

DESIGN TOOLS FOR EVALUATING ALTERNATIVE STRATEGIES' IMPACT ON HUMAN COMFORT

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ABSTRACT

Many designers recognize that energy savings can be achieved with alternative or innovative strategies; however, few design tools have been available to assist designers with evaluating alternatives. This paper demonstrates the use of a standard psychrometric chart enhanced with an expanded comfort zone plot based on multiple energy conservation strategies. Average local weather conditions can be plotted by month on the psychrometric chart to indicate which design alternatives have the greatest potential benefits. By utilizing a familiar engineering design tool to communicate integrated design techniques, better coordination can be achieved between architects and engineers. Victor Olgyay pioneered similar work at Notre Dame in the 1950's; however, his unusual graphical presentation has hindered widespread understanding and use of the fundamentals of expanded comfort zones.

This paper outlines the basic concept of the expanded comfort zone with applications for use of mean radiant temperatures, direct radiation, air movement and evaporative cooling with examples shown for Dallas and Houston climates.

INTRODUCTION

Buildings are designed to house man's ongoing activities. These activities encompass a wide variety of ideals, goals and purposes. At the outset of a building's design, many desires and objectives are developed to define the purposes and set standards for the range of conditions which the building will provide. One of the major conditions which must be established is that of human comfort. Provisions for human comfort in a building, most notably those of thermal comfort and visual comfort, define the single most energy consuming factor in the ongoing operation of a building. Energy is required to provide for comfort conditions because the natural climate is not always ideal; therefore we have developed systems to overcome the natural environment. The objective of the paper is to show that the building, through a judicious design approach, may become the primary comfort - attaining system by offsetting the varied and often uncomfortable natural climate.

HUMAN PHYSIOLOGY

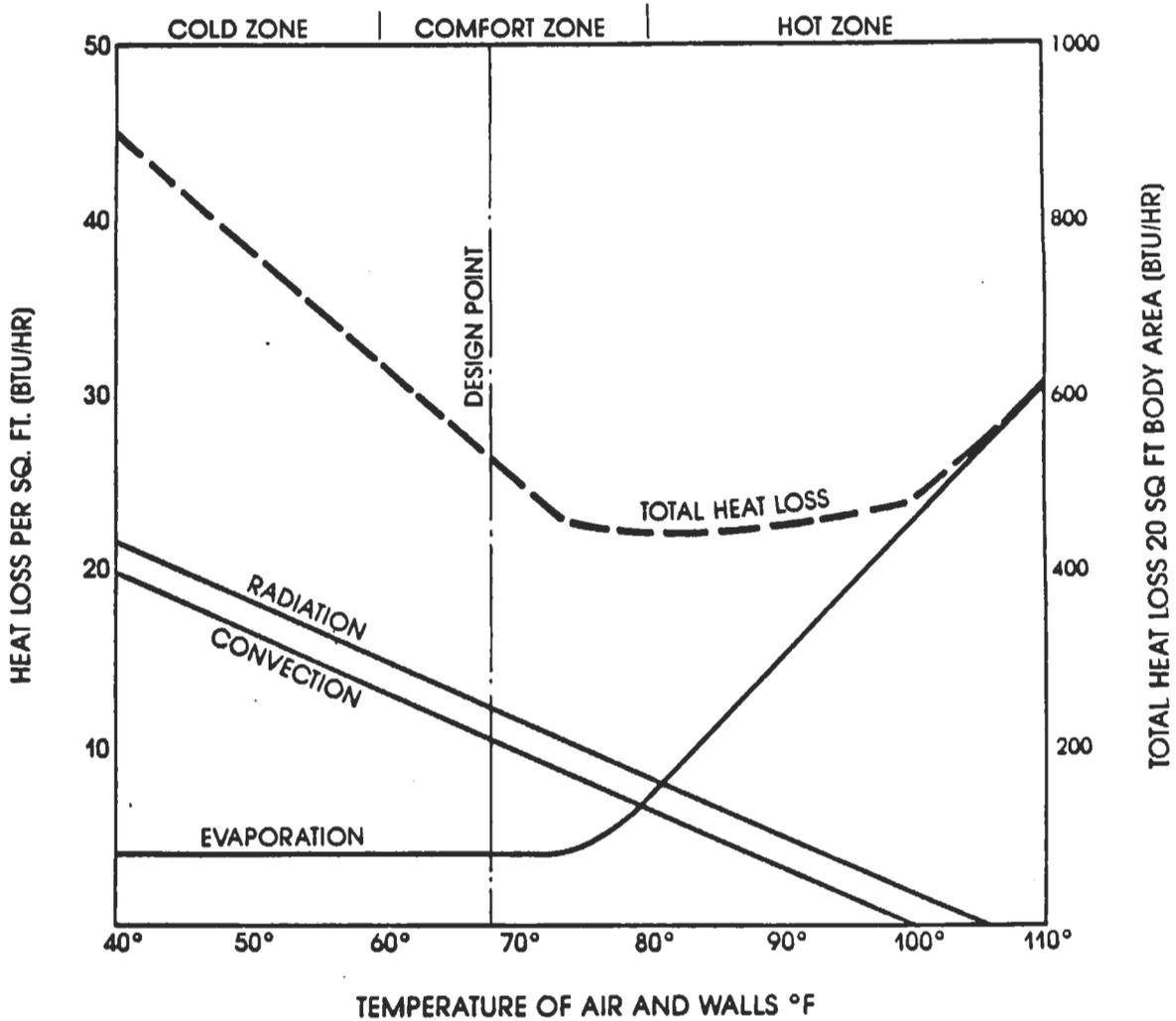
Energy - efficient building design necessitates the understanding of man's comfort level within the natural environment and the climatic zone.

