

4.1 BIOLOGICAL MACHINE

The human being is a biological machine that burns food as a fuel and generates heat as a by-product. This metabolic process is very similar to what happens in an automobile, where gasoline is the fuel and heat is also a significant by-product (Fig. 4.1a). Both types of machines must be able to dissipate the waste heat in order to prevent overheating (Fig. 4.1b). All of the heat-flow mechanisms mentioned in Chapter 3 are employed to maintain the optimum temperature.

All warm-blooded animals, and humans in particular, require a very constant temperature. The **hypothalamus**, a part of our brain, regulates our bodies to maintain an interior temperature of about 98.6°F (37°C), and any small deviation creates severe stress. Only 10 to 15 degrees higher or 20 degrees lower can cause death. Our bodies have several mechanisms to regulate heat flow to guarantee that the heat loss equals the heat generated and that thermal equilibrium will be about 98.6°F (37°C).

Some heat is lost by exhaling warm, moist air from the lungs, but most of the body's heat flow is through the skin. The skin regulates heat flow partly by controlling the amount of blood flowing through it. In summer the skin is flushed with blood to increase the heat loss, while in winter little blood is allowed to circulate near the surface and the skin becomes an insulator. The skin temperature will, therefore, be much lower in winter than in summer. Skin surface temperatures can vary over 50°F (27°C) in response to the ambient temperature. The skin also contains sweat glands that control body heat loss by evaporation.

Hair is another important device to control the rate of heat loss. Although we no longer have much fur, we still have the muscles that could make our fur stand upright for extra thermal insulation. When we get gooseflesh, we see a vestige of the old mechanism. After some days of exposure, the body can acclimatize to very

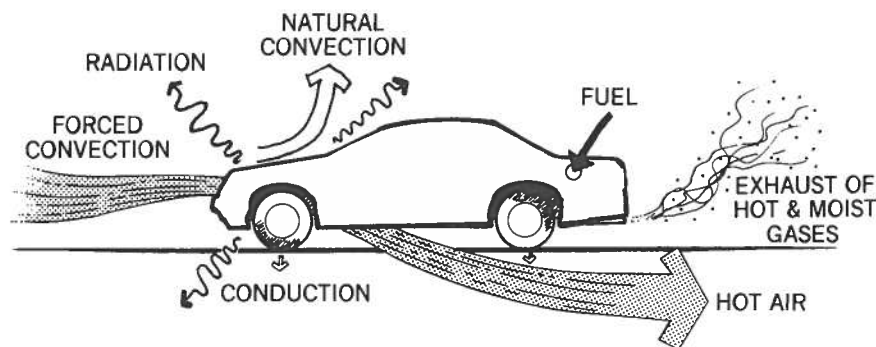


Figure 4.1a Methods of dissipating waste heat from an automobile.

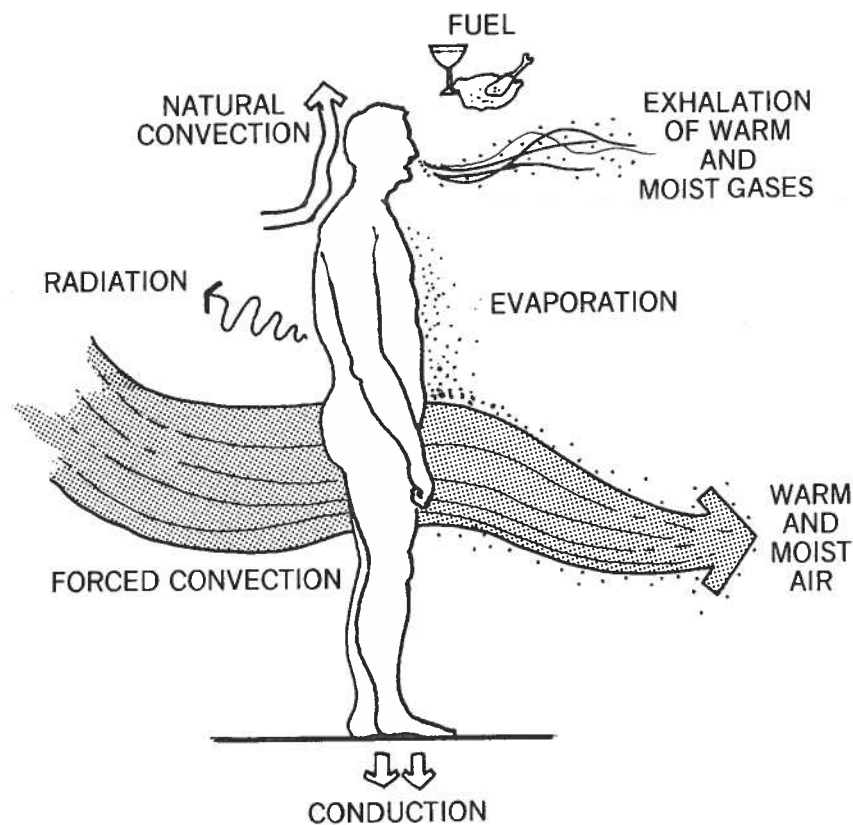


Figure 4.1b Methods of dissipating waste heat from a biological machine.

high or low temperatures. Changing the total amount of blood is one important mechanism, with more blood produced under warmer conditions. Excessive heat loss is called **hypothermia**, while insufficient heat loss is **hyperthermia**.

The graph in Fig. 4.1c shows how the effectiveness of our heat loss mechanisms varies with the ambient temperature. Curve 1 represents the heat generated by a person at rest as the ambient temperature changes. Curve 2

represents the heat lost by conduction, convection, and radiation. Since the heat loss by these mechanisms depends on the temperature difference, it is not surprising that heat loss decreases as ambient temperature increases. When the ambient temperature reaches the body temperature of 98.6°F (37°C), no heat loss can occur by conduction, convection, and radiation. Fortunately, another heat-loss mechanism is not affected by the ambient temperature. Heat loss by evaporation actually

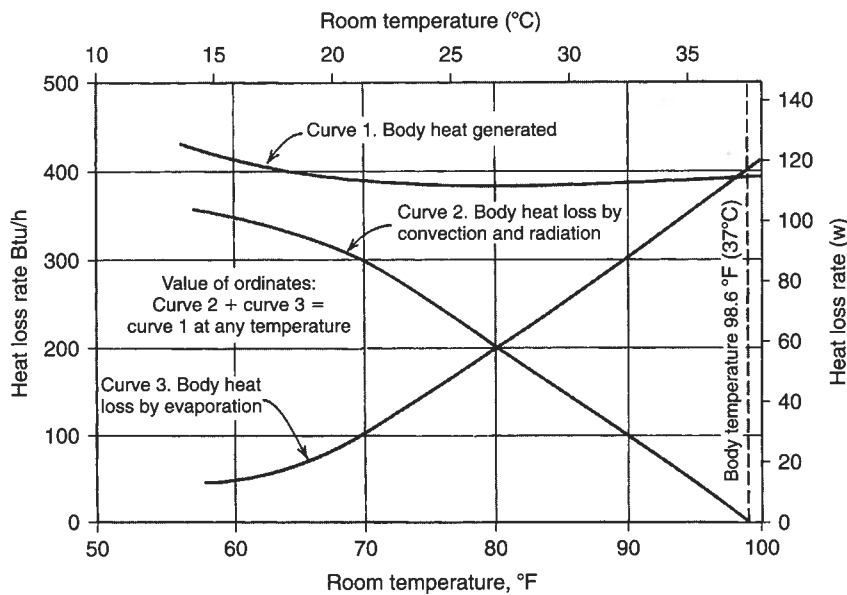


Figure 4.1c The way heat is lost from a body depends on the ambient temperature. This chart assumes the person is at rest and that the relative humidity is 45 percent. (From *Mechanical and Electrical Equipment for Buildings*, 9th edition, Stein and Reynolds, © 2000 John Wiley & Sons, Inc.)

works better at higher temperatures. Curve 3 (Fig. 4.1c) represents the heat lost by evaporation as the ambient temperature changes with the relative humidity fixed at 45 percent.

Although the nerve endings in our skin cannot sense humidity very well, they can sense wetness, which is often related to high RH. The nerve endings also do not sense temperature

but rather heat flow. Thus metal, with its high conductivity, will feel cooler than wood at the same temperature.

