Analysis of supplemental dehumidification for increased energy efficiency of shoulder seasons based on climate change predictions in Austin Texas

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Abstract
This research project compared a standard vapor compression system and a standard desiccant dehumidification system with heat wheel to determine if there was some potential energy savings for “shoulder season” hours in Austin Texas. “Shoulder season” hours as defined in the paper are hours during which the dry bulb temperature falls within the American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) comfort bound but the humidity is above the comfortable humidity point. These hours are normally addressed with vapor compression systems which dehumidify by cooling the air under the comfort setpoint to dehumidify, which is wasteful of energy. The study found that for these shoulder season hours a desiccant dehumidification system was around 4.5 times more energy efficient at reaching comfort setpoints if free heating was used for drying the desiccant.

1. Introduction
Air-based conditioning systems must deal with not only sensible (air temperature) energy but also latent (humidity) energy when providing thermal comfort to a building’s occupants. During seasons in which outdoor air temperatures are very close to or within thermal comfort conditions, air-based conditioning systems using sensible temperature sensors will not run for very long before a sensible setpoint is reached. Unfortunately, in these situations, latent energy is not addressed due to the large difference in specific heat between air and water vapor. Because the latent heat is unaddressed, thermal comfort is often not met with standard temperatures and to reach thermal comfort conditions the outside air must be cooled under the comfort point and reheated. In these shoulder seasons the difference between thermal comfort and thermal discomfort can be accomplished by removal of latent heat (humidity) solely. This is an area of potential energy savings and thus a reduction in emissions which this paper will explore.

These hours in which the outdoor temperature and humidity are within ASHRAE comfort ranges [1] are referred to as “free cooling” hours. They are already being taken advantage of by HVAC engineers with the use of economizers which switch off the vapor compression systems in larger units and supply the buildings they are installed in with 100% outdoor air. This reduces energy use drastically since the systems only need run fans to supply this outside air and exhaust the building air. There is a point, however, when the outside air temperature is within acceptable comfort bounds, but the humidity is above acceptable comfort bounds which for the purposes of this paper will be referred to as “shoulder season” hours. These are the hours in which potential energy savings can occur and what this study is focused on.
2. Methods

Shoulder season hours

Analysing weather data for the city of Austin, Texas each hour that fell within acceptable (ASHRAE) temperature bounds (20-27.7 °C) but above acceptable (ASHRAE) humidity bounds (0.012 kg w/kg air) was considered. Beyond discovering how many hours fell into the “shoulder seasons” category, the two major questions are, how does climate change affect these shoulder seasons and how much energy can be saved by using a desiccant system as opposed to a standard vapor compression system during these shoulder seasons. A related question comes from climate change predictions forecast of warmer weather for the future. Warmer air has the potential to contain more water vapor which will increase the latent energy to be removed. Because there will be more warm weather hours and those hours have the potential for higher humidity ratios, would standalone dehumidification systems be able to save even more energy than before the climate started warming [2]? However, one of the predictions by the International Panel on Climate Change is that desertification is a possibility in the Western United states [7]. Taking weather data for Austin, Texas provided by Meteonorm Version 7 that was statistically generated for each decade from 2020-2100, the hours that fall into the shoulder seasons were used for analysis. The Meteonorm data was generated for three different climate change scenarios outlined by the International Panel of Climate Change (IPCC): A1B, A2, B1[3].

Climate Change and Enthalpy

To calculate the enthalpy, several things must be calculated first.

\[ \theta = 1 - \left( \frac{T}{T_C} \right) \]  \[\text{[4]}\]

Where: \( \theta \) for the purposes of this paper will be referred to as the critical temperature ratio; the critical temperature \( T_C = 647.096 \text{K} \); \( T \) is the air temperature [K]

\[ P_{WS} = P_C \times e^{\left( \frac{T_C}{T} \times (A_1 \times \theta + A_2 \times \theta^{1.5} + A_3 \times \theta^3 + A_4 \times \theta^4 + A_5 \times \theta^5) \right)} \]  \[\text{[4]}\]

Where: \( P_{ws} \) is the Saturated Water Vapor Pressure [MPa]; \( P_C \) is the critical pressure \( 22.064 \text{ [MPa]} \)

The “a”s are empirical constants [4]

\( A_1 = -7.85951783, A_2 = 1.84408259, A_3 = -11.7866497, A_4 = 22.6807411, A_5 = -15.9618719, A_6 = 1.80122502 \)

\[ P_W = RH \times P_{WS} \div 100 \]  \[\text{[4]}\]

Where: \( P_W \) is the water vapor pressure [MPa]; \( RH \) is the relative humidity [%]

\[ W = 621.97 \times P_W \div (P - P_W) \]  \[\text{[4]}\]

Where: \( W \) is the humidity ratio [g/kg]; \( P \) is the ambient pressure [MPa]

\[ h = T \times (1.01 + 0.00189 \times W) + 2.5 \times W \]  \[\text{[4]}\]

Where: \( H \) is enthalpy [kJ/kg]; \( T \) is air temperature [C]

Using these equations, the enthalpy was found for each hour of data that fell in the shoulder season parameters.