Humans produce energy through the metabolic process of digested food. The rate of metabolism is dependent upon the activity of the individual.

Since the body often produces an excess amount of heat, people must be able to dissipate heat to the surrounding environment in order to maintain comfort. There are three primary ways in which this heat may be dissipated: convection, radiation, and evaporation. Based on those temperatures and conditions commonly associated with human comfort, the percentage contribution of each facet of body heat loss are: radiation, 55%; evaporation of skin and lung moisture, 30%; and convection, 15%, Figure 1. Conduction, the fourth means of transferring heat, has a negligible impact on body heat loss under normal conditions.

As the temperature of air and materials in the surrounding environment rise, the loss of body heat by convection and radiation decreases. As the temperatures drop, the loss of body heat by convection and radiation increases. If the temperature of air and materials in the surrounding environment equal the internal body temperature of people, body heat loss through convection and radiation would cease. If the temperatures exceed that of internal body temperature, the body would gain heat from the environment through convection and radiation, thus causing the body to overheat.

The moisture content of the air has a major impact on the body's ability to dissipate heat through evaporation. As relative humidity in the surrounding environment increases, the body's evaporative means of dissipating heat becomes less effective. Air movement around the body has a major impact on the evaporative process by assisting in the removal of skin moisture.



FORMS OF HEAT LOSS FROM THE HUMAN BODY UNDER VARYING CONDITIONS

Figure 1

PSYCHROMETRICS

A Psychrometric Chart is a tool to help designers understand the interaction of factors affecting human comfort. It has been widely accepted as the standard method for identifying climatic conditions affecting human comfort.

Atmospheric air is a mixture of several gases and water vapor. Dry air is a term used to describe a theoretical air which has had all of the water vapor removed. The composition of the dry component of air remains essentially constant while the quantity of water vapor varies greatly. Therefore, air can be treated as a two component mixture consisting of dry air and water vapor.

Although only .24 Btu is required to raise the temperature of a pound of air one degree F, 970 Btu are required to convert one pound of water from liquid to vapor at a standard atmospheric pressure. Thus, while water vapor may represent only a small portion of the mass of air, the energy required to add or remove water from air often represents a significant component of the total heat added or removed from air when its state is changed from one condition to another. This, coupled with the fact that the quantity of water vapor in air has a major impact on human comfort, makes the study of moist air characteristics very important. This study is termed psychrometrics.

Psychrometric charts plot various characteristics of moist air over a broad range of conditions. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) publishes a variety of these charts for different temperature ranges and elevations. Abridged versions of the chart for standard atmospheric pressure appear in Figures 2 through 4.

As noted earlier, the quantity of moisture that air can hold increases as the temperature increases. At any given temperature the condition at which air can hold no more water vapor is called saturation. The term relative humidity refers to the existing percentage of the maximum possible moisture that is