4.2 THERMAL BARRIERS

If we could all live in the Garden of Eden, it would be easy for our body mechanisms to control heat flow. The real world, however, places our bodies under almost constant thermal stress. Any barrier as thin as the skin will have great difficulty maintaining a constant temperature in a widely changing environment. Consequently, additional barriers are needed to achieve thermal comfort. Clothing, though it acts as an extra skin, is not always sufficient for thermal comfort. Buildings provide a milder environment for the clothed human being. In the drafty buildings of previous ages, still more barriers were needed. The canopy bed was one solution (Fig. 4.2a). In modern buildings we come close to re-creating the thermal aspects of the Garden of Eden.

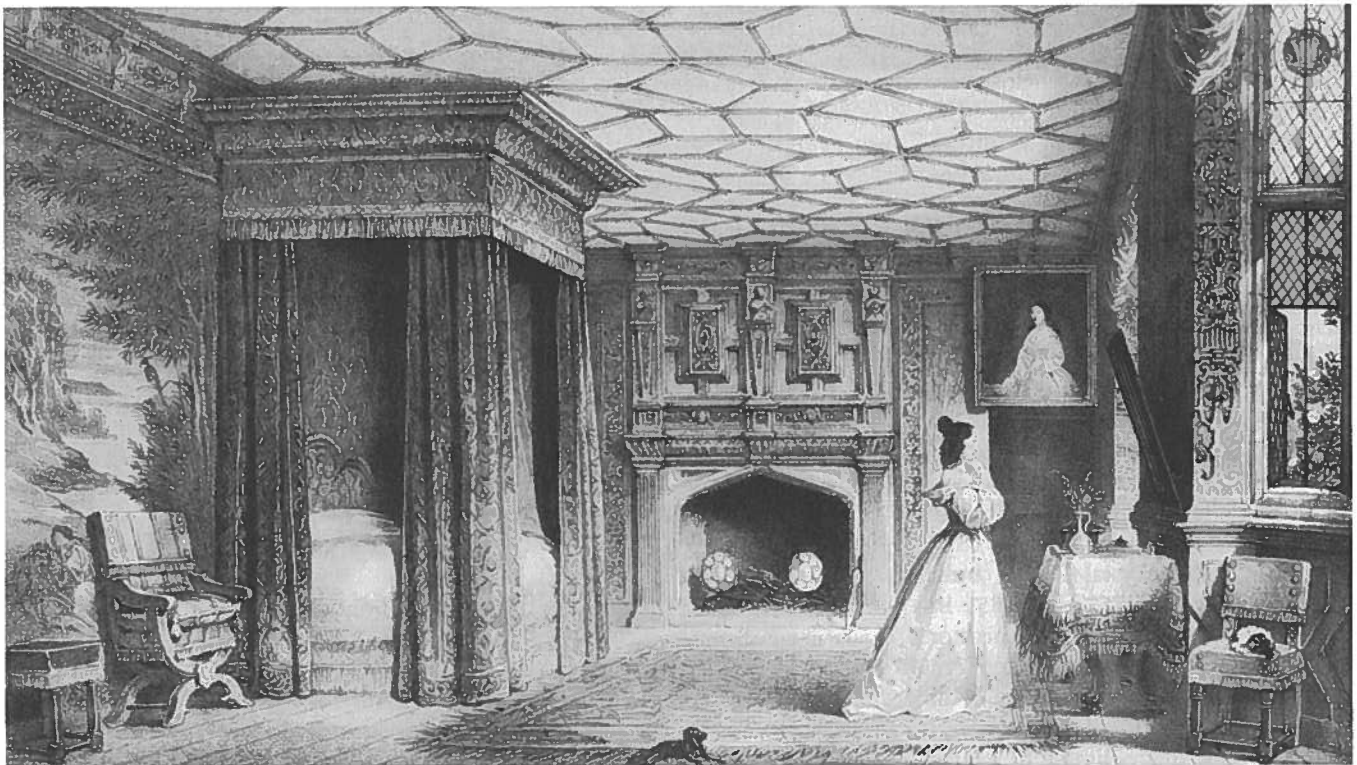


Figure 4.2a The concept of multiple barriers is very appropriate for thermal comfort. Three barriers are shown: clothing, canopy bed, and building. (From *Mansions of England in Olden Time* by Joseph Nash.)

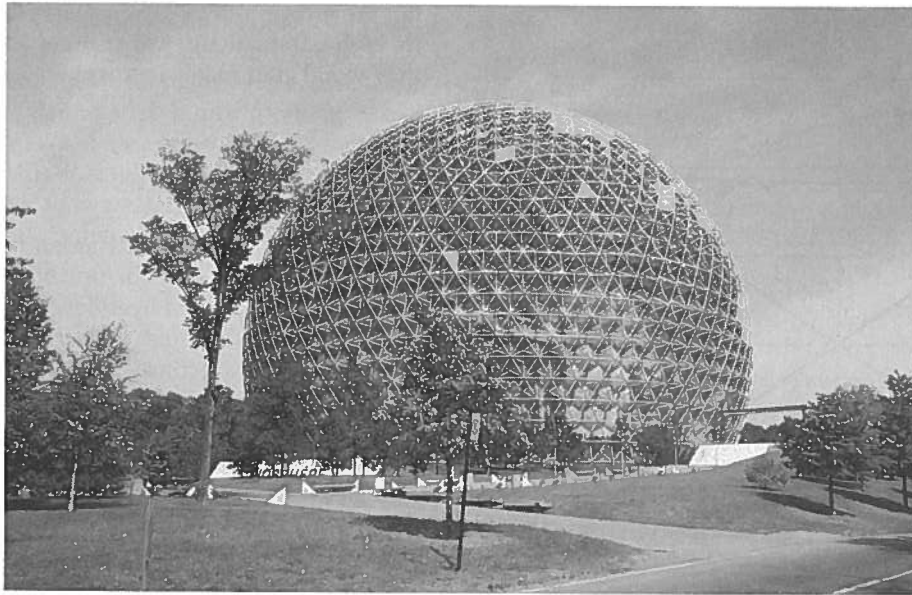


Figure 4.2b The geodesic dome of the U.S. Pavilion, Expo 67, Montreal, protects the interior structures from extreme temperatures, sun, wind, and rain.

This concept of progressive barriers promises to be continued. There was a serious suggestion, for example, to enclose the new capital of Alaska in a pneumatic membrane structure and thereby greatly reduce the thermal stress on the building's inside. Pneumatic structures are ideal for this purpose because they can enclose very large areas at reasonable cost. The U.S. Pavilion for Expo 67 in Montreal, Canada, used a different structural system for the same purpose. Figure 4.2b shows the geodesic dome that created a microclimate within which thermally fragile structures were built. Vents and shades were used to control this microclimate (see Fig. 9.16a).

More modest but quite common are the sheltered streets of our modern enclosed shopping malls, which had their beginnings in such projects as the Galleria Vittorio Emanuele in Milan, Italy, completed in 1877 (Fig. 4.2c). The Crystal Palace, built for the Great Exhibition of 1851 in London (Fig. 4.2d), was the ancestor of both the Galleria and the modern Expo pavilion mentioned above. With an area of 770,000 ft² (71,500 m²), it created a new microclimate in a large section of Hyde Park.



Figure 4.2c The Galleria Vittorio Emanuele, Milan, Italy, completed 1877, protects both the street and buildings. (Photograph by Clark Lundell.)



Figure 4.2d The Crystal Palace, built for the Great Exhibition of 1851, created a benign microclimate in Hyde Park, London. (Victoria and Albert Museum, London.)

4.3 METABOLIC RATE

To maintain vital thermal equilibrium, our bodies must lose heat at the same rate at which the metabolic rate produces it. This heat production is partly a function of outside temperature but mostly a function of activity. A very active person generates heat at a rate more than eight times that of a reclining person. Table 4.3 shows the heat production related to various activities. For a better intuitive understanding, the equivalent heat production in terms of 100-watt lamps is also shown.

Table 4.3 Body Heat Production as a Function of Activity

		Heat Produced (Btu/h)	Watts	
Activity				
	Sleeping	340		100
	Light work	680		200
	Walking	1020		300
	Jogging	2720		800

Notes:

1. The numbers given are approximate.
2. 1w = 3,412 Btu/h.

4.4 THERMAL CONDITIONS OF THE ENVIRONMENT

To create thermal comfort, we must understand not only the heat dissipation mechanisms of the human body but also the four environmental conditions that allow the heat to be lost.

