White Paper: Relative Humidity Impacts of the AirFloor System in the Built Environment

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Introduction

Relative humidity is specified as one of the seven thermal comfort parameters in ASHRAE Standard 55. Figure 1 shows the relationship between relative humidity, the dew-point temperature, the operative temperature, and thermal comfort. The thermal comfort ranges are based on the Predicted Mean Vote (PMV) of 80% acceptability.

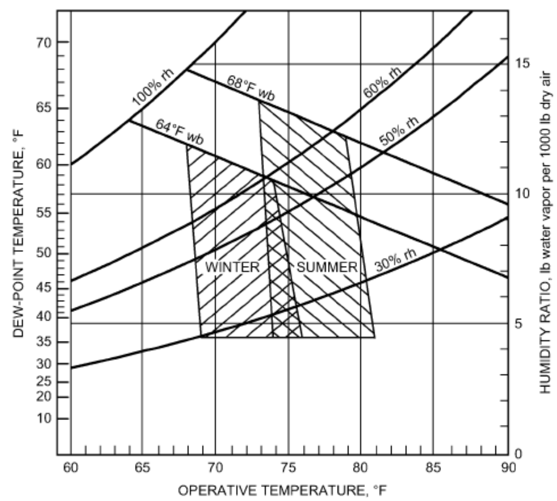

Figure 1. Thermal comfort chart from ASHRAE Standard 55.

Figure 1 illustrates that relative humidity plays an important role in whether or not an individual "feels" thermally comfortable. Unfortunately, the relative humidity is a function of the local temperature as well as the mass of water vapor contained in the air.

This white paper first explains the thermodynamic principles that govern relative humidity. The discussion then evolves to explain how relative humidity is impacted by various heating and cooling systems within the built environment, specifically the AirFloor system.

Humidity thermodynamic principles

Humid air is typically treated as a homogeneous mixture of dry air and water vapor. While the composition of dry air remains constant, the concentration of water vapor within the air depends on evaporation, condensation, and mixing of humid air volumes. There are two common methods to quantify the concentration of water vapor contained within the air: humidity ratio and relative humidity.

The humidity ratio is <u>only</u> a function of the mass of water vapor and mass of dry air. The humidity ratio is mathematically defined as:

$$\omega = \frac{m_v}{m_a} \tag{1}$$

The term m_a is the mass of air and the term m_v is the mass of water vapor. The only way to change the humidity ratio is to change the mass of water vapor in the air. Humidification and de-humidification systems accomplish this task. The right vertical axis in Figure 1 represents the humidity ratio. By assuming that water vapor and dry air can be modeled as ideal gases, the humidity ratio is calculated from the barometric pressure and the partial pressure of the water vapor:

$$\omega = \frac{0.622\, p_v}{p - p_v} \tag{2}$$

The number 0.622 is the ratio of the water vapor molecular weight to the molecular weight of air. The term p is the barometric pressure and the term p_v is the partial pressure of the water vapor. The water vapor partial pressure is typically a small number less than 0.5 psia.

The second water vapor metric, the relative humidity, is more commonly used and referred to in HVAC conversations. However, as shown in the following discussion, the relative humidity is a function of the mass of water vapor and the dry air temperature. The definition of the relative humidity is the ratio of the mass of water vapor to the mass of water vapor that would exist at saturated conditions. The mass of water vapor at saturated conditions is the maximum quantity of water that the air can hold at the dry-bulb temperature without condensation. The mathematical definition of relative humidity is:

$$\phi = \frac{m_v}{m_g} \tag{3}$$

The new term m_g is the mass of water vapor at saturated conditions. Substituting the ideal gas law into equation (3) results in the typical mathematical description of the relative humidity:

$$\phi = \frac{p_v}{p_g} \tag{4}$$

The term p_g is the saturation pressure at the local dry bulb air temperature. Figure 2 shows the relationship between the local dry bulb temperature and the saturation pressure of water.

