Heat can only travel from warm to cold, so in order for the heat that is carried away by the evaporation to be replaced, the temperature of the skin drops relative to the body's normal temperature and the temperature difference causes heat to flow from inside the bodies to the skin to replace it. This is exactly how sweating cools the body. The rate of evaporation depends on the humidity of the air. If the air has a high relative humidity, it does not have a lot of room to absorb more moisture, so the evaporation rate is low. If the air is dry, then the rate of evaporation is high, which is what causes the body to feel chilled when coming out of water on a warm day.

A Tale of Two Temperatures

The first of this two-part series discusses wet-bulb and dry-bulb temperatures as they relate to the human body.

By Jamie Kitchen

When talking about the temperature of air it needs to be clarified which temperature is being discussed. That is correct, there is actually more than one temperature required when talking about air. The temperature scale most used is actually called the “dry-bulb” scale. The word “dry” here is important because it does not take into account the evaporation of moisture. When the weather announcer states it is 80°F/26°C outside, they are referring to dry-bulb, or db, temperature.

As many can probably relate to, this can be misleading depending on the humidity outside. This is where the other temperature scale comes into play. The opposite of dry bulb is wet bulb. The wet-bulb temperature measures the temperature due to the effect of evaporation. In a wet-bulb thermometer, a “wet sock” covers the thermometer bulb, and it is placed in a moving air stream or spun around in still air. Its temperature is affected by the rate of evaporation. As the evaporation rate goes up, the wet-bulb temperature goes down. See Figure 1 on pg. 28 for an illustration of a wet-bulb thermometer in both moist and dry environments.

The human example

The human body experiences this effect quite often. When a person gets out of a pool or a lake on a breezy day, s/he will feel cold. Why? The answer to this is the water evaporating off of the body and carrying away heat. This heat comes from the body and makes a person feel cold. In fact, the drop in the temperature of the skin is a requirement for the evaporation to continue.
If the air is dry, then the rate of evaporation is high. If evaporation carries heat away, then the higher the evaporation rate, the higher the rate of heat removal.

Heat can only travel from warm to cold, so in order for the heat that is carried away by the evaporation to be replaced, the temperature of the skin drops relative to the body’s normal temperature and the temperature difference causes heat to flow from inside the bodies to the skin to replace it. This is exactly how sweating cools the body.

However, the rate of evaporation also depends on the humidity of the air that it is trying to evaporate into. If the air has a high relative humidity, it does not have a lot of room to absorb more moisture, so the evaporation rate is low. If the air is dry, then the rate of evaporation is high. If evaporation carries heat away, then the higher the evaporation rate, the higher the rate of heat removal. For example, in Arizona, it may be 95°F db out, but when a person gets out of the pool, s/he may just about freeze to death. This is because the air in Arizona is very dry as well as warm, so the rate of evaporation is very high. Welcome to evaporative cooling.

Based on what was just covered, one would expect the wet-bulb temperature—which depends on the rate of evaporation—to be lower on a dry day and higher on a moist day; this is, in fact, what happens. The rate of evaporation of the wet sock on the bulb is higher when it is dry so the amount of heat removed is also high. This causes the wet sock to drop in temperature so the heat can be replaced and this, in turn, cools the thermometer bulb. On a moist day the inverse is true.

An example of a hot and humid day would have a db temperature of say 88°F and a wb temperature of 82°F. A day with the same db but with less humidity would have a wb temperature of 72°F. In %RH, the humid day would have a relative humidity of 78%, while the dry day would have a relative humidity of only 45%. The first example would feel uncomfortable while the second would be ideal for playing outside.

The important point here is that the difference between the dry-bulb and wet-bulb temperatures, also known as the “spread” determines the amount of moisture in the air. The greater the spread, the drier it will be.
No sweat

This phenomenon is so important to our well-being that it is essential to point out what happens when the body overheats and under what conditions that is likely to happen. A few years back, a heat wave hit Chicago and a lot of people were severely affected because their bodies could not effectively cool themselves. To understand why, we need to look at the total energy of the air and not just the standard temperature reading.

To keep cool, in the simplest terms, the body needs to reject energy in the form of heat. The process that powers the body also produces heat, which is used to keep the body above the temperature of the ambient air. When the body is exerted through exercise or work, the rate of chemical energy production goes way up, as does the amount of heat created. When this exceeds the amount that is required to keep the body warm, the excess must be discarded or the person will overheat. The human body uses water from inside and forces it up through fine pores on the surface of the skin. As was mentioned earlier, this water will evaporate and carry heat energy away from the skin. Small capillaries carry blood under the skin, which has been cooled by the evaporation to give up heat, and then carry it back into the body’s core to cool it. The hotter we get, the more moisture is forced to the skins surface to cool it. [Note: The Association of the British Pharmaceutical Industry provides a great animated example of this process on their website showing how this works. Visit www.abpischools.org.uk/page/modules/skin/skin3.cfm?coSiteNavigation_allTopic=1 ©2013 ABPI for more information].

On a dry day, this cooling process is very efficient and most people do not even notice the moisture unless they are wearing clothes that do not breath. However, as was noted earlier, when the humidity is high, the rate of evaporation possible from the skin surface is limited. The body is trying to cool itself but the amount of heat removal through evaporation is just not sufficient to keep the body from overheating. The moisture (sweat) continues to build on the skin’s surface until the person becomes drenched. In most cases, people can find respite by finding a place that is cool enough or by utilizing a fan to help with the evaporation and heat removal.

However, as was the case in Chicago, if the combined heat and humidity is too high, then there is no way to keep cool. In other words, the air contains more energy than the body, so heat continues to flow into it instead of out it, which can literally cause overheating. France had a similar incident where thousands of people died from the heat because they did not have air-conditioning available in their homes. The elderly, children and pets are particularly vulnerable and luckily have been made a prime focus in future heat-wave planning by the authorities.

Because of the additional amount of moisture required to cool the body when it is humid outside, this should be sufficient reason to heed the advice to drink lots of fluids and keep activity levels to a minimum. Lots of water, relaxation and shade are the best advice for keeping healthy on a hot day. [©2013 ABPI]

References

If the combined heat and humidity is too high, then there is no way to keep cool.

[Editor’s Note: Part 2 of this feature will cover psychrometrics, ADP, air flow and metering devices.]

Jamie Kitchen is the Training Manager at Danfoss (a global manufacturer of HVACR and industrial technology) and lives in Ontario, Canada. Kitchen is responsible for both internal and external technical training, as well as the development of outreach programs to industry supporting organizations and technical schools. He can be reached at 519-925-4397 (direct), 416-570-7782 (cell) or jamiekitchen@danfoss.com. For more information, visit Danfoss Learning at learning.danfoss.com/English.