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Humidification Requirements in Economizer-Type HVAC Systems (DA-13-022)

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Learning Objectives

- Learn formulae that can be used, together with ASHRAE-provided climate data, to find the maximum humidification load in both temperature-based and enthalpy-based economizer systems.
- Understand how to better simulate the performance of whole-house tankless water heaters.
- Learn about a new boiler model for dynamic simulations that aims for easy parameterization.
- Assess the performance of portable disk humidifiers.

Agenda for Session

- Learn formulae that can be used, together with ASHRAE-provided climate data, to find the maximum humidification load in both temperature-based and enthalpy-based economizer systems.

The problem

- In an economizer type system, the ratio of outside air vs. return air varies as a function of outside conditions
- How do you calculate the loads, specifically the humidification load, as a function of outside conditions?

Fundamental equations

- Can be derived easily from first principles (statistical thermodynamics)
- Basic relationship between enthalpy (h) temperature (T) and humidity ratio (w) is given by

$$h = c_P T + h^{\mathrm{vap}} w,$$

  (c_P: specific heat at constant pressure, h^{vap}: latent heat of vaporization)
- NB: c_P can be derived from first principles

Enthalpy and temperature

- ASHRAE Handbook sets $h = 0$ at the start of the temperature scale (0°C or 0°F)
- This ignores the fact that the heat content of dry and moist air are not the same at that temperature
- Derivative of the equation that connects T, h, c_P and *w* reads:

$$\frac{\partial h}{\partial w} = T\frac{\partial c_P}{\partial w} + h^{\mathrm{vap}}$$

- This equation only makes sense if *T* represents absolute temperature
- For accurate results for processes that change the humidity content, **enthalpy should be normalized** such that $h = 0$ **at absolute zero**

Conservation laws

- The properties of air in an HVAC system can be calculated using conservation laws
- Conserved quantities are:
  - The mass of dry air
  - The mass of moisture
  - Energy (enthalpy)
- These quantities can only change in response to external influences (e.g., adding outside air, heating)

Mixing air

- Consider two quantities of air characterized by masses m_1 and m_2, humidity ratios w_1 and w_2, and enthalpies h_1 and h_2. When you mix them, conservation laws determine the values of m, w and h for the mixture:

$$m = m_1 + m_2,$$
$$w = \frac{w_1 m_1 + w_2 m_2}{m_1 + m_2},$$
$$h = \frac{h_1 m_1 + h_2 m_2}{m_1 + m_2}.$$