Shoulder seasons hours and dehumidification

Using these enthalpies and assuming some common variables including:

\( COP \) (coefficient of performance) = 4
\( \text{Air Flow Rate} = 0.1 \text{ [m}^3/\text{s}] \)
\( \text{ACH (air changes per hour)} = 5 \)
\( \text{Temperature setpoint} = 13 \text{ [C]} \)
\( \text{Humidity ratio setpoint} = 0.0092 \text{ [kg water/kg air]} \)
\( \text{Effective heat recovery} = 75\% \)
\( \text{Desiccant temperature difference} = 20 \text{ [C]} \)
The energy usage in kilowatt hours was calculated using these assumed variables for both a vapor compression system and a desiccant system. The outside air enthalpy was computed using equation 5 and the enthalpy change for each process was computed based on the Meteonorm 7 predicted weather files. In the figure below, the basic vapor compression dehumidification cycle (blue) and desiccant dehumidification cycle (grey) are shown taking the same outside air point and reaching the same room air point. Each process uses both refrigerant cooling and some added heat. The vapor compression system is more straightforward but uses more cooling energy than the desiccant system. Likewise, the desiccant system is more complicated and uses more heating energy than the vapor compression system.

![Psychrometric Comparison](image)

**Figure 1:** Psychrometric Comparison. ASHRAE 1992

### 3. Results

The resulting data was an average of 1801 hours per year which is 20.5% of the total hours per year [5] as shown in figure 2. Although the average number of shoulder season hours across the 9 decades was 1801, there was a slight trend toward desertification in the A1B and A2 climate scenarios. However, the largest swing was from the A2 scenario with a difference in shoulder season hours from 2020 to 2100 of 151 hours. This is only 1.72% of the hours of the year. The number of hours of shoulder season conditions may be going down slightly, but what about the enthalpy, energy per unit of mass, of these hours? After all the difference in enthalpy should give an indication of the difference in latent energy for removal. Also, since weather is predicted to become more extreme maybe even though the shoulder season hours are going down, the enthalpy in these hours could be larger. Like the number of shoulder season hours, the enthalpy during these shoulder season hours seems to be decreasing for the A2 and B1 climate scenarios as shown in figure 3. The enthalpy percent difference is the highest again for the A2.
scenario at 6.43%. The B1 scenario interestingly gains 2.34% enthalpy from 2020 to 2100 even while losing 10 shoulder season hours. These are some interesting findings, but how does this apply to HVAC?

As can be seen in the energy comparison in the next two figures, the total energy input for the desiccant system is almost double that of the vapor compression system. However, the second graph tells a more nuanced story. Most of the energy input for the desiccant system is heat energy used to recharge the desiccant after the chemical process soaks up the water vapor. This distinction matters because that heat energy can be harvested “for free” from solar energy or waste heat from processes either in the building or the machinery around the building rather than use line energy. There are, of course, costs associated with piping, pumps, and maintenance to harvest this “free” heat energy which will need to be considered when completing an economic comparison between the two dehumidification strategies.
Figure 4: Enthalpy for shoulder season hours per representative year per decade according to different climate change models.

Figure 5: Total Dehumidification Energy

Figure 6: Dehumidification energy without including reheat
4. Conclusion
Averaging the energy usage of the vapor compression system and the desiccant systems across this data range (2020-2100) and specifically for these shoulder season hours gives an energy usage that is an order of magnitude of energy savings between the two dehumidification strategies (4.5x more energy efficient for the desiccant system). Since they are averages of multiple climate scenarios which are again approximations of weather files based on approximations of climate change due to approximations of emissions orders of magnitude is probably the safest estimate for comparison.

For humid climates like Austin, there are around 20% of the hours of the year in which dehumidification is all that is needed to achieve thermal comfort as defined by the American Society of Heating Refrigeration and Air-Conditioning. These hours are predicted to decrease very slightly as well as the enthalpies associated with these hours, but the decrease is so slight (1.72% yearly hours, 6.43% enthalpy difference change in worst case scenario) that shoulder season dehumidification should be safe bet for energy savings for years to come. Of the two analysed dehumidification strategies, the vapor compression system is better if a heat generation via a “free” means is difficult or not cost effective. If possible, though, the desiccant system is significantly better (4.5x less energy) if a “free” means of heating can be used (solar, waste heat, etc).

References
[1] American Society of Heating, Refrigerating and Air-Conditioning Engineers. 2017. Thermal Environmental Standards for Human Occupancy: ASHRAE standard. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.
[2] American Society of Heating, Refrigerating and Air-Conditioning Engineers. 1992. Psychrometric Chart NO. 1, Normal Temperature, Barometric Pressure 101.325 KPa. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.
[3] Rudd, A. “Measure Guideline: Supplemental Dehumidification in Warm-Humid Climates,” 2014. [4] Nakicenovic, Nebojsa, et al. Special report on emissions scenarios (SRES), a special report of Working Group III of the intergovernmental panel on climate change. Cambridge University Press, 2000.
[5] Humidity Calculations Using Temperature, Relative Humidity, Pressure, AVMcL LLC. All Rights Reserved Worldwide., 2021, www.aqua-calc.com/calculate/humidity.
[6] Marshall, B. G. (Unpublished). Artificial Trichome Mesh for Membrane Dehumidification [In Progress Master’s thesis]. University of Texas at Austin
[7] In P. R. Shukla, J. Skeg, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, S. van Diemen, M. Ferrat, E. Haughey, S. Luz, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi & J. Malley (eds.), Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (2019)