568
10	43,238	41,660	48,982	38,135	29,842	31,138	34,249
11	44,709	30,324	34,827	23,334	17,397	18,044	19,039
12	45,140	23,830	28,761	19,197	13,793	15,553	14,481
Total	**567,700**	**513,026**	**671,085**	**550,909**	**453,786**	**453,857**	**516,234**

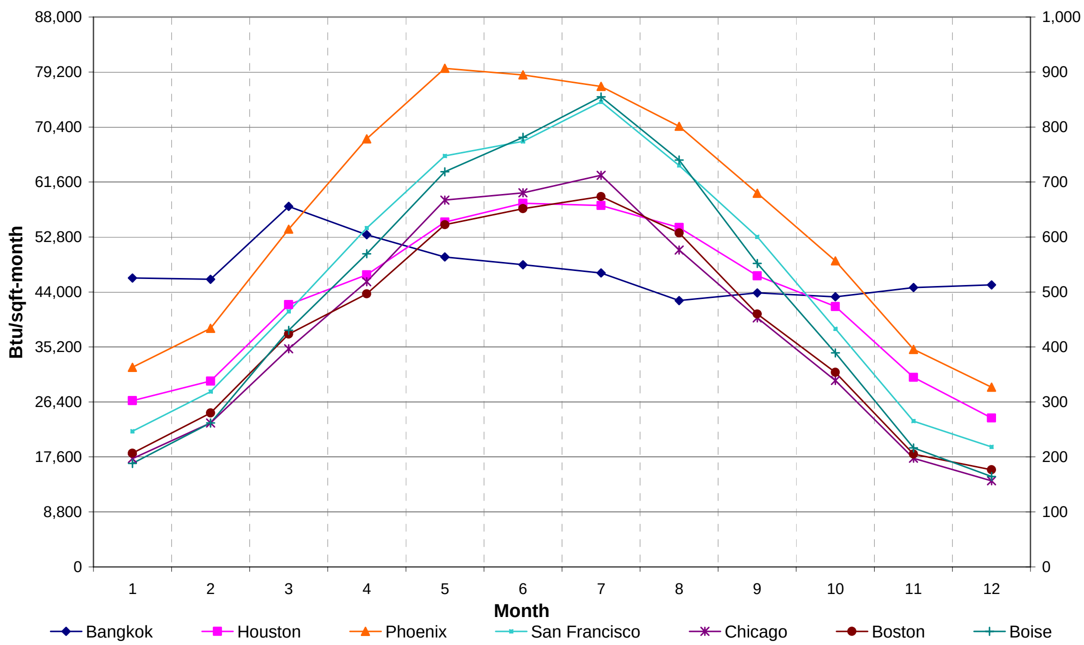


Figure E.1 *A time-series plot of the monthly global horizontal solar radiation of the seven selected climates.*