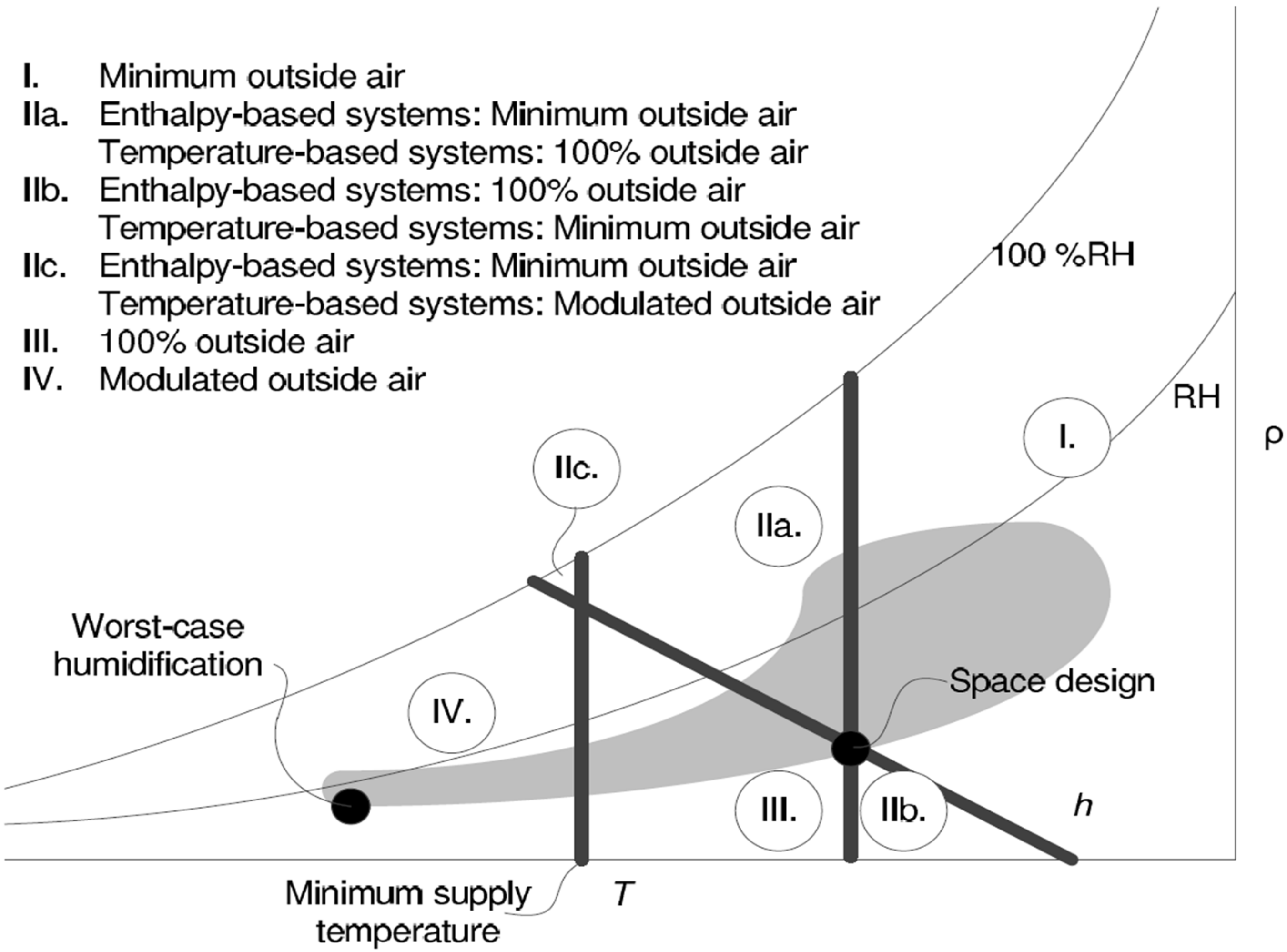
Economizer systems

- Vary the ratio of outside vs. return air based on outside conditions:
    - Minimum outside air when it's hot, to reduce air conditioning costs;
    - 100% outside air when it's cool, to maximize the benefits of acceptable outside conditions;
    - Modulated outside air when it's very cold, to minimize heating costs.

Enthalpy-based systems

- Temperature-based system draws in outside air so long as it's colder
- Slightly colder but very humid outside air can result in increased A/C costs
- Problem is avoided if enthalpies are compared instead.

Economizer systems



Humidification in economizers

- Worst-case humidification is at the bottom end of the outside air conditions region in the psychrometric chart
- This may be to the left (OA modulated) or to the right (100% OA) of the minimum supply temperature requirement
- Mixed air state point is calculated accordingly

Key results

- Outside air quantity is given by:

$$m_{\mathrm{OA}} = \max\left(-\frac{\left[c_P^{\mathrm{wv}} w_{\mathrm{RA}} + c_P^{\mathrm{da}}\right]\left[T_{\mathrm{RA}}^{\star} - T_{\mathrm{MA}}^{\star}\right]}{\left[c_P^{\mathrm{wv}} w_{\mathrm{OA}} + c_P^{\mathrm{da}}\right]\left[T_{\mathrm{OA}}^{\star} - T_{\mathrm{MA}}^{\star}\right]}, \alpha\right) m_{\mathrm{RA}},$$

- Mixed air humidity ratio is given by:

$$w_{\mathrm{MA}} = \frac{w_{\mathrm{OA}} m_{\mathrm{OA}} + w_{\mathrm{RA}} m_{\mathrm{RA}}}{m_{\mathrm{OA}} + m_{\mathrm{RA}}}.$$

