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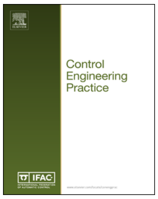

Experimental evaluation of anti-windup extremum seeking control for airside economizers

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ABSTRACT

The performance of anti-windup extremum seeking control (ESC) as a model free online optimization strategy is evaluated by experimental studies for energy efficient operation of both chilled-water and direct-expansion airside economizers. For the chilled-water based system, the ESC takes the chilled-water valve control signal as the feedback, and controls the outdoor air damper (OAD) position to minimize the cooling coil load. For the direct-expansion system, the ESC takes the total electricity power consumption as the feedback, and controls the OAD position to minimize the power consumption. Experimental results verify the effectiveness of the ESC scheme for model-free operation without temperature and humidity measurements.

1. Introduction

Commercial and institutional buildings commonly require year-round cooling regardless of their geographic location (Mumma, 2005). Airside economizers enable outdoor air in excess of the amount necessary for ventilation to be introduced to a building when outdoor conditions are suitable for cooling. In doing so, economizers can significantly reduce or even eliminate the need for mechanical cooling when these conditions exist. Airside economizers are required by energy standards for most commercial buildings (ASHRAE, 2004).

Fig. 1 shows a schematic diagram of a single-duct air-handling unit (AHU). The components of the AHU are commonly controlled to maintain a setpoint temperature for the air supplied to the building. When outdoor conditions are cooler than the supply air temperature setpoint, outdoor air is mixed with return air from the building to satisfy the setpoint condition and no mechanical cooling is necessary. When outdoor air conditions are warmer and mixing of outdoor air and return air can no longer satisfy the setpoint, mechanical cooling is needed. In this situation the chilled water cooling coil valve in Fig. 1 will open and modulate the flow of chilled water to maintain the supply air temperature setpoint. If the airside economizer is enabled, the AHU will use 100% outdoor air when mechanical cooling is needed. If it is disabled, the AHU will use the minimum outdoor air necessary for ventilation.

Airside economizers are comprised of controllable dampers, temperature and in some cases relative humidity sensors, actuators and controls. The elements of the economizer used to determine whether it is enabled or disabled are referred to collectively as the *high limit switch*. Four of the most common *high limit control* strategies are described below:

- *Fixed dry-bulb temperature high limit control* compares the outdoor air temperature with a transition temperature. If the outdoor air temperature is less than the transition temperature, the economizer is enabled. Otherwise the economizer is disabled.
- *Differential dry-bulb temperature high limit control* compares the outdoor air temperature with the return air temperature. If the outdoor air temperature is less than the return air temperature, the economizer is enabled. Otherwise the economizer is disabled.
- *Fixed enthalpy high limit control* compares the outdoor air enthalpy with a transition enthalpy. If the outdoor air enthalpy is less than the transition enthalpy, the economizer is enabled. Otherwise the economizer is disabled.
- *Differential enthalpy high limit control* compares the outdoor air enthalpy with the return air enthalpy. If the outdoor air enthalpy is less than the return air enthalpy, the economizer is enabled. Otherwise the economizer is disabled.

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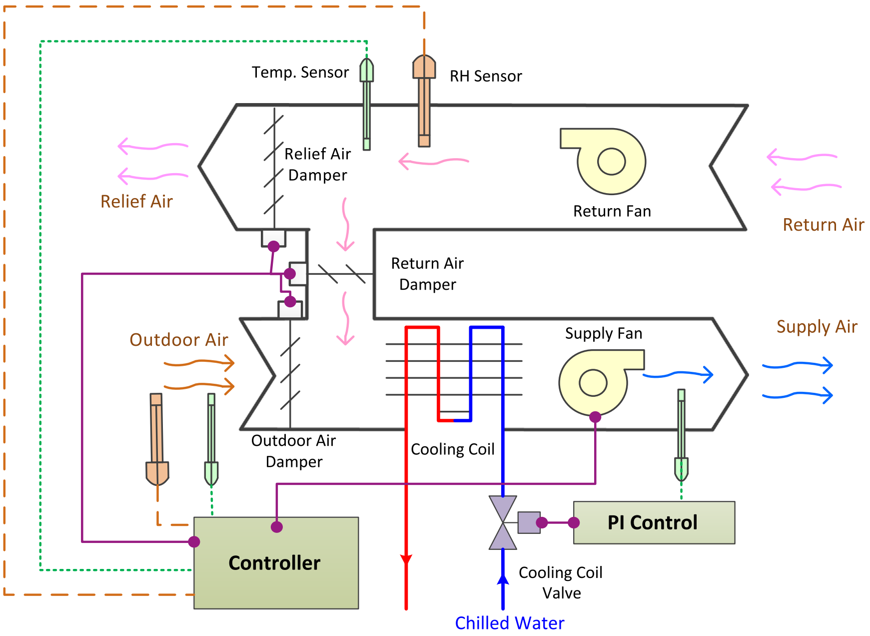

Fig. 1. Schematic diagram of a single-duct air-handling unit.