These four conditions are:

1. Air temperature ($^{\circ}\text{F}$) ($^{\circ}\text{C}$)
2. Humidity
3. Air movement (feet/minute) (m/s)
4. Mean radiant temperature (MRT)

All of these conditions affect the body simultaneously. Let us first examine how each of these conditions by itself affects the rate of heat loss in human beings.

1. *Air temperature* The air temperature will determine the rate at which heat is lost to the air, mostly by convection. Above 98.6°F (37°C), the heat flow reverses and the body will gain heat from the air. The comfort range for most people (80 percent) extends from 68°F (20°C) in winter to 78°F (25°C) in summer. The range is this large mostly because warmer clothing is worn in the winter.
2. *Relative humidity* Evaporation of skin moisture is largely a function of air humidity. Dry air can readily absorb the moisture from the skin, and the resulting rapid evaporation will effectively cool the body. On the other hand, when the relative humidity (RH) reaches 100 percent, the air is holding all the water vapor it can and cooling by evaporation stops. For comfort the RH should be above 20 percent all year, below 60 percent in the summer, and below 80 percent in the winter. These boundaries are not very precise, but at very low humidity levels there will be complaints of dry noses, mouths, eyes, and skin and increases in respiratory illnesses. Static electricity and shrinkage of wood are also problems caused by low humidities.

High humidity not only reduces the evaporative cooling rate, but also encourages the formation of skin moisture (sweat), which the body senses as uncomfortable. Furthermore, mildew growth is frequently a serious problem when the humidity is high.

3. *Air movement* Air movement affects the heat-loss rate by both convection and evaporation. Consequently, air velocity has a very pronounced effect on heat loss. In the summer, it is a great asset and in the winter a liability. The comfortable range is from about 20 to about 60 feet/minute (fpm) (0.1 to 0.3 m/s). From about 60 to about 200 fpm (0.3 to 1 m/s), air motion is noticeable but acceptable depending on the activity being performed. Above 200 fpm (2 mph) (3.2 k/h), the air motion can be slightly unpleasant and disruptive (e.g., papers are blown around). A **draft** is an undesirable local cooling of the human body by air movement, and it is a serious thermal comfort problem. See Table 10.8 for a more detailed description of how air velocity affects comfort. Air motion is also required to prevent excessive stratification, which tends to make heads warmer and feet colder—exactly the opposite of what is comfortable.

In cold climates, **windchill factors** are often given on weather reports because they better describe the severity of the cold than is possible with temperatures alone. The windchill factor is equal to the still-air temperature that would have the same cooling effect on a human being as does the combined effect of the actual temperature and wind speed.

Although air movement from a breeze is usually desirable in the summer, it is not in very hot and dry climates. If the air is above 98.6°F (37°C), it will heat the skin by convection while it

cools by evaporation. The higher the temperature, the less the total cooling effect.

4. *Mean radiant temperature* When the MRT differs greatly from the air temperature, its effect must be considered. For example, when you sit in front of a south-facing window on a sunny day in the winter, you might actually feel too warm, even though the air temperature is a comfortable 75°F (24°C). This is because the sun's rays raised the MRT to a level too high for comfort. As soon as the sun sets, however, you will probably feel cold even though the air temperature in the room is still 75°F (24°C). This time the cold window glass lowered the MRT too far, and you experience a net radiant loss. It is important to realize that the skin and clothing temperature is not 98.6°F (37°C) but varies greatly with the ambient temperature. To help visualize the radiant exchange, assume the skin temperature to be about 80°F (27°C). In general, the goal is to maintain the MRT close to the ambient air temperature. In a well-insulated and shaded building, the MRT will be close to that of the indoor air temperature.

The psychrometric chart described in the next section is a powerful tool for understanding how the combination of temperature and humidity affects comfort.

4.5 THE PSYCHROMETRIC CHART

A useful and convenient way to understand some of the interrelationships of the thermal conditions of the environment is by means of the psychrometric chart (Fig. 4.5a). The horizontal axis describes the temperature of the air, the vertical axis describes the actual amount of water vapor in the air, called **humidity ratio** or **specific humidity**, and the curved

lines describe the **relative humidity (RH)**. The diagram has two boundaries that are absolute limits. The bottom edge describes air that is completely dry (0 percent RH), and the upper curved boundary describes air that is completely saturated with water vapor (100 percent RH). The upper boundary is curved because as air gets warmer, it can hold more water vapor. Even if we know how much water vapor is already in the air, we cannot predict how much more it can hold unless we also know the temperature of the air. The RH is affected by changes in either the amount of moisture in the air or the temperature of the air.

Every point on the psychrometric chart represents a sample of air at a particular temperature and moisture level (Fig. 4.5a). Moving vertically up on the chart indicates that moisture is being added to that air sample (see Fig. 4.5b), while a downward motion on the chart represents water vapor removal (dehumidification). Movement to the right indicates that the air sample is being heated, and movement to the left indicates cooling of the air. Thus, if a sample of air at 80°F (27°C) and 40 percent RH (point A) is cooled to 60°F (15°C), the point representing the air sample will move horizontally to the left on the psychrometric chart to point B (Fig. 4.5c). Its RH, however, has increased to about 78 percent even though there was no change in the moisture content of the air (i.e., no vertical movement on the chart). The RH increased because cool air can hold less moisture than warm air, and the existing moisture level is now a larger percentage of what air can hold at that cooler temperature.

On the other hand, if the air at point A is heated to 100°F (38°C) (point C in Fig. 4.5d), then its relative humidity will be about 22 percent. The RH changed because warm air can hold more moisture than cool air, and the existing moisture level is now a smaller percentage of what the air can hold at that higher temperature.

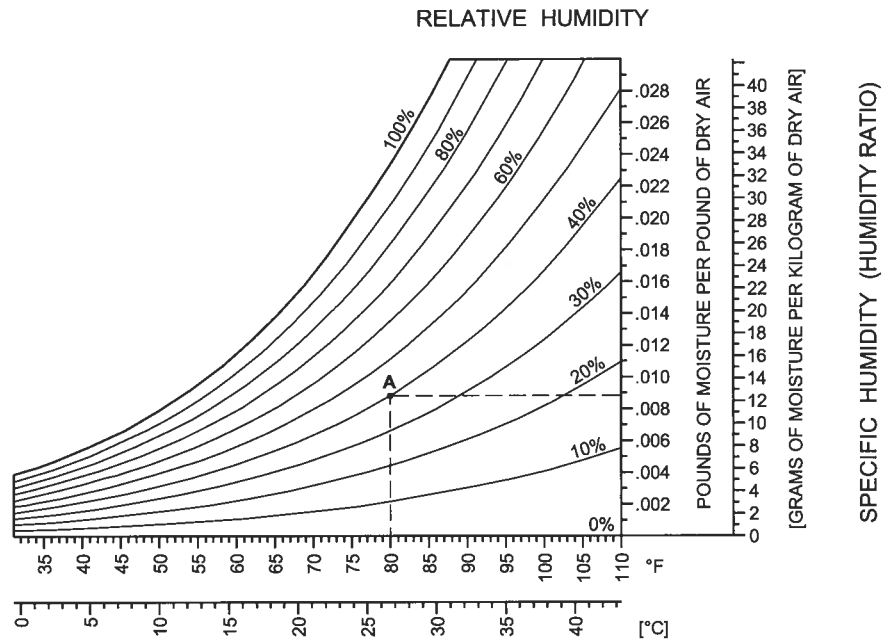


Figure 4.5a Each point on the psychrometric chart represents the properties of a sample of air at a particular temperature and moisture level. At point A, for example, the air sample has a temperature of 80°F (27°C), an RH of 40 percent, and an actual moisture content of about 0.009 lb of water per pound of dry air (14 g of water per kilogram of dry air).