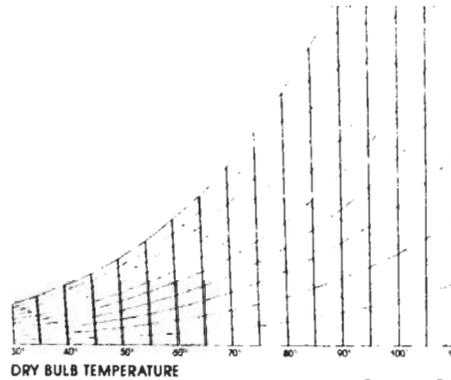


Figure 2

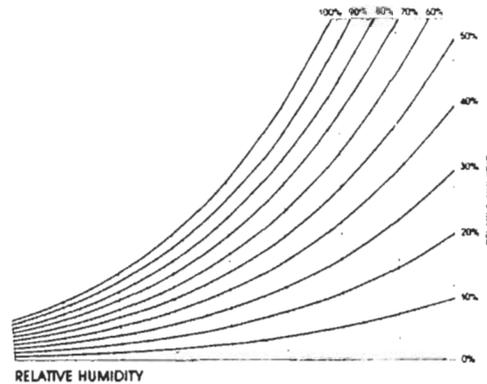


Figure 3

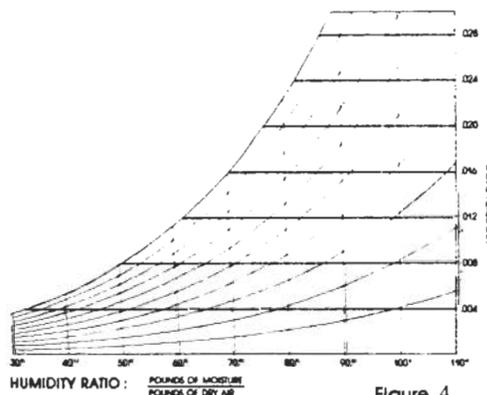


Figure 4

contained in the air. This parameter is important because it is an indicator of how readily moisture can be added to the atmosphere. Figures 2 and 3 are abridged psychrometric charts showing lines of constant relative humidity and dry bulb temperature.

The ratio of moisture to dry air in a moist air mixture is termed the humidity ratio. Lines of constant humidity appear as horizontal lines on the abridged psychrometric chart in Figure 4. These lines represent a heating or cooling process, in which no moisture is added or removed from the air.

Another process in which water is evaporated into the air while no heat is added or removed, is shown by diagonal lines in Figure 5. These lines are called lines of constant wet bulb temperature. They are indicative of supply air conditions that can be achieved in an evaporative cooling process.

Heating and air conditioning processes involve the movement of air at modified conditions into the occupied space. Of primary concern in the design of heating and cooling systems is the determination of how much energy is required to change conditions from one state to another during the flow process. A parameter which aids in this determination is termed enthalpy. Enthalpy (Figure 6) is a thermodynamic property of a fluid which defines the potential to do work due to the temperature, pressure, and moisture content on the fluid. Functionally, enthalpy is used to determine the amount of work required to change air from one condition to another for comfort conditions. The equation to describe this process is: $\text{heat flow rate} = \text{mass flow rate} \times (\text{enthalpy @ state one} - \text{enthalpy @ state two})$. Technically this is not how enthalpy is defined, but how it is applied. For the purpose of this text it provides the simplest and most useful explanation of the concept of enthalpy. Lines of constant enthalpy appear on psychrometric charts as diagonal lines which are almost parallel to lines of constant wet bulb temperature. For the purpose of evaluating building energy performance, the error resulting from the assumption that a constant wet bulb line is a constant enthalpy line is negligible.

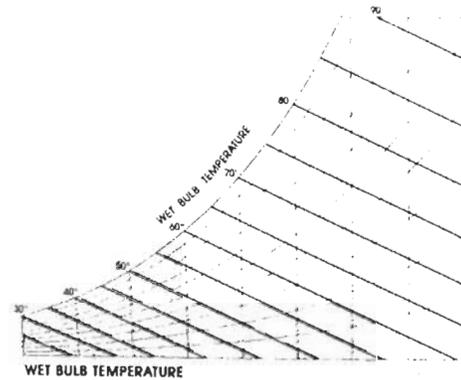


Figure 5

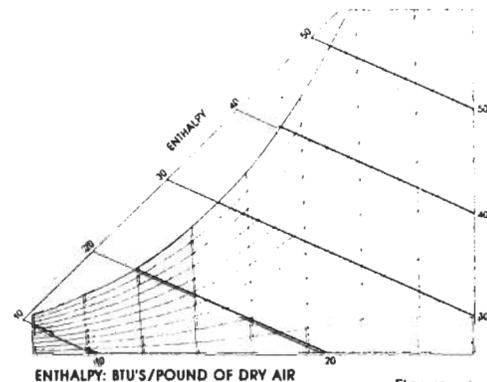


Figure 6

Therefore this simplification will be made in the energy analysis approach of this text.

