

Optimizing Electric Humidifier Operation with an Air Side Economizer

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Abstract

Air side economizer cycle is a control scheme that is often used in HVAC systems to reduce cooling energy consumption by introducing variable quantities of ambient air into a conditioned space to satisfy the space cooling load (free cooling). Humidifiers are used to maintain the pre-set humidity levels in a conditioned space by introducing steam or atomized water into the space.

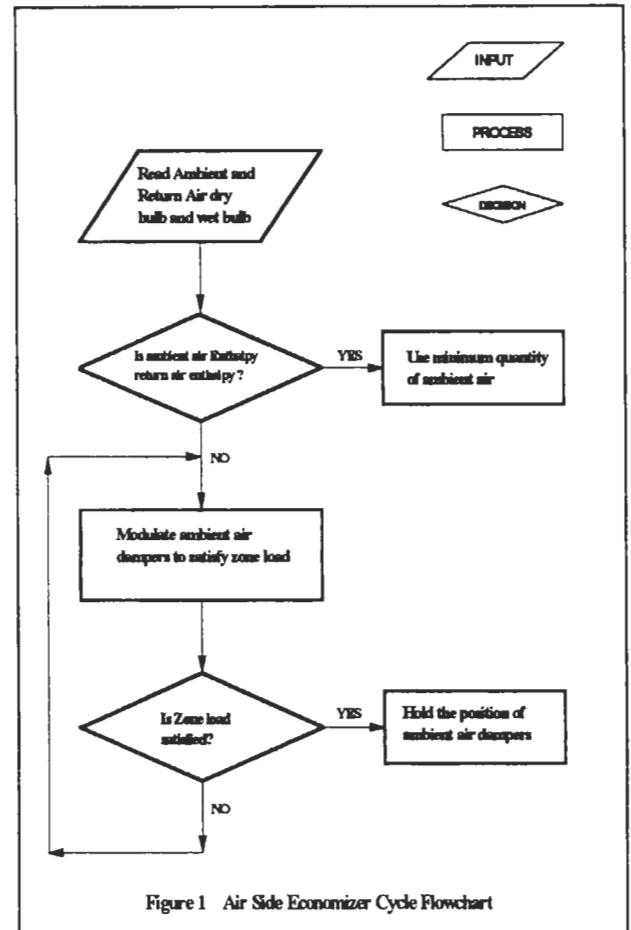
An HVAC system containing both electric humidifier and air side economizer cycle can appear to be energy efficient, but has the potential of being inefficient due to lack of proper controls. The economizer, which often operates independently of the humidifier, introduces large quantities of cool and dry ambient air into the space to reduce the mechanical cooling energy, but because of the environmental requirement of the space, the air has to be humidified. The humidification energy could offset the energy savings from the reduction in mechanical cooling energy.

The solution for this potential problem is a control scheme that makes the operation of the economizer and electric humidifier interdependent. The control scheme will use ambient conditions and space environmental requirements to calculate the appropriate amount of outside air that the economizer should draw into the space. The control scheme can be implemented through a Direct Digital Control system.

Introduction

Many facilities such as computer rooms, digital switch equipment rooms, museums, and libraries, use electric humidifier to maintain required humidity levels in the space. In the case of electronic equipment, low humidity levels promotes the accumulation of electrostatic charges on equipment and people which can result in overloading electronic circuits, while high humidity levels could result in electrolytic and chemical corrosion of the equipment. The museum or library environment has to be maintained at a proper humidity level to preserve paintings and paper.

Air side economizers are used in many HVAC systems to reduce mechanical cooling when ambient air temperature is appropriate to meet the space loads. Figure 1 is a flowchart representing the logic flow for an air side economizer.



An HVAC system with an air side economizer and an electric humidifier operating independently, could operate inefficiently during the periods when outside air is cool and dry.

Optimizing the operation of the economizer and the humidifier requires the use of a DDC system to measure ambient and space conditions and then decide on the appropriate outside air amount that can be used without paying a humidification penalty.

Psychrometric Analysis

The psychrometric chart in Figure 3 indicates three psychrometric regions with a sub-region indicating the comfort zone for most facilities. The 40°F dew

point line, the 60°F dew point line, and the 72 °F dry bulb line are used to define the different regions.

Those chosen limits of the different regions were determined based on desired and undesired ambient conditions (temperature and humidity ratio) for most facilities. Psychrometric region I falls between the 40°F dew point line, the 60°F dew point line, the saturation line, and the 72°F dry bulb line.

Psychrometric region III falls between the dry bulb axis, the 72°F dry bulb line, the 40°F dew point line, and the 35°F dry bulb line. Any condition outside of Region I and Region III is considered to be in Region II. Region I represents desirable ambient conditions, while region II represents undesirable ambient conditions. Region III includes both desirable and undesirable conditions.