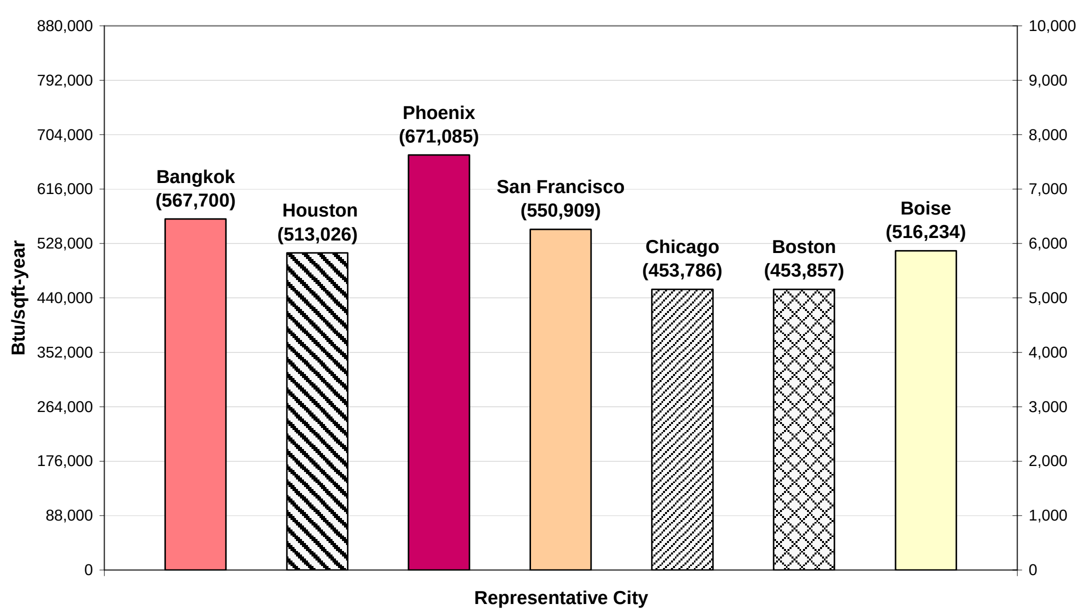


Figure E.2 *Comparison of the annual global horizontal solar radiation bar chart of the seven selected climates.*

Table E.1 and Figure E.1 show that the range of the monthly global horizontal solar radiation for the whole year of the very hot-humid, Bangkok, stayed in the range of 42,000 to 58,000 Btu/ft²-month (480 to 660 MJ/m²-month), which was significantly narrower than the other selected climates, where the monthly global horizontal solar radiation was highest in the summer and lowest in the winter. The monthly global horizontal solar radiation for Bangkok was highest in March (57,693 Btu/ft²-month, 655 MJ/m²-month) and lowest in August (42, 693 Btu/ft²-month, 485 MJ/m²-month). The range of the global horizontal solar radiation of the cool-dry climate (Boise, Idaho) was in the range of 15,000 to 76,000 Btu/ft²-month (170 to 870 MJ/m²-month), which was wider than the ranges of the other selected climates. The monthly global horizontal solar radiation for Boise was highest in July (75,218 Btu/ft²-month, 854 MJ/m²-month) and lowest in December (14,481 Btu/ft²-month, 165 MJ/m²-month). Table E.1 and Figure E.1 also show the highest and the lowest monthly global horizontal solar radiation of the hot-humid climate, Houston (57,829 and 23,830 Btu/ft²-month, 657 and 271 MJ/m²-month); hot-dry climate, Phoenix (79,809 and 28,761 Btu/ft²-month, 907 and 327 MJ/m²-month); warm-marine climate, San Francisco (74,417 and 19,197 Btu/ft²-month, 845 and 218 MJ/m²-month); cool-humid climates, Chicago (62,687 and 13,793 Btu/month-ft², 712 and 157 MJ/m²-month) and Boston (59,272 and 15,553 Btu/ft²-month, 673 and 177 MJ/m²-month).

Table E.1 and Figure E.2 show the annual global horizontal solar radiation for Bangkok (657,000 Btu/ ft²-year, 7,464 MJ/m²-year), Houston (513,026 Btu/ ft²-year, 5,828 MJ/m²-year), Phoenix (671,085 Btu/ ft²-year, 7,624 MJ/m²-year), San Francisco (550,909 Btu/year-ft², 6,258 MJ/m²-year), Chicago (453,786 Btu/year-ft², 5,155 MJ/m²-year), Boston (453,857 Btu/ ft²-year, 5,156 MJ/m²-year), and Boise (516,234 Btu/ ft²-year, 5,864 MJ/m²-year). The result shows that the annual global horizontal solar radiation was highest in Phoenix and lowest in Chicago.

APPENDIX F

HUMIDIFICATION AND DEHUMIDIFICATION ANALYSIS

The DOE-2 simulation results of the lightweight house (base case), the lightweight house without internal loads, the high thermal mass house, and the lightweight house with an economizer in the hot-humid climate (Houston, Texas) (Sections 5.2.1.1, 5.2.2.1, 5.2.3.1, and 5.2.4.1) showed that there were many hours-per-year that the indoor humidity fell above or below the humidity constraint of the ASHRAE comfort zone (ASHRAE, 1992); which were above the 80% of relative humidity (RH) line or below the 36 °F of dewpoint temperature line. The data of the indoor and outdoor conditions of these periods were extracted and superimposed onto the psychrometric chart (Figures F.1 through F.3). The number of hours-per-year of these periods were calculated and presented in Tables F.1 and F.2