METHODS OF CHANGING VALUES

The methods for changing values on the psychrometric chart are straightforward and easily understood. Refer to Figure 7 and the following explanation of the methods of changing values for comfort conditions.

1. Assuming the existing conditions are cold, sensible heating will raise the dry-bulb temperature without adding or removing moisture to the air.
2. Humidification is directly adding moisture to the air and doesn't change the dry-bulb temperature. (Although some changes in sensible temperature may occur depending upon the equipment used.)
3. Evaporative cooling takes warm air and adds moisture to it, thereby lowering the dry-bulb temperature. Evaporative cooling is merely the exchange of latent heat (moisture) for sensible heat (temperature) in the air.
4. Sensible cooling is just the opposite of sensible heating, the dry-bulb temperature is lowered without adding or removing moisture.
5. Conventional air conditioning serves two purposes: first, warm air is circulated through cold coils which reduces the temperature, then the moisture in the warm air condenses on the cold coils which reduces humidity.
6. Dehumidification is the opposite of humidification; it removes moisture from the air without affecting the dry-bulb temperature. (Again, depending upon the system or equipment, some sensible temperature change may occur.)

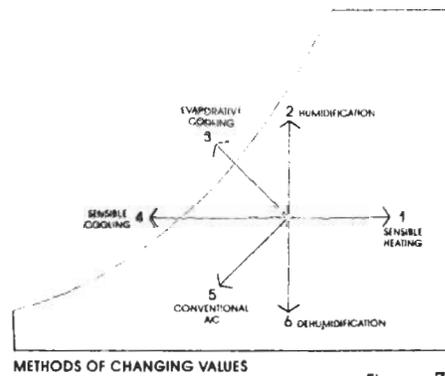
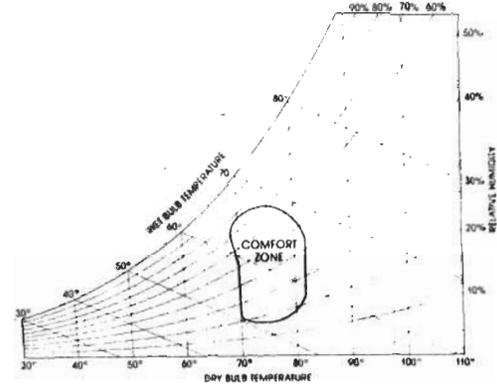


Figure 7

HUMAN COMFORT ZONE

From the preceding discussion, it becomes apparent that it is the combination of temperatures of air and surrounding materials, humidity, air movement and radiation that determine human comfort; thus, a variety of combinations can provide the same perception of comfort or discomfort. The comfort zone is defined as those temperatures and humidity conditions where 50% or more people feel comfortable. There are a number of examples where the comfort zone has been graphically presented.

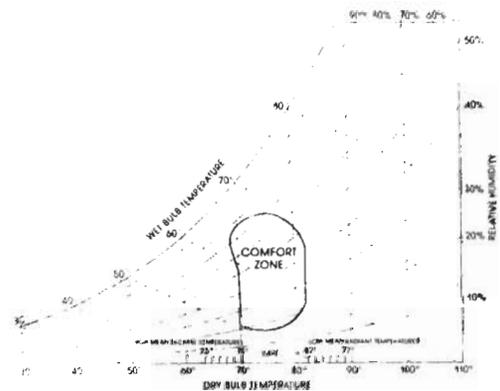
The first example is that of Victor Olgyay's work, carried out at Notre Dame in the early 1950's. He was the first to present human comfort within the context of an architectural environment. To better understand the relationship of human comfort under conditions of still air and no radiant input, we will be projecting the data from Olgyay's "bioclimatic" comfort chart onto the psychrometric chart shown in Figure 8.



PSYCHROMETRIC CHART AND COMFORT ZONE IN STILL AIR

Figure 8

A series of overlays are presented on this chart to illustrate the impact of various environmental inputs. The first element we will study is radiation, broken into two categories: mean radiant temperature (average temperature of objects in the surrounding environment) and insolation (radiant energy from the sun). Looking at the impact of mean radiant energy, an overlay is added above the dry bulb temperature scale in Figure 9. It can be seen from this combination that the raising of mean radiant temperature would allow cooler space air temperature and still achieve human comfort levels. Likewise, the lowering of mean radiant temperature would allow higher than normal air temperatures to still be perceived as comfort levels. It should be noted that mean radiant temperature can also be detrimental by exaggerating discomfort. This frequently occurs in the built environment when abnormally high or low mean radiant temperatures occur while dry bulb temperatures are within the comfort zone. A good example of this is poorly insulated buildings that must be cooled to a lower temperature in summer and heated to higher temperatures in winter to achieve human comfort.