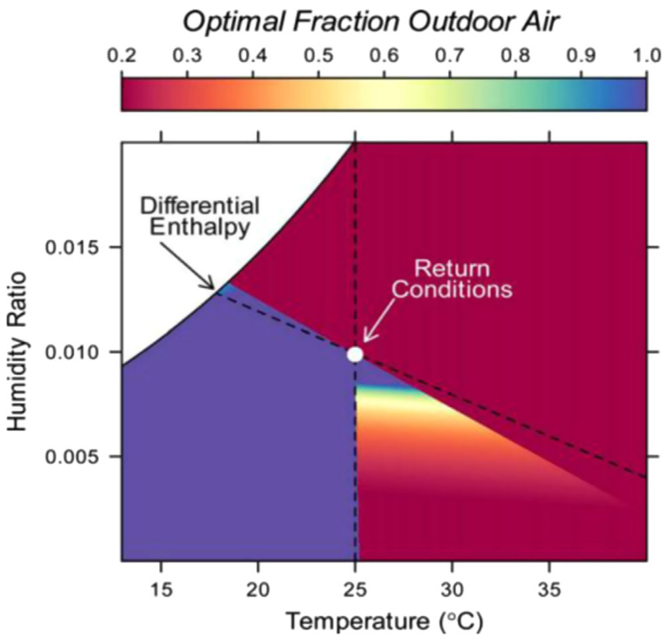

Fig. 2. Optimal outdoor air fraction obtained with optimization-based control for a bypass factor of 0.1, and return air conditions of 25 °C and 50%RH (Seem & House, 2010).

Seem and House (2010) described an economizer *high limit switch* that uses a model of the cooling coil and measurements of the outdoor air and return air enthalpy to predict the outdoor air damper position (i.e., minimum outdoor air for ventilation or 100% outdoor air) that will result in the smaller mechanical cooling load. This same model was also used to calculate the optimal outdoor air fraction that minimizes the mechanical cooling load. Fig. 2 shows the optimal outdoor air fraction for a continuum of outdoor conditions and return air conditions of 25 °C and 50% RH (Seem & House, 2010). Three major regions of outdoor conditions can be identified in Fig. 2, namely, one where minimum outdoor air is optimal (burgundy), one where 100% outdoor air is optimal (indigo), and one where a fraction between minimum and 100% is optimal (gradient).

Although economizers can significantly reduce the need for mechanical cooling for certain conditions, energy savings achieved in practice may fall far short of expectations due to sensor error. Concerns about the reliability of relative humidity sensors and the impact of sensor error on economizer performance have been reported in the literature for more than 25 years (Spitler, Hittle, Johnson & Pederson, 1987). Survey studies on field operated economizers have revealed that high failure rates of relative humidity sensors is one of the key reasons for economizer malfunctions (Energy Design Resources). Simulations have shown that in humid climates airside economizers with large sensor errors (±2 °C for temperature sensors and ±10%RH for relative humidity sensors) can actually increase energy use compared to systems that do not have an economizer (Seem & House, 2010). A study by the National Building Controls Information Program (NBCIP) reported testing results of heating, ventilating and air-conditioning grade relative humidity sensors from six manufacturers (NBCIP, 2004, 2005). The results included comparisons of measurements obtained at 5-min intervals from 12 test sensors and a reference sensor installed for a one-year period in an AHU outdoor air duct. The largest mean error among the test sensors was 10%RH, and the largest standard deviation of the error was 10.2%RH. The NBCIP results have been used to support the position that economizers with high limit controls based on relative humidity sensor measurements should not be used in practice (Taylor & Cheng, 2010).

The results in Fig. 2 demonstrate that for certain indoor and outdoor air conditions the optimum performance of the economizer is not always achieved by either using minimum outdoor air or 100% outdoor air; however, sensor and modeling errors make it difficult to exploit this opportunity. Self-optimizing controls offer an alternative to traditional HVAC control strategies and may enable improved performance to be realized without the need for a system model and/or unreliable measurements. The inherent strength of self-optimizing control strategies is their minimal