By comparing equations (2) and (4), one sees that the numerator in equation (4) is a function of the mass of water vapor in the air and the denominator in equation (4) is a function of the local dry-bulb temperature. Consequently, the relative humidity is a function of the mass of water vapor in the air and the local dry bulb temperature of the air.

Finally, the relationship between the humidity ratio and the relative humidity is derived by substituting equation (4) into equation (2):

$$\phi = \frac{\omega p}{\left(0.622 + \omega\right) p_g} \tag{5}$$

The humidity ratio is determined by measuring the wet bulb and the dry bulb air temperatures. The wet bulb temperature is measured using a psychrometer, and is approximately equal to the adiabatic saturation temperature of humid air. The end result is a functional relationship between the wet bulb temperature, the dry bulb temperature, the barometric pressure, and the humidity ratio.

Referring again to equation (4), the relative humidity is a measure of how “full” the air is of water. For example, if the relative humidity is 50%, then the drive for evaporation is stronger than it would be if the relative humidity were 75%.

Impact of Relative Humidity on Thermal Comfort

Because relative humidity is a measure of the "drying ability" of humid air, it has a direct impact on whether or not a person feels cold or warm. The two cases are summer (cooling season) and winter (heating season).

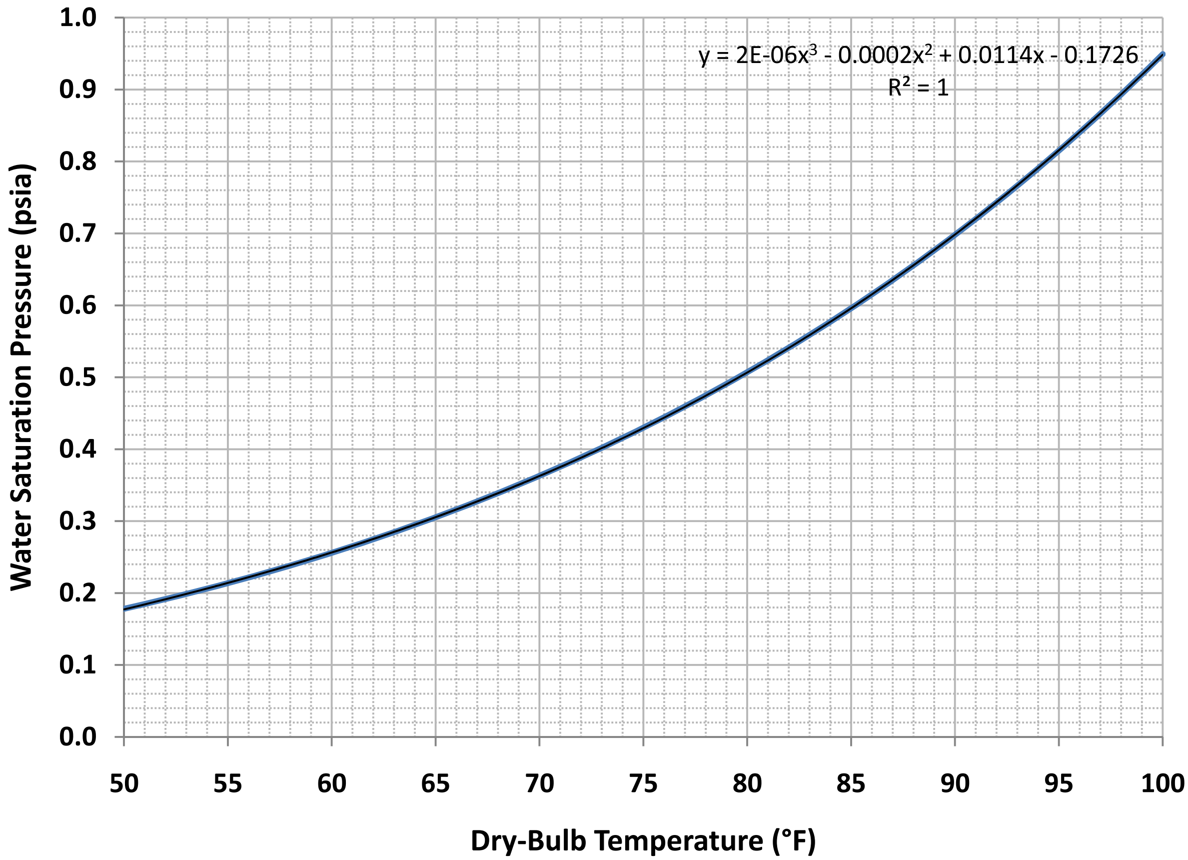

Figure 2. Saturation pressure as a function of dry-bulb temperature.