Figure F.1 shows the DOE-2 simulation results of the lightweight house (base case) (Figure F.1a), the lightweight house without internal loads (Figure F.1b), the high thermal mass house (Figure F.1c), and the lightweight house with an economizer (Figure F.1d) houses in the hot-humid climate (Houston, Texas). The figures show the indoor and the corresponding outdoor conditions for the whole year when the indoor humidity was too low (i.e., below 36 °F dewpoint line). The indoor conditions are presented in dark purple dots and the outdoor conditions are presented in light purple squares. Figures F.1 shows that for all prototype houses the outdoor conditions fell upon the area below the 36 °F dewpoint line to the left of the comfort zone, which indicates the need for humidification.

In a similar fashion as Figures F.1, Figure F.2 show the DOE-2 simulation results of the lightweight house (base case) (Figure F.2a), lightweight house without internal loads (Figure F.2b), the high thermal mass house (Figure F.2c), and the lightweight house with an economizer (Figure F.2d) in the hot-humid climate (Houston, Texas). The Figures show the indoor and the corresponding outdoor conditions for the whole year when the indoor humidity was too high (i.e., above 80% relative humidity line).

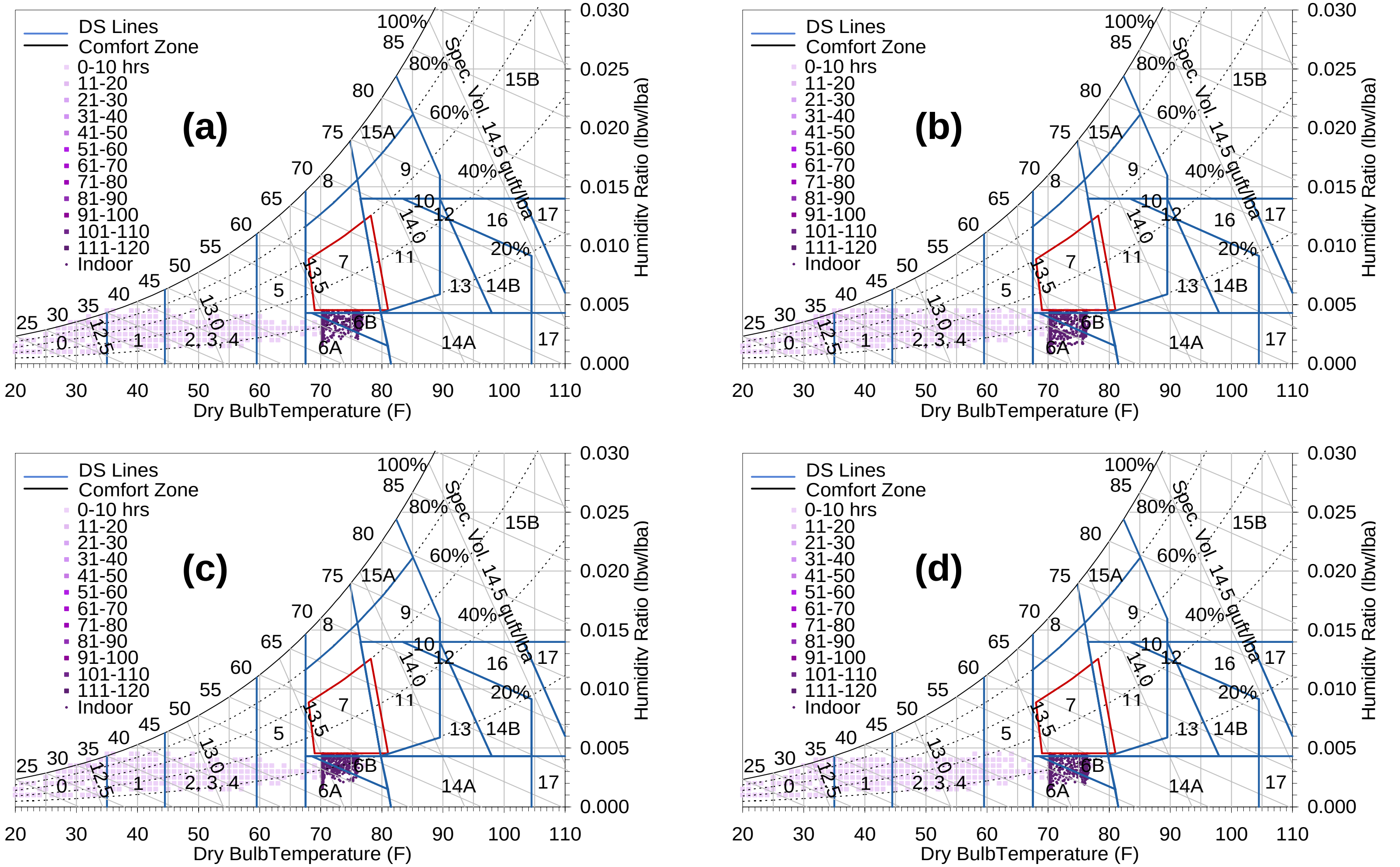


Figure F.1 *Annual hourly outdoor conditions for all periods, when the indoor humidity is too low, of the prototype houses in the hot-humid climate, Houston, Texas. (a) lightweight (base case), (b) lightweight with no internal loads, (c) high thermal mass, and (d) lightweight with an economizer.*