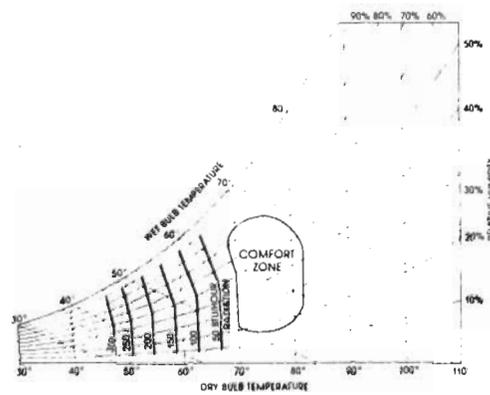
THE EFFECT OF MEAN RADIANT TEMPERATURE ON HUMAN COMFORT

Figure 9

The second form of radiation to be discussed is insolation (incoming solar radiation). By studying Figure 10, it can be seen that insolation introduced into a cool environment can effectively create an environment where conditions are comfortable. Again, it should be noted that solar radiation allowed into a comfortable or overheated environment would require a cooling strategy to compensate for it. Most of the built environment allows excessive isolation during the cooling season which decreases comfort and increases load.

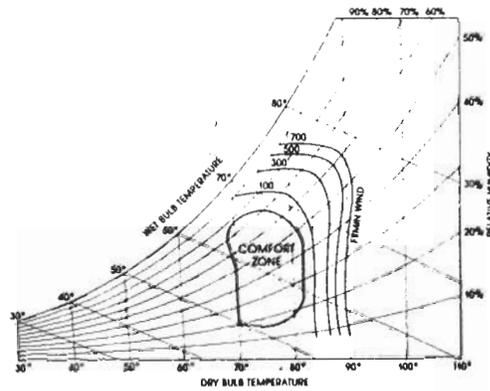
Figure 11 presents the positive impact of air movement on human comfort. The comfort zone, through increased natural or induced ventilation, may be extended upward into higher temperatures and humidities. A number of items are worth noting related to air movement. It is desirable for purposes of comfort to maintain a minimum of 10 to 20 feet per minute of air movement to remove stuffiness and air stratification. Air movement in the range of 40 to 100 fpm is quite tolerable under most conditions. The feeling of draftiness can occur in a range of approximately 200 to 350 fpm, but, in warm conditions, will assist in body cooling through evaporation and can be quite acceptable even in office environments. At this velocity, the perceived temperature is 4 to 7 degrees lower. In the 350 to 500 fpm range, air movement may become objectionably noisy and drafty for an office environment, although comfort can still be achieved for the building's occupants. According to Olgay, this is no comfort benefit above 850 fpm (10 mph) air movement. The increased awareness of the positive attributes of air movement is demonstrated by the current proliferation of ceiling fans in residential and commercial buildings.

The benefits of increasing grains of water per cubic foot of air are illustrated by Figure 12. In drier climates, as the moisture content is increased, there is a perceptible cooling effect. This principle is incorporated into the evaporative water coolers used in dry climate areas. Another important by-product of increased relative humidity is improved human health. Several research projects carried out by ASHRAE have



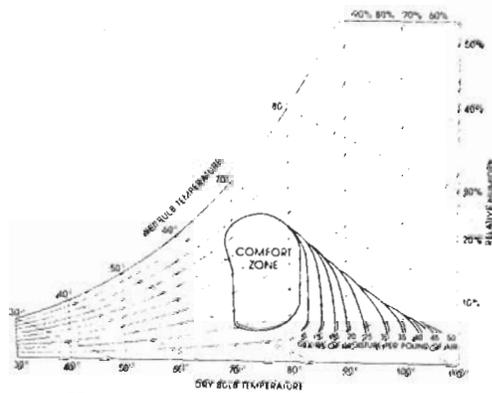
THE EFFECT OF SOLAR RADIATION ON HUMAN COMFORT

Figure 10



THE EFFECT OF AIR MOVEMENT ON HUMAN COMFORT

Figure 11



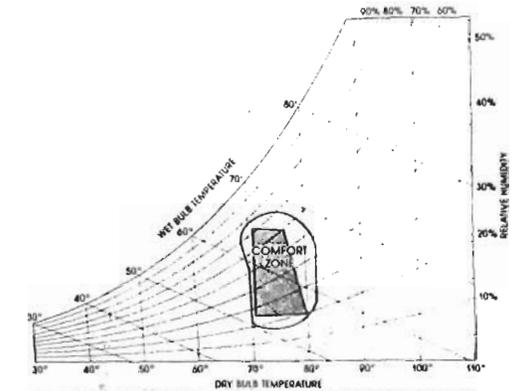
THE EFFECT OF MOISTURE ADDITIONS ON HUMAN COMFORT

Figure 12

shown the benefits to health with increased humidity. These benefits can even be found in humid climates, when higher humidity levels increase well-being in interior spaces during the winter.