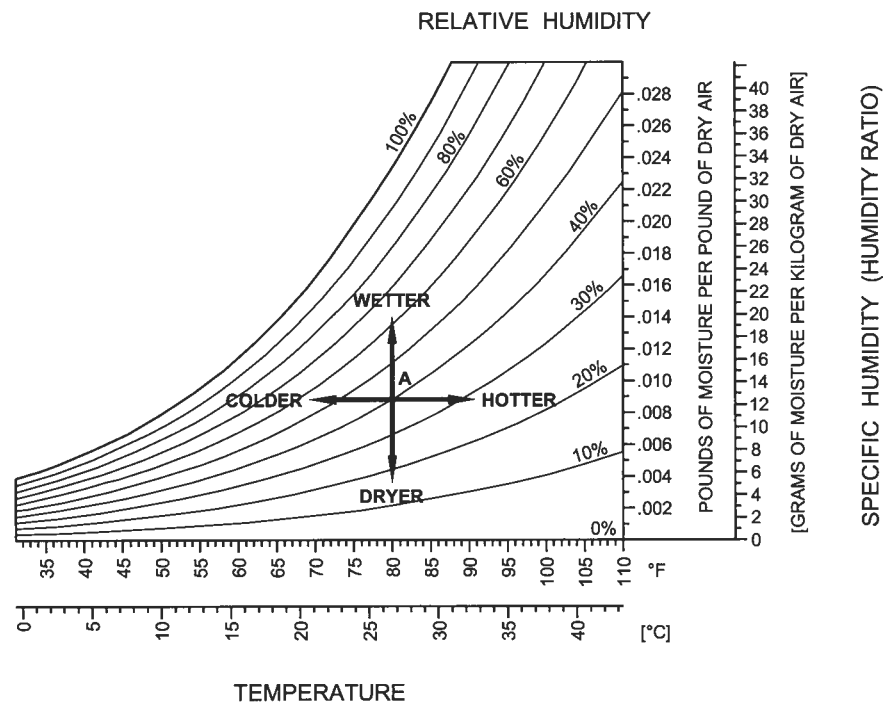


Figure 4.5b Changes in the temperature or moisture of a sample of air are represented by movement on the psychrometric chart.

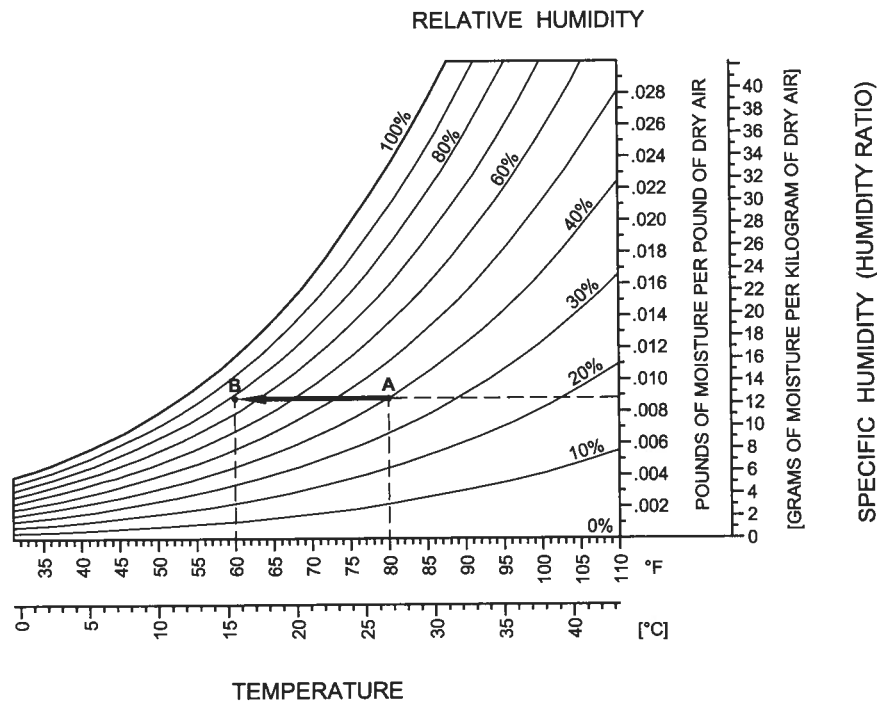


Figure 4.5c If an air sample is cooled, its RH will increase even though there was no change in moisture content.

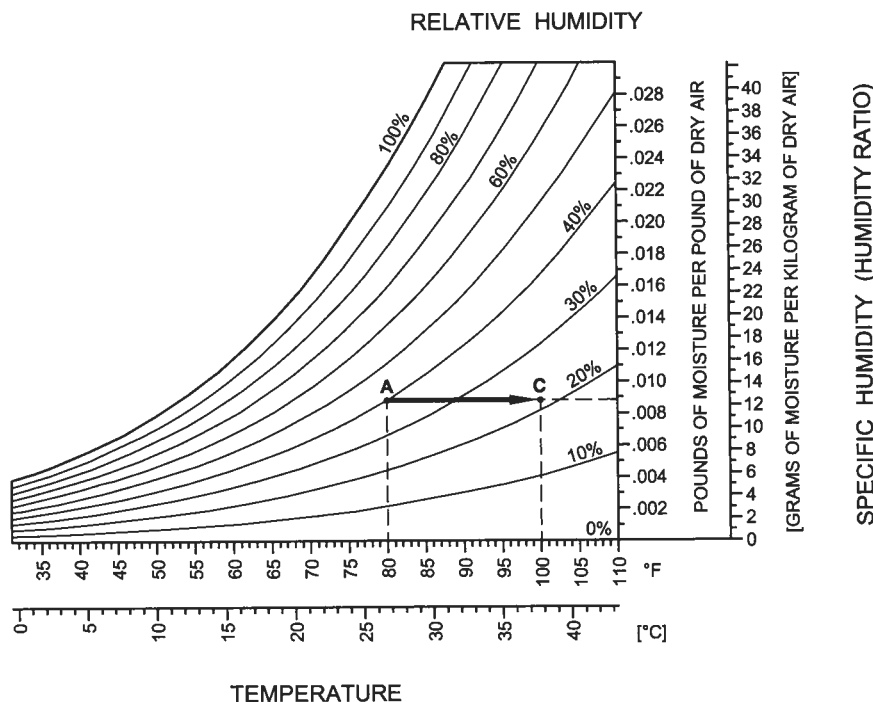


Figure 4.5d If an air sample is heated, its relative humidity will drop even though there was no change in moisture content.

4.6 DEW POINT AND WET-BULB TEMPERATURES

What would happen to air that is at 80°F (27°C) and 40 percent RH if it were cooled to 53°F (12°C)? Look at point A in Fig. 4.6a. As the air is cooled, the RH keeps increasing until it is 100 percent at about 53°F (12°C) (point D). This is a special condition called the **dew point temperature (DPT)**. At this point the air is fully saturated (100 percent RH) and cannot hold any more moisture. Any cooling beyond this point results in condensation where some of the water comes out of solution in the air. This phenomenon is also seen in rain, snow, fog, hoarfrost, and the "sweating" of a cold glass of water.

If the above sample of air is cooled beyond 53°F (12°C) to 40°F (4°C), it will reach point E on the psychrometric chart (Fig. 4.6a). Although its RH is still 100 percent, its specific humidity (humidity ratio) has decreased. Note the downward movement on the psychrometric chart from a humidity ratio of about 0.009 to about 0.0055 lb of water per pound of dry air (12 to 8 g/kg). Consequently, about 0.0035 lb of water per pound of dry air (4 g/kg) was removed from the air when it was cooled from 80°F (27°C) to 40°F (4°C). We can say that the air was **dehumidified**.

The DPT is also an indication of how much moisture is in the air at any temperature. The higher the DPT, the more moisture. Thus, the DPT can be used to describe the actual amount of moisture in the air. Weather reports often give the DPT to describe the moisture content of the air.