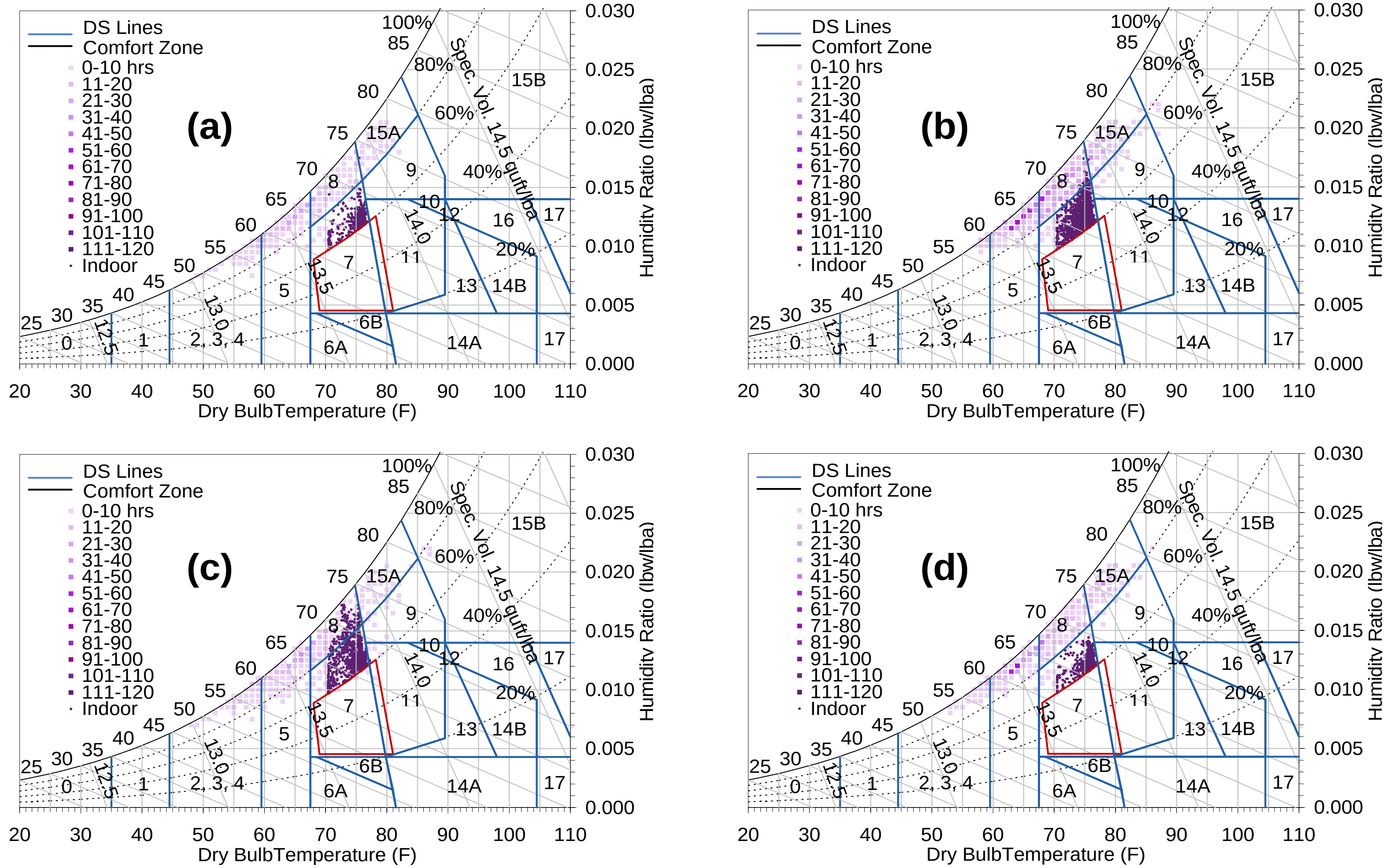


Figure F.2 *Annual hourly outdoor conditions, when the indoor humidity is too high, of the prototype houses in the hot-humid climate, Houston, Texas. (a) lightweight (base case), (b) lightweight with no internal loads, (c) high thermal mass, and (d) lightweight with an economizer.*