A linear correlation between relative humidity and percent absenteeism was found in Canadian public schools, showing a 20 percent reduction in overall absenteeism as the average relative humidity was increased from 22 to 35 percent. Similar results were obtained in a Swiss school and in U.S. Army barracks.

A second comfort zone with wide acceptance today is the comfort zone of ASHRAE, with its latest revision patterned after the work of P.O. Fanger. The ASHRAE comfort zone is a smaller zone which fits within the zone described by Victor Olgay. Figure 13 illustrates the ASHRAE comfort zone superimposed on Olgay's comfort zone.



ASHRAE'S COMFORT ZONE SUPERIMPOSED ON OLGAY'S COMFORT ZONE

Figure 13

ZONES OF STRATEGIES

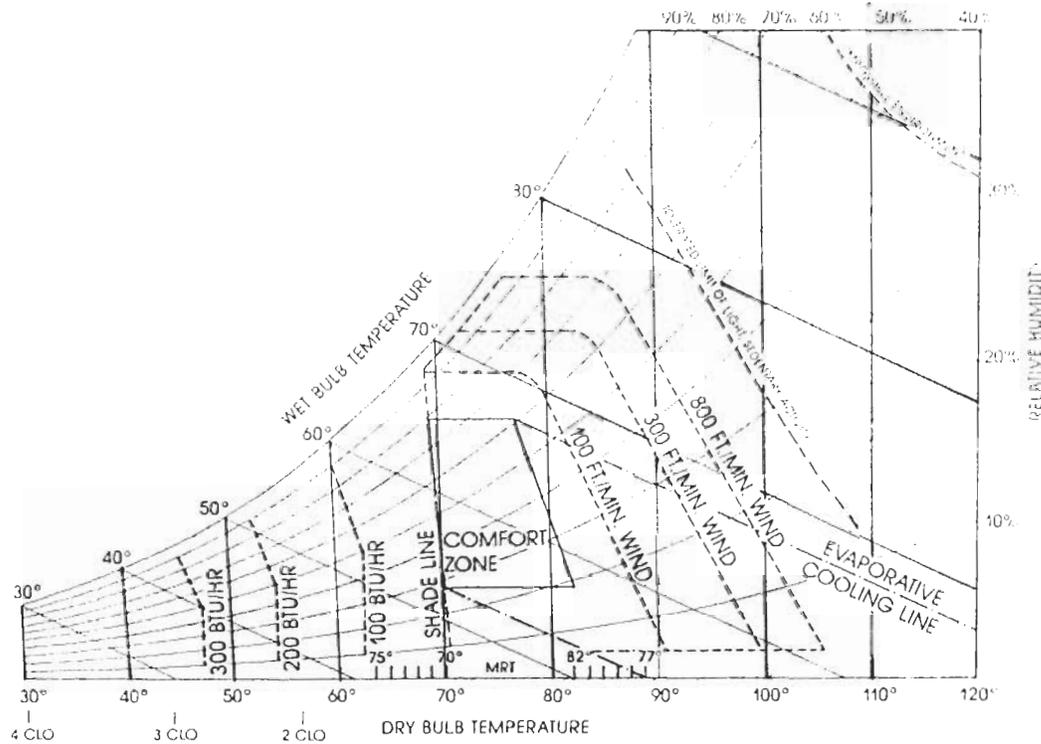
Figure 14 illustrates strategies for analyzing the comfort zone based upon human comfort studies by Victor Olgay. The ranges of various climate factors should not be viewed as set zones for single strategies, but rather as suggested ranges for possible solutions working within the constraints established by the particular program parameters.

Climate-induced design strategies shown on the psychrometric chart include wind and solar factors working within the temperature and humidity limits of human comfort. The area to the left of the comfort zone indicates strategies for including solar radiation within a built environment to offset heating requirements by mechanical means. The cooling zone above 80 degree F indicates zones for strategies that can be influenced by ventilation, either natural or mechanical, or evaporative cooling. Areas outside the limits of these zones can be brought into the comfort zone by mechanical heating or cooling systems.