Another way to describe the amount of moisture in an air sample is by giving its **wet-bulb temperature**. The wet-bulb temperature is determined by slinging two thermometers side by side through the air. One thermometer has its bulb covered with a wet sock. If this **sling psychrometer** is slung around in dry air, the temperature of the wet-bulb thermometer will drop significantly below the temperature of the dry-bulb thermometer

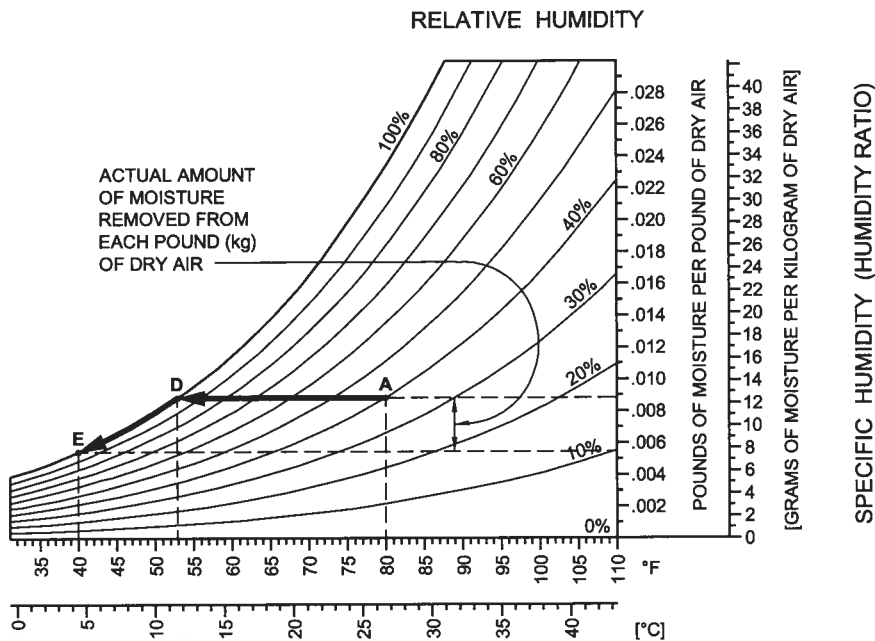


Figure 4.6a When an air sample is cooled sufficiently, its RH increases until it reaches 100 percent, which is also called the "saturation" or "dew point." Any cooling beyond this point results in moisture condensing out of the air.

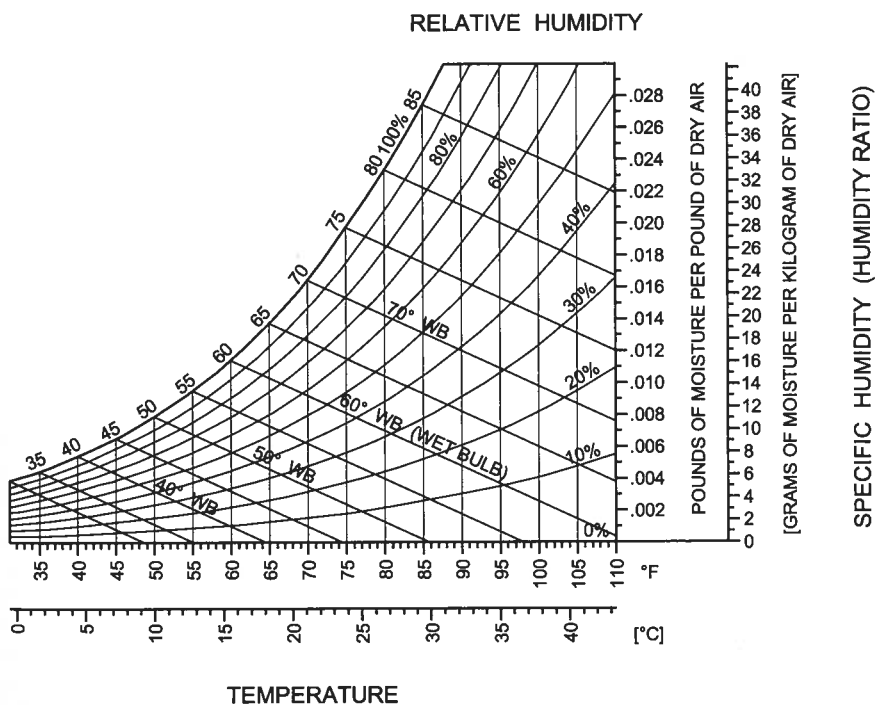


Figure 4.6b The wet-bulb temperature can be measured with a sling psychrometer. It is an indicator of the RH, the actual moisture content, and the heat content of the air.

because of the large evaporation of water. Similarly, if the air is humid, the wet-bulb temperature will drop only a little. And, of course, if the air is at 100 percent RH, no evaporation will take place, and the wet-bulb and dry-bulb temperatures will be the same. Figure 4.6b shows how at 100 percent RH, the wet-bulb temperatures (slanted lines) and the dry-bulb temperatures (vertical lines) are the same.

4.7 HEAT CONTENT OF AIR

The psychrometric chart can also be used to describe the sensible-, latent-, and total-heat content of an air sample. The total-heat or **enthalpy** (sensible plus latent heat) scale is a standard part of the psychrometric chart and is shown in Fig. 4.7a. Note that an upward movement on the chart increases not only the moisture content but also the latent-heat content. This is not a surprise if you remember that water vapor is a form of latent heat. Also, note that a movement to the right increases not only temperature but also the sensible-heat content of an air sample. This also is not a surprise because temperature is an indicator of sensible-heat content.

Figure 4.7b shows air that is being both heated and humidified. Thus, when the air reaches point F, it has both more sensible and more latent heat than it had at point A. The total increase in Btus per pound of dry air (kJ/kg) can be read directly from the enthalpy scale.

In Fig. 4.7c, we see a sample of air that is being cooled by the evaporation of water. If the air is humidified to 80 percent RH, the moisture content will increase and the temperature will decrease. Since the loss of sensible heat equals the gain in latent heat, the total-heat content is the same for point G as it was for point A. Note that there is no change on the total-heat scale. A change in the air that does not result in a change of total-heat content is called an **adiabatic change**. This is an important and common phenomenon since this

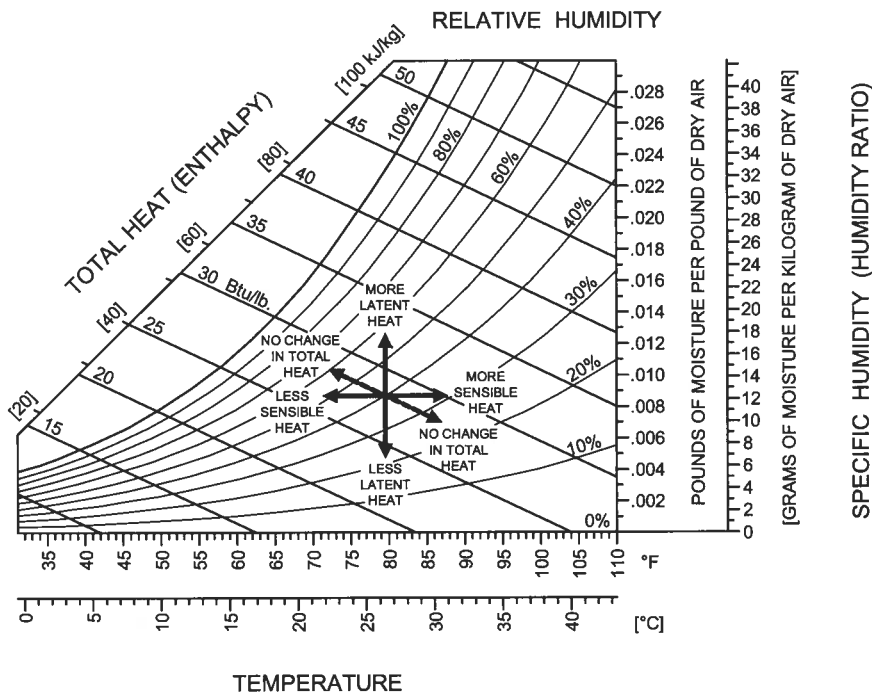


Figure 4.7a The psychrometric chart also presents information on the heat content of a sample of air. Heat is gained by either an increase in temperature (sensible heat) or an increase in moisture (latent heat) or both.