Optimization Scheme

The optimization scheme is developed to deal with the difficult task of introducing the appropriate quantities of outside air to the conditioned space at given conditions.

The flowchart in Figure 2 indicates the logic flow for the optimization scheme and lists the parameters needed to implement the scheme. The required parameters can be measured and recorded periodically using the DDC system.

These parameters are:

- Ambient dry bulb temperature and relative humidity
- Return air temperature and relative humidity
- Cooling coil leaving air temperature and relative humidity
- Conditioned space temperature and relative humidity.

The optimization scheme conditions are:

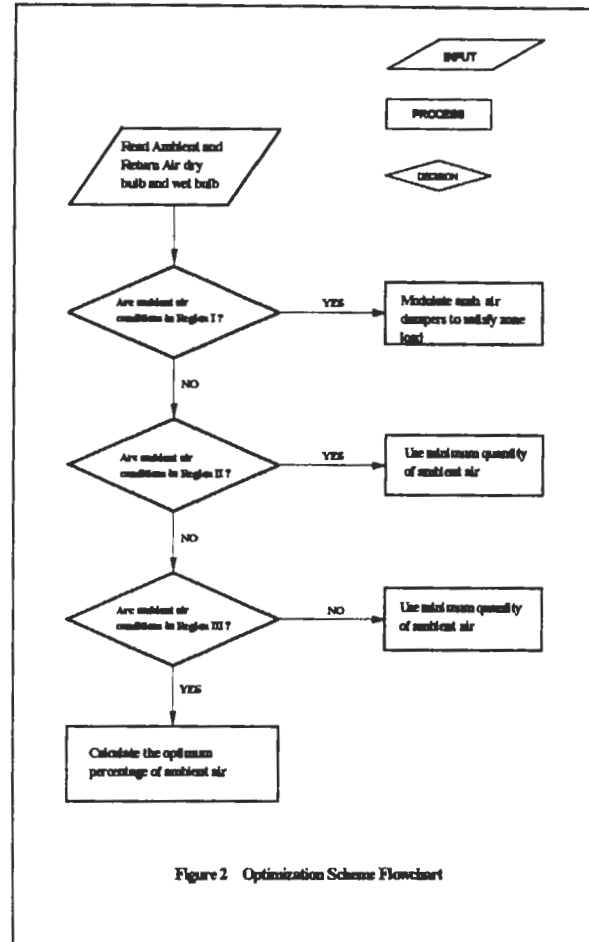


Figure 2 Optimization Scheme Flowchart

1. If the ambient air conditions fall in Region I:

$$40\text{ }^{\circ}\text{F} \leq T_{\text{amb. Dew Point}} \leq 60\text{ }^{\circ}\text{F} \cap T_{\text{amb. Dry Bulb}} \leq 72\text{ }^{\circ}\text{F}$$

Then the humidifier is disabled in this region while the economizer is enabled to modulate the quantity of ambient air to maintain space conditions at desired levels.

2. If the ambient air conditions fall in Region II:

$$T_{\text{amb. Dry Bulb}} > 72\text{ }^{\circ}\text{F} \cup T_{\text{amb. Dew Point}} > 60\text{ }^{\circ}\text{F} \\ \cup T_{\text{amb. Dry Bulb}} < 35\text{ }^{\circ}\text{F}$$

Then the economizer is disabled and only the minimum required quantity of ambient air is allowed into the conditioned space. The humidifier and mechanical cooling will both be operable in this region to satisfy space

conditions.

3. If the ambient air conditions fall in Region III:

$$T_{amb. Dew Point} < 40 \text{ } ^\circ\text{F} \cap 35 \leq T_{amb. Dry Bulb} \leq 72 \text{ } ^\circ\text{F}$$

Then the quantity of ambient air that can be introduced to the space has to be calculated.

The analysis to calculate the percentage of ambient air that can be introduced into the conditioned space will depend on the energy usage of cooling and humidification. The DDC System logic will have to decide between closing off outside air dampers to allow only the minimum required ambient air into the conditioned space (minimum quantity of ambient air strategy), or modulating outside air dampers to bring in variable quantities of ambient air into the conditioned space (variable quantity of ambient air strategy). The goal of the optimization scheme is to choose the strategy with lowest energy use.