PLOTTING CLIMATE DATA

Climate data for Austin, Houston, and Dallas are superimposed upon the strategy charts in Figures 15, 16, and 17. The information for plotting this data is found in the NOAA Local Climatological Data Sheets. The values to be plotted are the average daily minimum and maximum temperatures and humidities, with the point for the minimum temperature and maximum humidity, (usually 6:00 a.m.) plotted as well as the point for the maximum temperature and minimum humidity (usually 4:00 p.m.). These values are found under "Normals, Means, and Extremes", with the temperature value found under "Daily maximum and Daily minimum", and the values for relative humidity found under "Relative Humidity Pct" with the values at different hours.

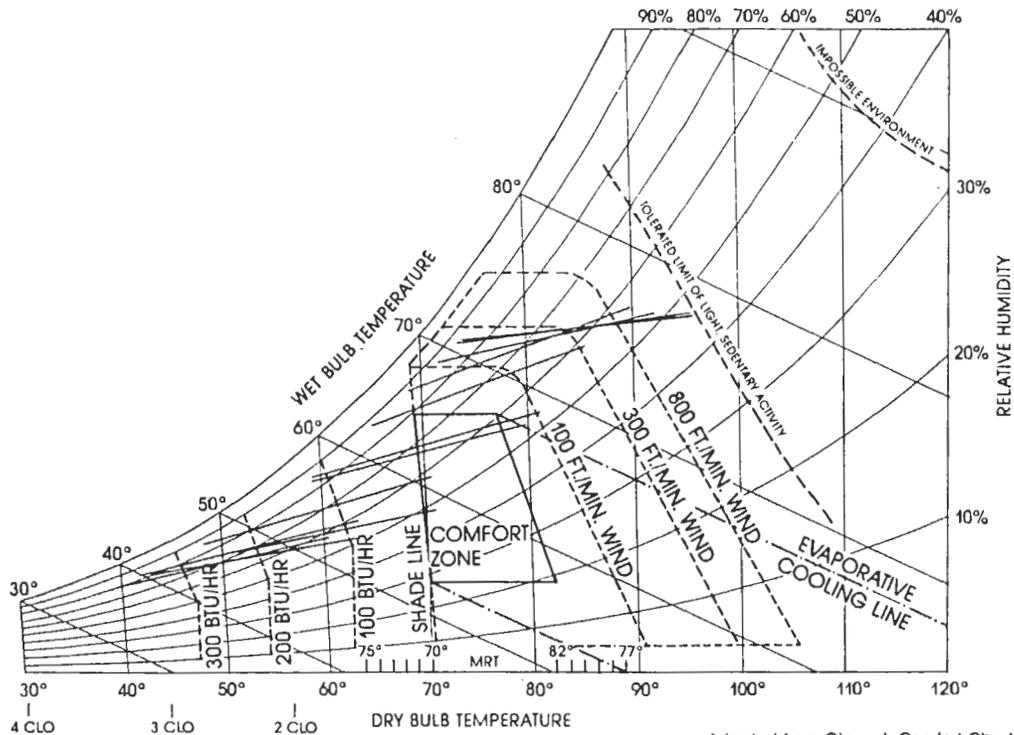
The two humidity/temperature extremes for each month are plotted on the psychrometric charts and a line is drawn between the two extreme values. The charting of this climate data provides assistance in determining the approximate heating and cooling strategies for our location.



ZONES OF STRATEGIES

Figure 14

Adapted from Olgay's Comfort Chart by L.M. Holder, Inc. Austin, Texas



AUSTIN CLIMATE DATA

Figure 15

Adapted from Olgay's Comfort Chart using NOAA weather data by L.M. Holder, Inc. Austin, Texas