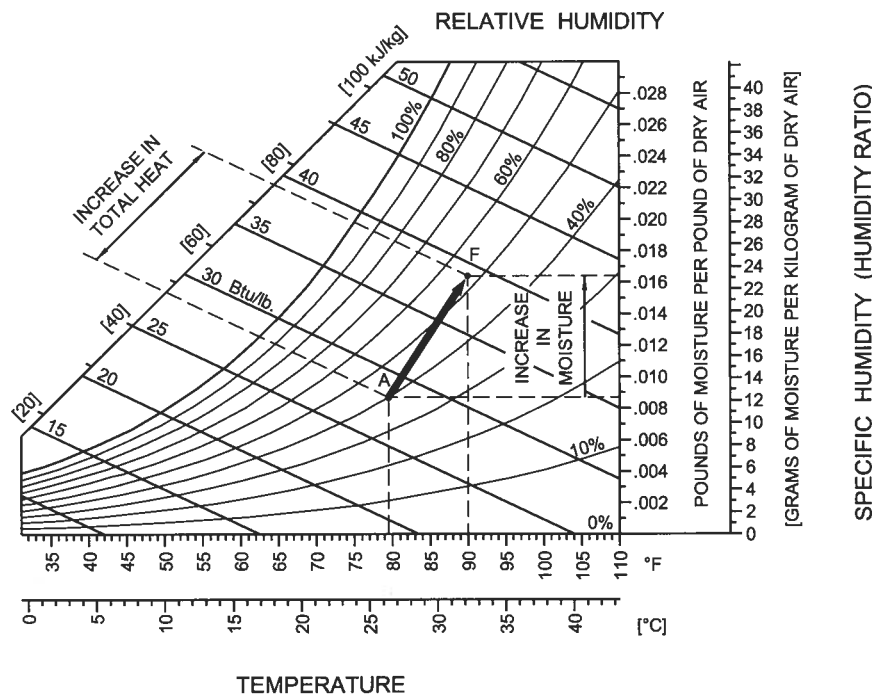


Figure 4.7b Heating and humidifying an air sample increases both its sensible heat and its latent heat. The total-heat gain can be read directly from the enthalpy scale.

is what happens in evaporative cooling, in which the evaporation of water converts sensible heat to latent heat and the total-heat content remains the same. Thus, although the air becomes cooler, it also becomes more humid. It is equally true that when water vapor condenses into water, the temperature rises, since latent heat is being converted to an equal amount of sensible heat.

4.8 THERMAL COMFORT

Thermal comfort occurs when body temperatures are held within narrow ranges, skin moisture is low, and the body's effort of temperature regulation is minimized (after ASHRAE, 1997). Certain combinations of air temperature, RH, air motion, and MRT will result in what most people consider thermal comfort. When these combinations of air temperature and RH are plotted on a psychrometric chart, they define an area known as the **comfort zone** (Fig. 4.8a). Since the psychrometric chart relates only temperature and humidity, the other two factors (air motion and MRT) are held fixed. The MRT is assumed to be near the air temperature, and the air motion is assumed to be modest.

It is important to note that the given boundaries of the comfort zone are not absolute, because thermal comfort also varies with culture, time of year, health, the amount of fat an individual carries, the amount of clothing worn, and, most important, physical activity. The American Society for Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) defines thermal comfort as "that condition of mind which expresses satisfaction with the thermal environment." While conditions required for thermal comfort vary from person to person, the comfort zone should be the goal of the thermal design of a building because it defines those conditions that 80 percent of people in our society find comfortable. A more detailed look at the comfort zone shows that it consists of both a

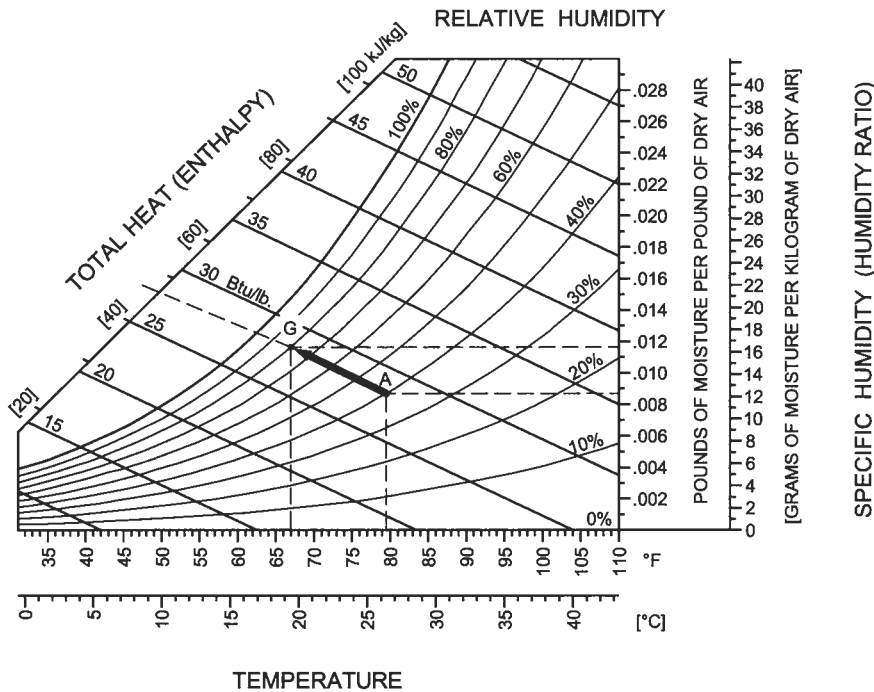


Figure 4.7c In evaporative cooling, the increase in latent heat equals the decrease in sensible heat. An adiabatic change is a change in which the total-heat content of the air remains constant.

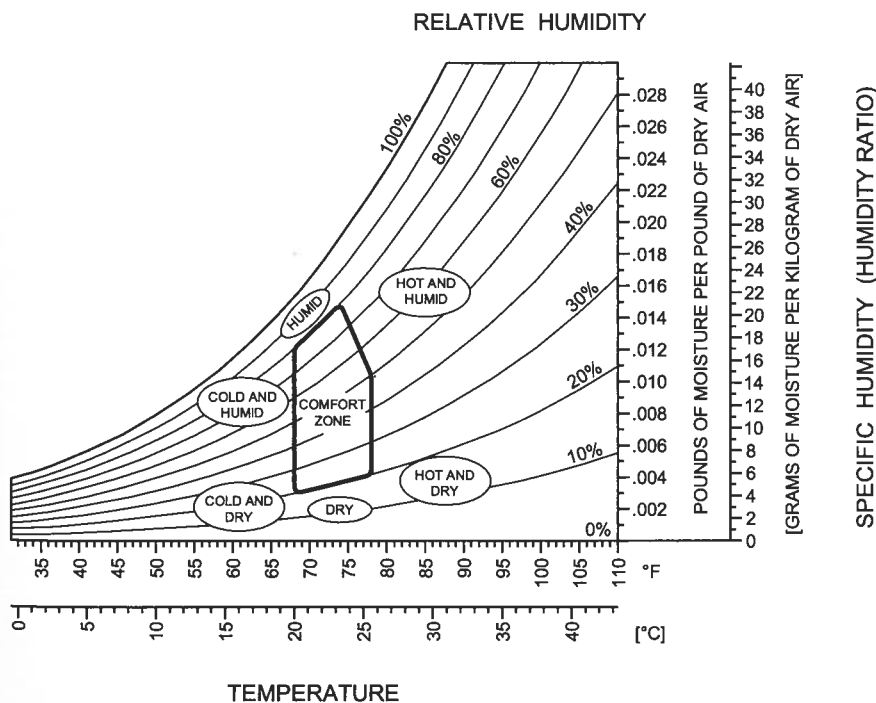


Figure 4.8a The comfort zone and various types of discomfort outside that zone are shown on this psychrometric chart.

summer and winter zone (Fig. 4.8b). For the sake of simplicity, this book continues to use the traditional zone, with the caveat that the left side of the zone is more appropriate for winter and the right side for summer.

Whenever possible, additional controls should be made available for the occupants of a building so that they can create the thermal conditions that are just right for them. Portable fans and heaters, numerous thermostats, and operable windows are devices people can use to fine-tune their environment. Mechanical equipment systems are now commercially available that allow individual thermal control at each work station.

The chart in Fig. 4.8a also indicates the type of discomfort one experiences outside of the comfort zone. These discomfort zones correspond to different climates. For example, the American Southwest has a summer climate that is hot and dry, found on the lower right of the psychrometric chart (Fig. 4.8a). Unfortunately, very few climates have a sizable portion of the year in the comfort zone.

The following discussion shows how the comfort zone shifts when certain variables that had been held constant are allowed to change.