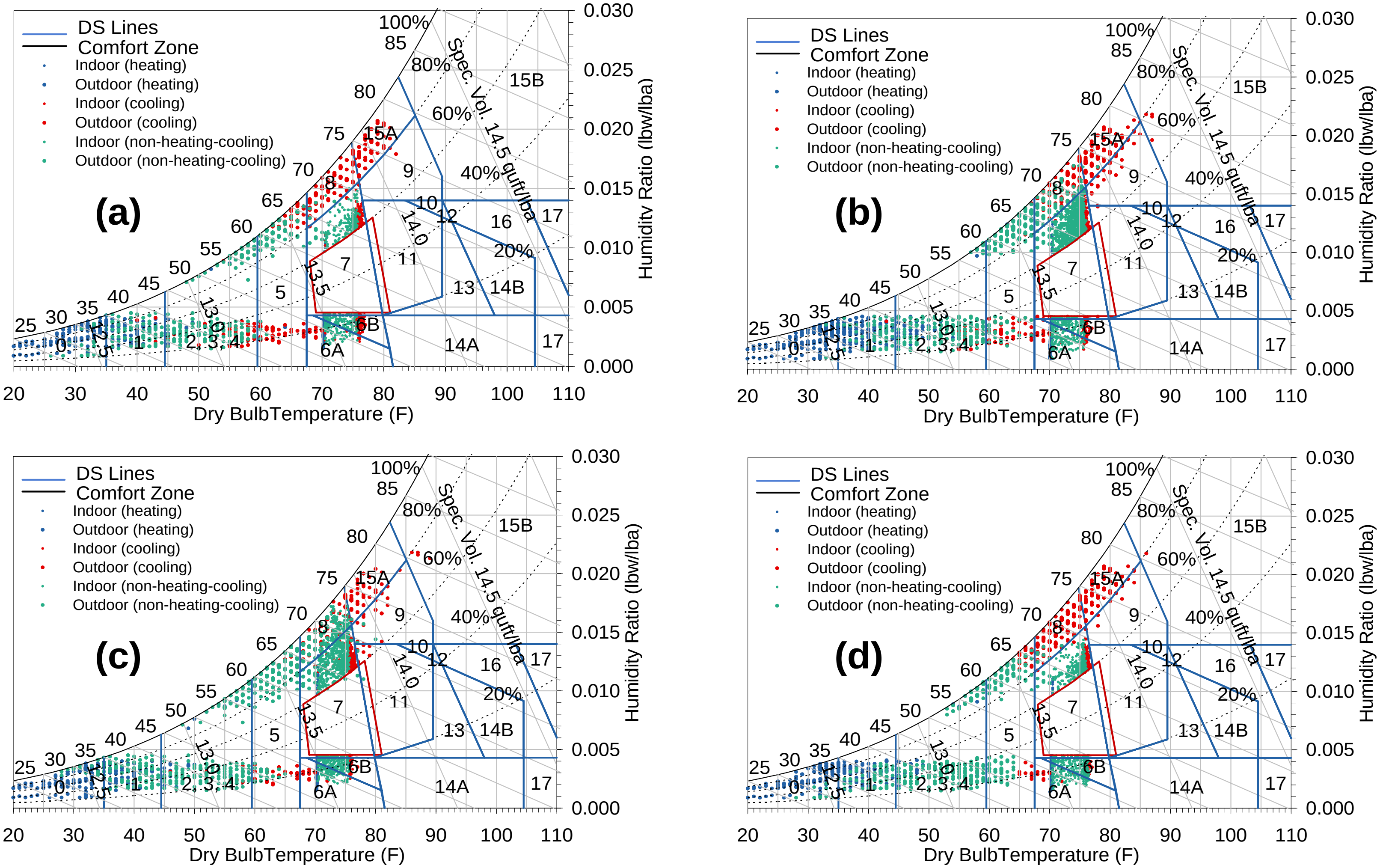


Figure F.3 *Annual hourly outdoor condition for heating, cooling, and non-heating-cooling periods, when the indoor humidity is too high or too low, of the prototype houses in the hot-humid climate, Houston, Texas. (a) lightweight (base case), (b) lightweight with no internal loads, (c) high thermal mass, and (d) lightweight with an economizer.*

Table F.1 *Annual humidification periods of the prototype houses, lightweight (base case), lightweight without internal loads, high thermal mass, and lightweight with an economizer, in the hot-humid climate, Houston, Texas.*

HUMIDIFICATION PERIODS

DOE-2 Simulations	Heating		Cooling		Non-Heating-Cooling		ALL	
	(hrs-per-year)	(%)	(hrs-per-year)	(%)	(hrs-per-year)	(%)	(hrs-per-year)	(%)
Lightweight (Base-case)	278	3.2%	117	1.3%	226	2.6%	621	7.1%
Lightweight without Internal Loads	626	7.2%	113	1.3%	308	3.5%	1047	12.0%
High Thermal Mass	272	3.1%	51	0.6%	293	3.3%	616	7.0%
Lightweight with an Economizer	300	3.4%	20	0.2%	330	3.8%	650	7.4%

Table F.2 *Annual dehumidification periods of the prototype houses, lightweight (base case), lightweight without internal loads, high thermal mass, and lightweight with an economizer, in the hot-humid climate, Houston, Texas.*

DEHUMIDIFICATION PERIODS

DOE-2 Simulations	Heating		Cooling		Non-Heating-Cooling		ALL	
	(hrs-per-year)	(%)	(hrs-per-year)	(%)	(hrs-per-year)	(%)	(hrs-per-year)	(%)
