Rad & Air text dump

Buildings use a lot of energy among other end-users in the United States. Their heating and cooling systems can be linked to up to 50% of the overall energy usage. Researchers and scientists have suggested many alternative systems that may drastically decrease the energy usage in buildings, but aside from retrofitting, interventions to the building’s set point settings are much more popular. Recent studies associating expanded set points also hinted improved thermal comfort, as studies have also shown that the productivity of occupants may improve when the thermal environment leans towards slightly cooler. Based on the existing literature, we are wondering whether pushing the air temperature set points further may have any implications not only to the energy savings but also humidity conditions in the built environment.

*Why radiant*

As there are many different types of heating and cooling systems that are widely available, we want to investigate particularly the implications of radiant systems in contrast to all-air systems since the contrast would be larger. This is because the radiant systems do not need to explicitly condition the air temperature, which will result in smaller heating and cooling load since water and other working fluids are better heat carriers. In the meantime, radiant systems appear to have comparable if not better thermal comfort implications according to existing studies, and are hence good comparison to the prevailing air-based heating/cooling systems in the US.

*The relationship to relative humidity.*

Unlike air temperature, or the targeted fluid/surface temperature that are often used in the control of air or radiant systems, relative humidity (RH) is a much less commonly observed control variable. Relative-humidity-based control is currently used in more strictly-controlled environments such as piano rooms, archival storage rooms and specialized medical facilities. RH-based control is currently very expensive for residential or large commercial projects to consider. This is not only because the demand of RH-specific environments are less common, but also because the value of RH is codependent on the condition of the moist air condition, and cannot be easily controlled through a feedback control loop.

*Air as we know it*

The moist air in a room is a mixture of both dry air and water vapor. Dry air has properties that are very close to ideal gas while the water vapor is ideal gas, we model their mixture using the ideal gas law and can estimate this mixture’s remaining properties (pressure, humidity ratio and enthalpy) when a specific set of property (temperature and RH, in this example) is given. Graphically, this is also often explained by the psychrometric chart published by ASHRAE. However, the actual psychrometric processes that air conditioners undergoes is a myth to most users, since the feedback variable that most of their systems would allow them to control is only the air temperature. Although ASHRAE does recommend RH to be maintained between 30% to 60%, adding humidity to the air is still a secondary concern when people are purchasing and installing home air conditioning systems.

*RH – dry and wet*

According to some latest research, the health implications of RH can be significant, although often in a delayed and indirect manner. Reports on RH below 20% could cause eye irritation and dryness/stuffiness complaints, and ultra-low RHs below that may even cause eye and air pathway and skin symptoms. RH below 10% could even desiccate the mucous membrane over time and lead to further agitation with both the eye and nasal cavity. Conversely, higher RH levels also have the potential to deteriorate building materials and grow mold that may lead to respiratory symptoms among building occupants. However, the RH that would allow rapid growth of bacteria and viruses are often found to be at least 75%, which is much higher than the mandate from ASHRAE or ISO 7730 (30% to 70%). There is, ultimately, very little regulation or guidelines regarding what the RH inside a room should be kept at, and anything above 30% and below 60% is acceptable. This is potentially also the reason why RH is much less controlled in conventional systems.

*Relationship to Energy*

Existing literature have already established the link between energy savings and expanded set points of air. The verified energy potentials were demonstrated through air-based systems in simulated building cases through different climates. This included both the sensible and latent heat following the underlying hypothesis of the building case used and the occupancy density that was selected. Using radiant systems may prevent the excessive energy usage needed to remove the latent heat in the air in the summer. The relationship between the sensible and latent cooling load is less often studied but has seen some recent advances: new concepts such as the enthalpy degree days and latent enthalpy days were proposed in contrast to the cooling degree day method used in estimating annual cooling loads.

*What we want to do with this study*

In this study, we hope to take advantage of the existing literature to understand the benefit of further expanding the set point temperatures through the usage of radiant systems. This would include discussions on the energy savings from preventing the latent loads that would otherwise have occurred when using all-air systems, as well as the improvement of RH without additional humidifiers for the heating season. To better illustrate the energy saving potentials and the corresponding improvement in RH, we will run the analysis through hypothetical household located across the 48 continental states in the US to illustrate the energy and humidity potentials that can be found across different areas.

**Methodology**

*Base Building Case*

Hoping to create a generic building energy footprint for comparison across the United States, we are assuming an average household with average square footage, household member counts, and energy consumption profiles that are made publicly available by the Department of Energy and US Census. For the purpose of this study, we consider only the residential conditioning systems. For this purpose, we assume the size of the household to be 2.52 occupants (cite US. Census.), which requires no more than 37.8 CFM of fresh air according to ASHRAE. In order to estimate the required fresh air rate, we assume the size of the house through the average size of buildings built (cite DOE?) as 2392 squared feet. As according to ASHRAE Standard 62, the newly-built buildings are instructed to achieve an infiltration rate of 2 CFM per every 100 squared feet, this allows us to estimate the ventilation rate of the hypothetical average house to have 47.84 CFM through infiltration. This is above the required fresh air amount for 2.52 hypothetical occupants in the average household in the United States. Assuming the height of the houses to be 9 feet, we obtained a fresh air percentage of 18 per cent, which allowed us to estimate the condition of the mixed air with a targeted indoor air condition and outdoor air condition. The set points and the psychrometric processes we are assuming are introduced separated in the subsequent sections.