4.9 SHIFTING OF THE COMFORT ZONE

The comfort zone will shift on the psychrometric chart if we change some of the assumptions made above. In Fig. 4.9a the shift of the comfort zone is due to an increase in the MRT. Cooler air temperatures are required to compensate for the increased heating from radiation. Likewise, a low MRT would have to be offset by an increase in the air temperature. For example, a room with a large expanse of glass must be kept warmer in the winter and cooler in the summer than a room with a more modest window area. The large window area creates a high MRT in the summer and a low MRT in the winter. For every 3-degree increase or decrease in MRT, the air temperature

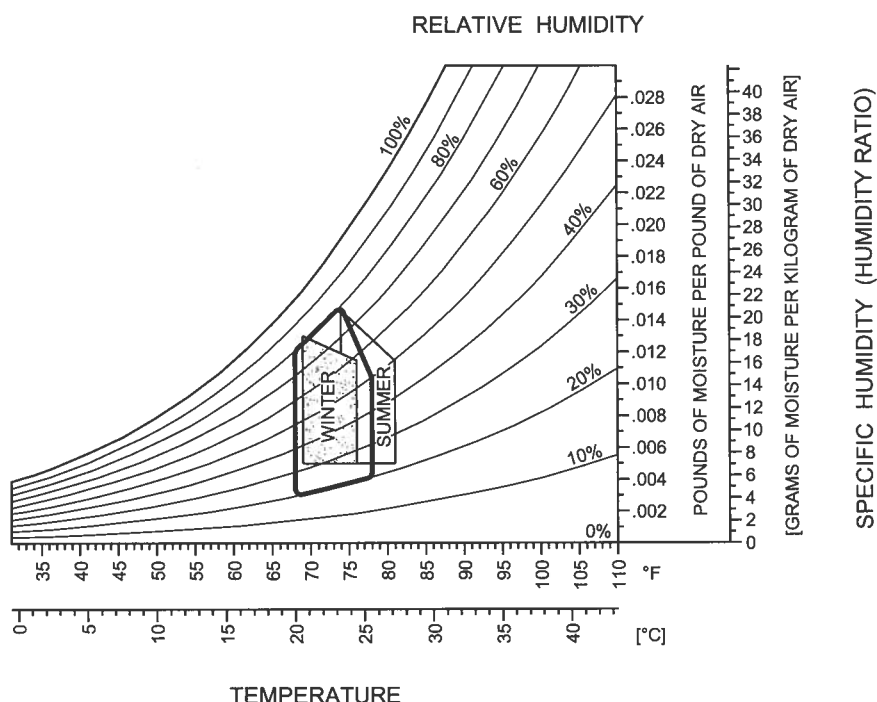


Figure 4.8b A more detailed look at the comfort zone shows that it actually consists of two slightly overlapping zones. (After ASHRAE Handbook of Fundamentals, 1997.)

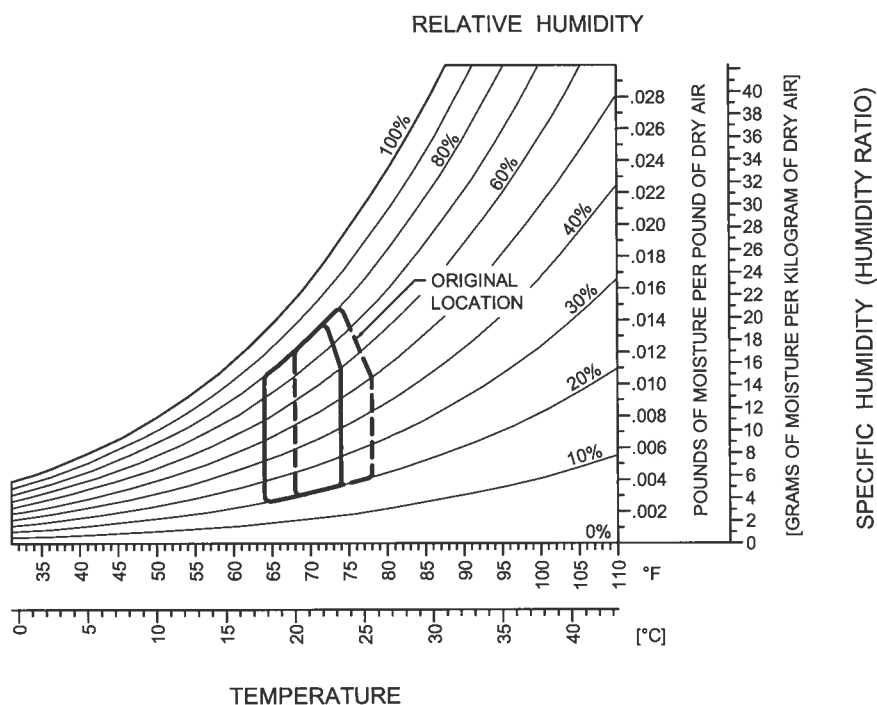


Figure 4.9a To compensate for a high MRT, the comfort zone shifts down to the left.

must be adjusted 2 degrees in the opposite direction. Window shading (Chapter 9) and better-insulated windows (Chapter 15) can have tremendous effects on the MRT.

In Fig. 4.9b the shift of the comfort zone is due to increased air velocity. The cooling effect of the air motion is offset by an increase in the air temperature. We usually make use of this relationship in the reverse situation. When the air temperature is too high for comfort, we often use air motion (i.e., open a window or turn on a fan) to raise the comfort zone so that it includes the higher air temperature. Every increase of 15 fpm (0.8 m/s) of air speed results in a 1-degree drop in the comfort zone. Chapter 10 will explain how air movement can be used for passive cooling.

There is also a shift of the comfort zone due to physical activity. Cooler temperatures are required to help the body dissipate the increased production of heat. Gymnasiums, for example, should always be kept significantly cooler than classrooms. Thus, the comfort zone shifts down to the left when physical activity is increased (Fig. 4.9c).

4.10 CLOTHING AND COMFORT

Unfortunately, an architect cannot specify the clothing to be worn by the occupants of his or her building. Too often, fashion, status, and tradition in clothing work against thermal comfort. In some extremely hot climates women were—in a few places still are—required to wear black veils and robes that completely cover their bodies. Unfortunately, some of our own customs are almost as inappropriate. A three-piece suit with a necktie can get quite hot in the summer. A miniskirt in the winter is just as unsuitable. Clothing styles should be seasonal indoors as well as outdoors so that our heating and cooling systems can work less hard. We could save millions of barrels of oil if men wore three-piece suits only in the

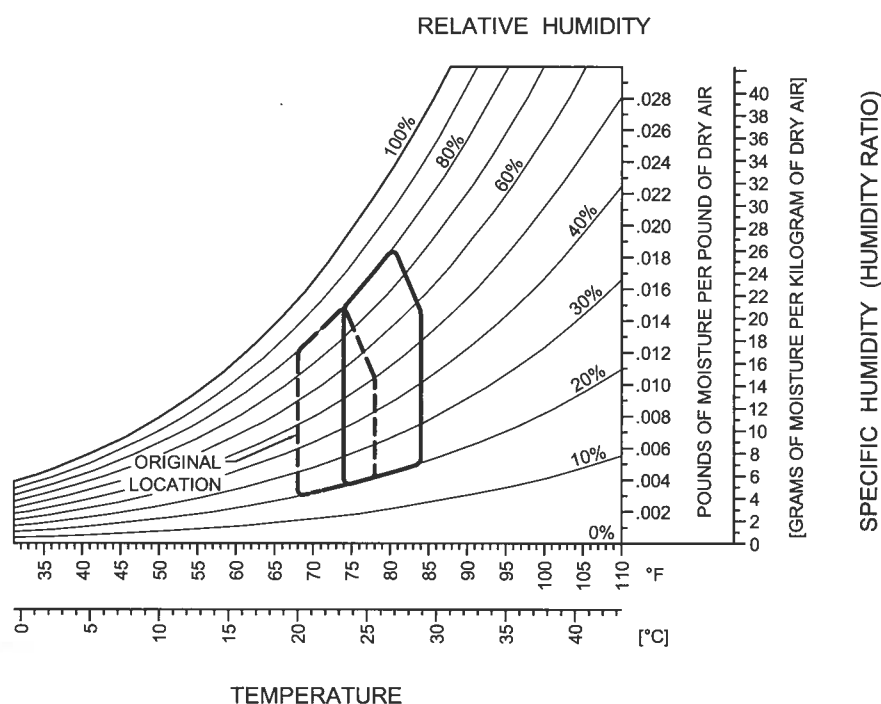


Figure 4.9b To compensate for high air velocity, the comfort zone shifts up to the right.