Lightweight (Base-case)	13	0.2%	547	6.2%	213	2.4%	773	8.8%
Lightweight without Internal Loads	53	0.6%	1081	12.3%	943	10.8%	2077	23.7%
High Thermal Mass	40	0.4%	470	5.4%	594	6.8%	1104	12.6%
Lightweight with an Economizer	23	0.3%	840	9.6%	432	4.9%	1295	14.8%

Figures F.2 shows that for all prototype houses the majority of the outdoor conditions fell upon the area above the 80% relative humidity line and the 54 °F dewpoint line, which this area indicates the need of dehumidification.

Figure F.3 shows the DOE-2 simulation results of the lightweight (base case) house (Figure F.3a), lightweight house without internal loads (Figure F.3b), the high thermal mass house (Figure F.3c), and the lightweight house with an economizer (Figure F.3d) in the hot-humid climate (Houston, Texas). The Figures combines the indoor and the corresponding outdoor conditions for the whole year when the indoor humidity was too high or too low (i.e., above 80% relative humidity line and below 36 °F dewpoint line). The indoor conditions during the heating, cooling, and non-heating-cooling periods are presented in blue, red, and green dots; respectively. The outdoor conditions during the heating, cooling, and non-heating-cooling periods are presented in blue, red, and green circles; respectively. The number of hours-per-year and its percentage for each period are calculated and shown in Tables F.1 and F.2.