(MA: mixed air, OA: outside air, RA: return air, wv: water vapor, da: dry air, α: minimum outside air ratio)

Completing the calculation

- Once w_{MA} is known, humidification requirement is trivially calculated
- Calculation can be repeated for the lower edge of the outside conditions range
- Worst-case result can be used to load-size the system
- Similar approach can be used to calculate heating, cooling, dehumidification loads

Conclusions

- Enthalpy- or temperature based? Really doesn't matter for humidification as we are concerned about the lower edge of the outside air regime
- But, this analysis can also be used for other (e.g., cooling, dehumidification) processes
- For processes involving changes in humidity ratio, using the correct starting point for the enthalpy scale is critical

Questions?

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Bibliography

- Humidification requirements in economizer-type HVAC systems

  ASHRAE Transactions 119(1) (pending publication).

Supporting slide for questions

- Outside air quantity is given by:

$$m_{\mathrm{OA}} = \begin{cases} -\dfrac{(c_P^{\mathrm{wv}} w_{\mathrm{RA}} + c_P^{\mathrm{da}})(T_{\mathrm{RA}}^\star - T_{\mathrm{MA}}^\star)}{(c_P^{\mathrm{wv}} w_{\mathrm{OA}} + c_P^{\mathrm{da}})(T_{\mathrm{OA}}^\star - T_{\mathrm{MA}}^\star)} m_{\mathrm{RA}} & \text{if } -\dfrac{(c_P^{\mathrm{wv}} w_{\mathrm{RA}} + c_P^{\mathrm{da}})(T_{\mathrm{RA}}^\star - T_{\mathrm{MA}}^\star)}{(c_P^{\mathrm{wv}} w_{\mathrm{OA}} + c_P^{\mathrm{da}})(T_{\mathrm{OA}}^\star - T_{\mathrm{MA}}^\star)} > \alpha, \\ \alpha m_{\mathrm{RA}} & \text{if } -\dfrac{(c_P^{\mathrm{wv}} w_{\mathrm{RA}} + c_P^{\mathrm{da}})(T_{\mathrm{RA}}^\star - T_{\mathrm{MA}}^\star)}{(c_P^{\mathrm{wv}} w_{\mathrm{OA}} + c_P^{\mathrm{da}})(T_{\mathrm{OA}}^\star - T_{\mathrm{MA}}^\star)} \leq \alpha. \end{cases}$$

- Mixed air humidity ratio is given by:

$$w_{\mathrm{MA}} = \begin{cases} \dfrac{w_{\mathrm{OA}} m_{\mathrm{OA}} + w_{\mathrm{RA}} m_{\mathrm{RA}}}{m_{\mathrm{OA}} + m_{\mathrm{RA}}} & \text{if } -\dfrac{(c_P^{\mathrm{wv}} w_{\mathrm{RA}} + c_P^{\mathrm{da}})(T_{\mathrm{RA}}^\star - T_{\mathrm{MA}}^\star)}{(c_P^{\mathrm{wv}} w_{\mathrm{OA}} + c_P^{\mathrm{da}})(T_{\mathrm{OA}}^\star - T_{\mathrm{MA}}^\star)} > \alpha, \\ \dfrac{\alpha w_{\mathrm{OA}} + w_{\mathrm{RA}}}{1 + \alpha} & \text{if } -\dfrac{(c_P^{\mathrm{wv}} w_{\mathrm{RA}} + c_P^{\mathrm{da}})(T_{\mathrm{RA}}^\star - T_{\mathrm{MA}}^\star)}{(c_P^{\mathrm{wv}} w_{\mathrm{OA}} + c_P^{\mathrm{da}})(T_{\mathrm{OA}}^\star - T_{\mathrm{MA}}^\star)} \leq \alpha, \end{cases}$$

(MA: mixed air, OA: outside air, RA: return air, wv: water vapor, da: dry air, α: minimum outside air ratio)