Summer/Cooling Season

In the summer, the body's mechanism for staying cool is to perspire. The rate of perspiration is limited by evaporation from the skin surface to the surrounding air. The evaporation rate is limited by the ability of the humid air to "take on" more water. The evaporation rate, which is a mass transfer mechanism, is inversely proportional to the relative humidity, i.e., the evaporation rate is greater for a lower relative humidity than it is for air with a higher relative humidity. Consequently, if the relative humidity is high, then the evaporation rate is reduced, and the body's ability to cool itself through perspiration is limited. Conversely, if the relative humidity is low, then the evaporation rate is higher and the body can more effectively control thermal comfort. Referring to Figure 1, the relative humidity must stay below approximately 60% to achieve a thermally comfortable environment at almost any operative temperature. However, 80% of the occupants will feel thermally comfortable at an operative temperature between approximately 74°F and 80°F.

Winter/Heating Season

In the winter, the body's mechanism for staying thermally comfortable is completely different than during the cooling season. In the winter, one of the more problematic issues is that the air is too dry, i.e., the relative humidity is too low. When the relative humidity is too low, the sinus cavities become dry and, if too dry, can begin to bleed. Most sources, including Figure 1, suggest that the relative humidity be maintained at least above 30% and preferably higher.

Impact of HVAC Systems on Humid Air

As explained above, the only way to change the humidity ratio of humid air is to change the ratio of the mass of water to the mass of dry air. The three pertinent methods that can accomplish this task are:

1. Physically add water to the air through a humidification mechanism;
2. Physically remove water from the air through a de-humidification mechanism; and
3. Mix two humid air masses that have different humidity ratios.

Winter/Heating Season

The main contributor to dry air in the built environment during the heating season is infiltration of outside air. Unfortunately, infiltration is difficult to quantify without employing some type of pressurized test method. However, infiltration has been shown to be impacted by the heating system. Typically, systems with higher discharge air temperatures will create the possibility of having a higher "stack effect" in the building, which then leads to higher infiltration rates. Additionally, the use of a fan to move air throughout the building creates an inside pressure that is typically higher than the outside pressure. The result is the exchange of inside and outside air. When outside air enters the built environment, its temperature increases to that of the inside air. The problem, as it pertains to relative humidity, is that the relative humidity of the infiltrated air decreases significantly when it is heated to the inside air temperature. For example, if the outside air conditions are 32°F at a relative humidity of 60%, when this air enters the built environment and subsequently heats to a temperature of 70°F, the relative humidity of that air decreases to only 14.7%. Consequently, higher infiltration rates lead to lower indoor relative humidity levels.

When this concept is applied to the AirFloor system, the AirFloor system functions as part radiant, part forced-air systems. The radiantly heated floor acts to increase the operative temperature while the lower diffuser discharge temperature decreases the infiltration rate when compared to a conventional forced air heating system. Consequently, a plausible argument can be made that the Airfloor system creates a more thermally comfortable environment because (1) it acts to increase the operative temperature and (2) acts to maintain a comfortable relative humidity level. The second aspect of the AirFloor system when compared to a conventional forced-air heating system is that the temperature of the air exiting the diffuser is significantly lower for the AirFloor system. This lower temperature is due to the transfer of heat from the heated air through the AirFloor system as radiant energy. The ultimate impact on the room occupants is a higher, more comfortable, relative humidity of the air exiting the diffuser.