In Table F.1, the DOE-2 simulation results for the lightweight house (base case) showed that there were 621 hours in the year (7.1%) when the indoor humidity was too low (i.e., below 36 °F dewpoint line); which the fraction of the hours in the year were 3.2% in the heating period, 1.3% in the cooling period, and 2.6% in the non-heating-cooling period. For the lightweight without internal load house, DOE-2 showed that there were 1,047 hours in the year (12.0%) when the indoor humidity was too low (i.e., below 36 °F dewpoint line). The fractions of these hours in the year were 7.2% in the heating period, 1.3% in the cooling period, and 3.5% in the non-heating-cooling period.

For the high thermal mass house, DOE-2 showed that there were 616 hours in the year (7.0%) when the indoor humidity was too low; inwhich the fraction of the hours in the year were 3.1% in the heating period, 0.6% in the cooling period, and 3.3% in the non-heating-cooling period. In Table F.1, the DOE-2 simulation results for the lightweight with an economizer house showed that there were 650 hours in the year (7.4%) when the indoor humidity was too low. The fraction of the hours in the year were 3.4% in the heating period, 0.2% in the cooling period, and 3.8% in the non-heating-cooling period.

In Table F.2, the DOE-2 simulation results for the lightweight house (base case) showed that there were 773 hours in the year (8.8%) when the indoor humidity was too high (i.e., above 80% relative humidity line); inwhich the fraction of the hours in the year were 0.2% in the heating period, 6.2% the in cooling period, and 2.4% in the non-heating-cooling period. For the lightweight without internal load house, DOE-2 showed that there were as much as 2,077 hours in the year (23.7%) when the indoor humidity was too high (i.e., above 80% relative humidity line). The fraction of the hours in the year were 0.6% in the heating period, 12.3% in the cooling period, and 10.8% in the non-heating-cooling period.

For the high thermal mass house, DOE-2 showed that there were 1,104 hours in the year (12.6%) when the indoor humidity was too high; which the fraction of the hours in the year were 0.4% in the heating period, 5.4% in cooling period, and 6.8% in the non-heating-cooling period. In Table F.2, the DOE-2 simulation results for the lightweight house with an economizer house showed that there were 1,295 hours in the year (14.8%) when the indoor humidity was too high. The fraction of the hours in the year were 0.3% in the heating period, 9.6% in the cooling period, and 4.9% in the non-heating-cooling period.

In summary, the DOE-2 simulations results for the four prototype houses, lightweight (base case), the lightweight without internal loads, the high thermal mass, and the lightweight with an economizer houses in the hot-humid climate (Houston, Texas) showed the that there were portions of the hours in the year that the indoor humidity fell outside the humidity constraint of the ASHARE comfort zone (ASHRAE 1992), which indicated the area that humidification or dehumidification design strategies should be employed. The corresponding outdoor conditions when the indoor humidity was too low covered the area below the 36 °F dewpoint line; hence, the needs of humidification design strategy. The corresponding outdoor conditions when the indoor humidity was too high covered the area above the 80% relative humidity ratio line and above the 54 °F dewpoint line; hence, the need of dehumidification design strategy.

The percentages of the hours-per-year when the humidification system is needed for each house is very close to each other except for the house without an internal loads. However, the percentages of the hours-per-year of this design strategy are slightly higher than the others. This is most likely due to the removal of the humidity from the occupants

The percentages of hours-per-year, which show the need for dehumidification, is lowest for the lightweight house (base case) and highest for the lightweight house without internal loads. This is due to the percentages of the cooling hours, which the air-conditioning system helps to remove moisture in the air, are highest for the lighweight house (base case), and lowest for the lightweight house without internal loads.

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Visitsak, S. and Haberl, J. S. 2004. An Analysis of Design Strategies for Climate Controlled Residences in Selected Climates, *Proceedings of the IBPSA Conference: SimBuild 2004*.International Building Performance Simulation Association, Boulder, CO, August.

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