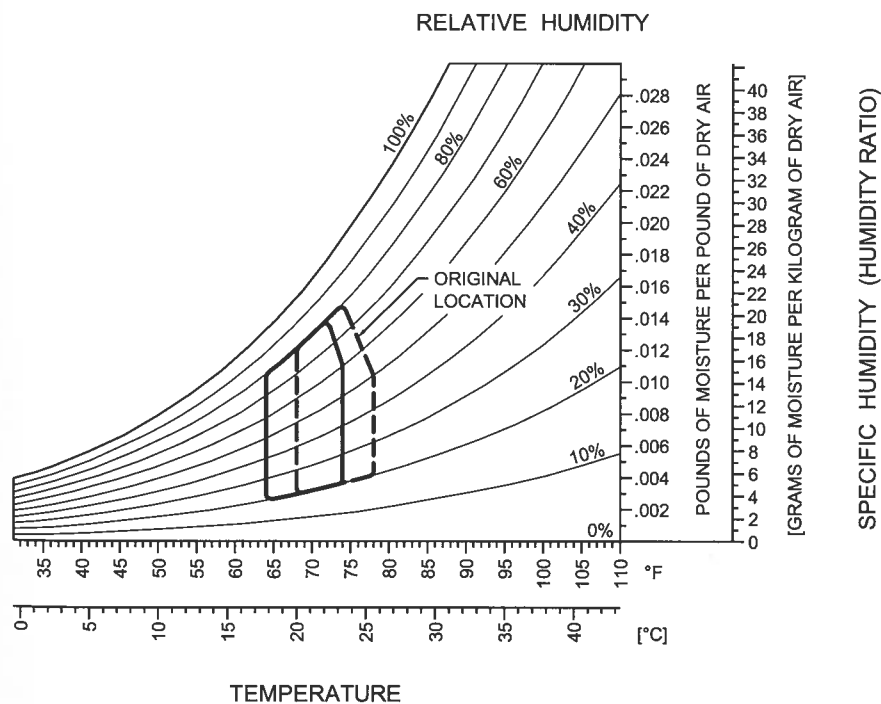


Figure 4.9c To compensate for an increase in physical activity, the comfort zone shifts down to the left.

winter and women wore miniskirts only in summer. Note to fashion designers: You can help fight global warming.

The insulating properties of clothing have been quantified in the unit of thermal resistance called the *clo*. In winter, a high *clo* value is achieved by clothing that creates many air spaces, either by multiple layers or by a porous weave. If wind is present, then an outer layer that is fairly airtight but permeable to water vapor is required.

In summer a very low *clo* value is, of course, required. Since it is even more important in the summer than in the winter that moisture can pass through the clothing, a very permeable fabric should be used. Cotton is especially good because it acts as a wick to transfer moisture from the skin to the air. Although wool is not as good as cotton in absorbing moisture, it is still much better than some man-made materials. Also, loose billowing clothing will promote the dissipation of both sensible and latent (water-vapor) heat by a little forced convection.

4.11 STRATEGIES

Much of the rest of this book discusses the various strategies that have been developed to create thermal comfort in our buildings. The version of the psychrometric chart shown in Fig. 4.11 is called the **building bioclimatic chart** because it integrates architectural strategies with human comfort needs. If you compare this chart with Fig. 4.8a, you will see the relationship between strategies and discomfort (climate) conditions more clearly. For example, the strategy of evaporative cooling (the lower-right area in Fig. 4.11) corresponds with the hot and dry discomfort zone (the lower-right area in Fig. 4.8a). The diagram shows that internal heat gains from sources such as machines, people, and lights are sufficient to heat the building in slightly cool conditions.

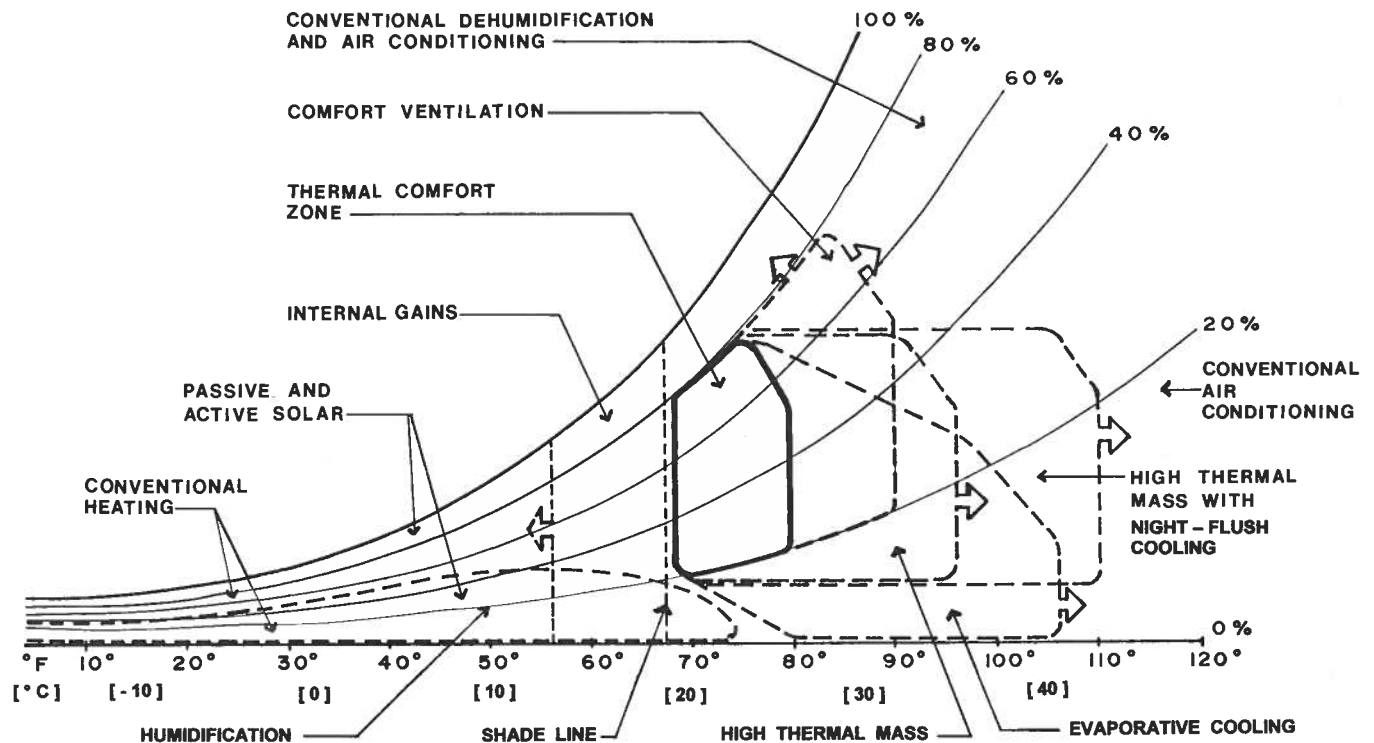


Figure 4.11 This building bioclimatic chart is a summary of design strategies as a function of ambient conditions (climate). (From *Psychrometric-Bioclimatic Chart*, copyright by Baruch Givoni and Murray Milne.)

Also, when the climate conditions are to the right of the shade line, the sun should be prevented from entering the windows. This line, as well as all the boundaries of the various zones shown in the diagram, are not precisely fixed but should be considered as fuzzy limits.

4.12 CONCLUSION

One of the primary functions of buildings is to help create thermal comfort. By understanding human comfort needs and the four conditions of the environment that affect comfort (i.e., temperature, RH, air speed, and

MRT), the architect can better design buildings that are comfortable, yet use a minimum of mechanical equipment and little energy. Because climate determines many of the specific architectural strategies that should be used, it is discussed in the next chapter.

KEY IDEAS OF CHAPTER 4

1. For thermal comfort, the body must eliminate waste heat by means of conduction, convection, radiation, and evaporation.
2. The amount of waste heat produced is mostly a function of the physical activity being performed.
3. Four factors of the environment together determine how easily the body can eject the waste heat. Their comfort ranges are:
 - a) Air temperature: 68° to 78°F (20° to 25°C)
 - b) Relative humidity: 20 to 80 percent in the winter and 20 to 60 percent in the summer
 - c) Air velocity: 20 to 60 fpm (0.1 to 0.3 m/s)
 - d) MRT (near air temperature)
4. Certain combinations of these four factors result in what is called "thermal comfort," which can be represented by the comfort zone on various charts such as the psychrometric chart.
5. When one or more of the four factors of the environment is somewhat outside the comfort range, the remaining factors can be adjusted up or down to compensate, thereby restoring thermal comfort.
6. The psychrometric chart describes the combined effect of temperature and its coincident humidity.
7. A certain set of temperatures and coincident humidities is called the "comfort zone" on the psychrometric chart.
8. The building-bioclimatic chart shows which architectural design strategies are appropriate for different climates, as determined by temperatures and their coincident humidities.