Referring again to Figure 1, a conventional heating system can only increase the operative temperature by increasing the actual room air dry-bulb temperature (Watson and Chapman, 2001). The end result is a room relative humidity that is plausibly less than the lower comfort limit of 30%. The AirFloor system operates differently by transferring a large percentage of energy from the heated air through the AirFloor system. A percentage of this energy is then transferred to the occupants by radiant exchange, which effectively increases the operative temperature without heating the air to as high a temperature. The result is a higher relative humidity at a given operative temperature when compared to that of a conventional heating system.

Summer/Cooling Season

As explained above, the thermal comfort physics are completely different for cooling than they are for heating. The main contributor to discomfort during cooling is the water vapor contained within the air, i.e., high relative humidity. Infiltrating air during the summer months is cooled to room temperatures, which increases the room relative humidity. Much of the energy used to condition the air in the occupied space during cooling is used to remove water vapor from the air. By definition, the air becomes saturated in the conditioning unit such that the relative humidity of the air leaving the conditioning coil is at 100%. In a conventional system, the conditioned air gains some energy in the duct before it is delivered to the room. However, the increase in temperature is modest at approximately 58°F, which means that the air entering the room through the diffuser is at a relative humidity of nearly 100%. In the AirFloor system, the air extracts heat from the AirFloor structure. This extraction impacts thermal comfort in two ways.

First, the floor surface temperature is cooler than the surrounding air. The occupants radiatively exchange energy with the floor, which lowers the operative temperature without significantly lowering the room dry-bulb temperature. Second, the air flowing through the AirFloor system is heated to approximately 68°F. This increase in temperature decreases the relative humidity from the nearly 100% in the conventional cooling case to something that is more amenable to creating a thermally comfortable space.

Conclusions

The AirFloor system functions in a way that moderates the relative humidity while at the same time creating a positive influence on the operative temperature. This effect is shown in Figure 3. The blue star illustrates the approximate condition of the air coming from the conventional forced air diffuser in cooling mode and the red star illustrates the corresponding condition in heating mode. Conversely, the AirFloor system will create a condition where the air exiting the diffuser will be in the shaded areas, or at least very near the shaded areas. Hence, the AirFloor system should require less energy to achieve the same level of thermal comfort when compared to a conventional forced-air heating and cooling system.

The definitions and discussion in this white paper clearly show that relative humidity and thermal comfort are not a given, but instead are a strong function of the method used to condition (heating or cooling) in the occupied space. ASHRAE Standard 90.1 has recently recognized this fact. The findings from ASHRAE Standard 90.1 are forthcoming in the new standard. These findings clearly show that radiant systems create a thermal comfort

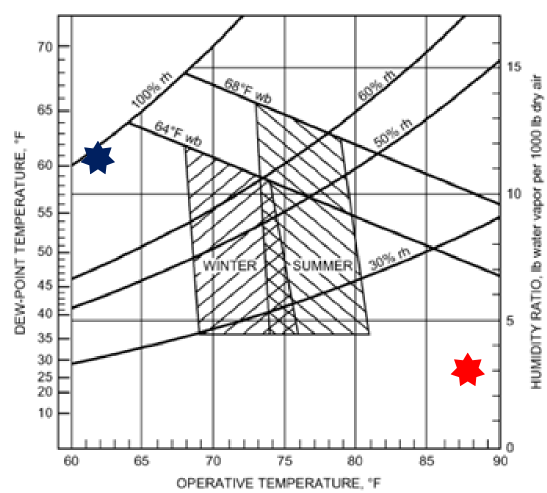

Figure 3. Thermal comfort chart from ASHRAE Standard 55.

moderating effect. When a hybrid system, such as the AirFloor system, is employed, it can also moderate relative humidity in a way that increases relative humidity during the heating season and lowers relative humidity during the cooling season. This impact is due to the recognition of operative temperature as the thermal comfort metric instead of the historically used dry-bulb temperature. In turn, the operative temperature can be controlled with a moderating impact on the relative humidity.

References

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Moran, M.J. and Shapiro, H.N., 2008, *Fundamentals of Engineering Thermodynamics*, John Wiley and Sons.