The energy used to condition the ambient air is the algebraic sum of the cooling energy and the humidification energy :

$$E_c = \frac{(1.08) \times cfm \times (T_{mix} - T_{cc}) \times \eta_{cl}}{12,000} \quad \text{Equation (1)}$$

and

$$E_h = \frac{45 \times cfm \times h_{fg} \times (\omega_{sa} - \omega_{mix})}{7000 \times 3413 \times \eta_{hm}} \quad \text{Equation (2)}$$

and

$$E_{Tot} = E_c + E_h \quad \text{Equation (3)}$$

Where:

- E_c : Mechanical cooling energy (kW)
- E_h : Electrical humidification energy (kW)
- E_{tot} : Total System Energy Usage (kW)
- cfm: Volumetric air flow (ft³/minute)
- T_{mix} : Mixed air temperature (° F)
- T_{cc} : Temperature of air leaving the cooling coil (° F)
- h_{fg} : Enthalpy of evaporation (Btu/lbm)
- ω_{sa} : Supply air humidity ratio (Grains of moisture per pound of dry air)

- ω_{mix} : Mixed air humidity ratio (Grains of moisture per pound of dry air)
- η_{cl} : Mechanical cooling efficiency (kW/ton). This value should include circulation pumps and cooling tower values if applicable
- η_{hm} : Humidifier efficiency (Percent)

The mixed air enthalpy and humidity ratio are the function of the percentage of ambient air introduced to the conditioned space.

$$T_{mix} = T_{RA} + (\%_{amb}) \times (T_{amb} - T_{RA}) \quad \text{Equation (4)}$$

$$\omega_{mix} = \omega_{RA} + (\%_{amb}) \times (\omega_{amb} - \omega_{RA}) \quad \text{Equation (5)}$$

Where:

- T_{RA} : Return air temperature
- h_{amb} : Ambient air temperature
- ω_{RA} : Return air humidity
- ω_{amb} : Ambient air humidity ratio
- $\%_{amb}$: Percentage of fresh air introduced to the space.

The following expressions are obtained when substituting T_{mix} and ω_{mix} in the energy equations:

$$E_c = \frac{(1.08) \times cfm \times ((T_{RA} + (\%_{amb}) \times (T_{amb} - T_{RA})) - T_{cc}) \times \eta_{cl}}{12,000} \quad \text{Equation (6)}$$

and

$$E_h = \frac{45 \times cfm \times h_{fg} \times (\omega_{sa} - (\omega_{RA} + (\%_{amb}) \times (\omega_{amb} - \omega_{RA})))}{7000 \times 3413 \times \eta_{hm}} \quad \text{Equation (7)}$$

The optimization calculations start by comparing the total system energy for the minimum quantity of ambient air strategy ($E_{Tot-min}$) and the variable quantity of ambient air strategy ($E_{Tot-var}$). To optimize the ambient air quantity, the energy consumption of the variable quantity strategy has to be less than the energy consumption for the minimum quantity strategy:

$$E_{Tot-min} > E_{Tot-var} \quad \text{Equation (8)}$$

Manipulating the equations, the following expression is derived:

$$\left(\frac{E_{Tot-min}}{cfm} - \frac{108X\eta_d X(T_{RA} - T_{cc})}{12,000} - \frac{45Xh_{fg} X(\omega_{sa} - \omega_{RA})}{(7,000)X(3413)X(\eta_{tm})} \right) >$$

$$(\%_{amb-opt}) \left(\frac{108X\eta_d X(T_{amb} - T_{RA})}{12,000} - \frac{45Xh_{fg} X(\omega_{amb} - \omega_{RA})}{7,000X3413X\eta_{tm}} \right)$$

Equation (9)

The solution of the above equation for the optimum quantity of ambient air that can be introduced will depend on the algebraic sign of the factor multiplied by the (%_{amb-opt}) on the right hand side of the equation. In Region III, the sign of the factor is positive, hence the solution to the above equation is:

$$(\%_{amb-opt}) <$$

$$\left[\frac{(c1X\eta_{tm}XE_{Tot-min}) - (c2XcfmX\eta_{tm}X\eta_d X(T_{RA} - T_{cc})) - (c3Xh_{fg} XcfmX(\omega_{sa} - \omega_{RA}))}{(c2XcfmX\eta_{tm}X\eta_d X(T_{amb} - T_{RA})) - (c3XcfmXh_{fg} X(\omega_{amb} - \omega_{RA}))} \right]$$

Equation (10)

Where:

$$c1 = 12,000 \times 7,000 \times 3,413 = 2.86692 \times 10^{11}$$

$$c2 = 7,000 \times 3,413 = 2.3891 \times 10^7$$

$$c3 = 12,000 \times 4.5 = 54,000$$

This equation is valid for sea level conditions. For higher elevations, an altitude density correction factor should be included. If the calculated amount of outside air is less than the minimum required for the space to maintain ventilation code, then the calculated value should be set equal to the minimum required value.

Conclusion

The economizer cycle and the electric humidifier in a typical HVAC system operate independent of each other which causes a waste of energy. The operation of such a system can be optimized to reduce energy consumption using a control scheme that calculates the optimum amount of outside air that can be introduced to the conditioned space that would minimize the overall system energy consumption. The control scheme can be implemented for constant or variable volume systems using a Direct Digital Control system. The above equations have to be modified for variable air volume systems to account for cfm variations at different conditions. The above scheme can also be modified and applied for systems with non-electric humidifiers.

References

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Figure 3 Psychrometric Regions