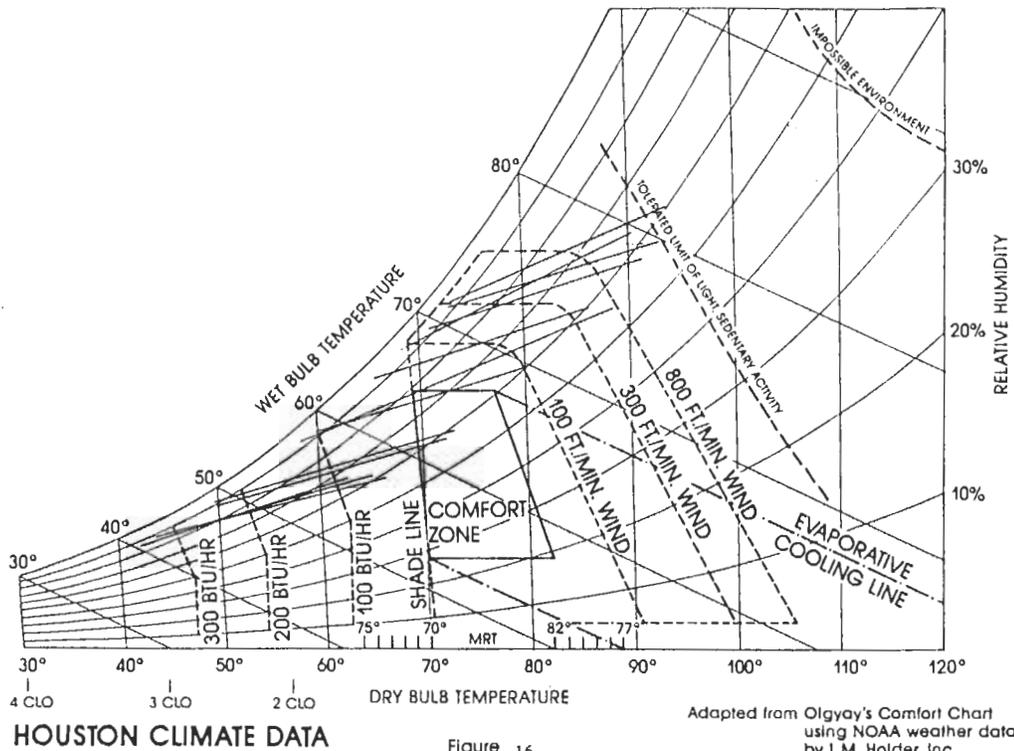


Figure 16

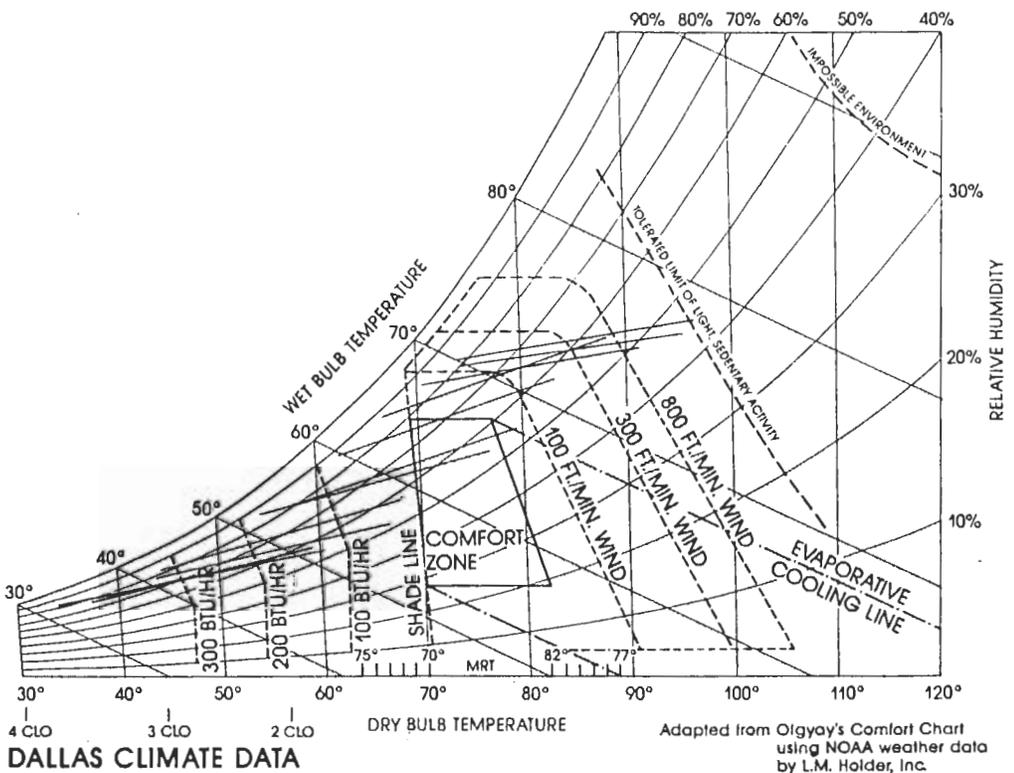


Figure 17