*Data Collection and Processing*

As we are interested in understanding the potential energy savings and RH improvement across continental US, we need the weather data collected from major cities across the continent with resolution smaller than every hour. The ISD-lite dataset made available by NOAA (National Oceanographic Association of America) provides air temperature, relative humidity and geographic location at weather stations across major city centers and airports across continental US. This data is publicly available on NOAA’s ftp server. We downloaded a total of 13,800 files for the monitored weather in 2018 for the purpose of this analysis. Since the climate zones, as we are plotting in the subsequent figure.

Upon scraping the NOAA ftp server for the 2018 weather files, we used the pandas data frame library in Python to clean up and regroup the files into time-stamped weather data, and re-sampled on an hourly rate. We also used the CoolProps library to calculate the enthalpy of moist air at different states, and appended the resulting hourly enthalpy states. The resulting weather files will therefore have the air temperature, relative humidity, specific enthalpy for 8760 hours in 2018 across all the stations. We are plotting an example of the data collected in one of the weather stations in the following figure.

Figure 1. Locations of climate station files (Is there a list for this to be plotted somewhere in ArcGIS?)

Figure 2. Processed Outdoor Dry-bulb temperature against outdoor specific enthalpy

*Degree-Day calculation*

Degree Day (DD) is a method that ASHRAE currently still recommend using when measuring how outdoor air temperature variation may impact the energy use. It compares the outdoor temperature to a defined base temperature, which is naturally a temperature-based method used to explain building energy consumption. As we are attempting to illustrate the differences between the radiant and air-based differences, DD is an apparent choice that circumvents the selection of more explicit building systems. In degree-day theory, the base temperature separates times where buildings need conditioning from times it does not. This applies to both the heating and the cooling case, or otherwise known as cooling degree day (CDD) and heating degree day (HDD) methods. (Use equations for both here). The base case can often be considered the equivalent of set-point temperature, and is recommended to be set at 18.3 C(65 F) by ASHRAE.

However, as both the CDD and HDD method are based solely on the outdoor dry-bulb temperature, the latent loads are apparently overlooked. This is particularly true for the cooling scenario. Researchers have proposed alternative such as the enthalpy degree days (EDD), where the enthalpy of the air of the day can be compared to the base case enthalpy. Huang et al. first suggested the possibility of estimating the latent loads through a concept known as latent enthalpy degree day, while Krese et al. further perfected it by suggesting the EDD approach in 2012 through 2013. This is further assessed in a more recent research by Jimeno and Schulter where they proposed a Degree of Enthalpy Gradient, or DEG. It is a new advancement in the direction of assessing the latent load in buildings by combining the heating and the cooling demands, but creates extra difficulty in analyzing the cooling and heating cases independently for us.

*Cooling – latent load savings*

For the cooling scenario, conventional air handling units uses evaporative cooling to cool the outdoor air down to set point per the design of the cooling system. This process can be simplified on the psychrometric chart as the air temperature from the outdoor condition being cooled down to the set point at the desired indoor condition. Previous study has demonstrated the clear energy benefit of expanding the set points, but has yet to unravel the latent energy benefit caused by the changes in set point temperature.

*Coolingcases.png, Example psychrometric processes under different set points for the cooling scenario.*

We want to compare the impacts of having different set points specifically focusing on the differences in latent loads, which we are showing in the psychrometric process in the figure above. While maintaining the same level of desired RH, the changes in the energy demand is not fully reflected by the changes in dry bulb air temperature. As can be observed from the figure above, the increase in enthalpy can only be reflected.

We want to illustrate the potential energy demand increase when attempting to achieve more desirable RH. This is currently a relatively overlooked area.

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The ASHRAE recommended set point range is 74 F to 80 F in the summer, while a typical radiant cooled space will use 75 F (24 C) air temperature with no greater than 50% RH, which is the equivalent of a lower dew point temperature (approx. 12.2 C) to avoid condensation.

*Heating – RH improvements modeling*

For the heating scenario, we will be assuming sensible heating only, where the outdoor air is heated up with the same humidity ratio. Following the indoor air temperature guideline recommended by ASHRAE, which is 68 F to 74 F (20 to 23 C) for winter, we will be using these temperatures as the base condition to be compared with. For the radiant scenario, since the radiant surfaces are often kept at a higher temperature, we will be setting the indoor air temperature slightly higher than that of the dew point temperature of assumed indoor air condition – which we assume to have a RH at 50%. This is equivalent of dew point temperatures at ??? and ??? degree C.

Similarly to the psychrometric process in the cooling case, we are expressing the heating of air in the psychrometric chart underneath. Since the majority of the heating is accomplished through furnaces and air conditioners, the outdoor air is assumed to go through a constant-humidity-ratio process as it is heated sensibly. Without additional humidifiers, the resulting RH could reach beneath 30% (as indicated in the figure), and potentially lead risks of the occupants’ wellbeing. Even when considering additional humidifiers, the energy that needs to be added to the air can also be characterized as additional energy demands (as marked by the red arrows in illustration we created.

It is, therefore, crucial to provide an estimation of the overall energy demand necessary to deliver air that is warm enough for all-air systems or radiant system, and additionally air that is moist enough to avoid strain on the respiratory system of the occupants. We believe it is crucial to highlight the energy savings in both the cooling and the heating condition when considering expanded set points. Using the psychrometric-driven approach, we are hoping to conduct both spatial and statistical analysis on the resulting RH and energy demand across continental US with the NOAA data we collected.