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Indirect evaporative cooling primary and secondary effects for the cooling energy consumption of the Air Handling Units

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Abstract. Buildings' energy consumption become one of the most important topics since energy prices increased. The aim of building services is to reduce energy consumption without decreasing the comfort level. Decreasing the cooling energy of the HVAC system could significantly cause energy consumption reduction. This paper focuses on the possibility of indirect evaporative cooling methods applying and emphasizes the possibility of its integration with existing and working HVAC systems. This topic was investigated under laboratory and real-life environmental conditions.

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1. Introduction

Cooling and ventilation systems are largely responsible for the energy use of buildings in summer [1]. With the increase in energy prices, the optimization of the operation of mechanical systems and the improvement of heating, ventilation and air conditioning systems (HVAC) have become a matter of high interest. [2] The primary objective for operators is to reduce energy consumption while maintaining the required comfort parameters. Direct evaporative air cooling (DEC) is a long-established technique that can significantly reduce the mechanical cooling energy needed to treat air, especially in areas with dry climates [3]. The process not only cools the air but also humidifies it, which makes it difficult to use in humid climates, where the handling of moisture loads in the air conditioning process is also a high energy demand [4]. In the indirect application of the process, working air is treated by evaporative cooling, which does not enter the conditioned space and thus does not cause an increase in humidity [5]. Air handling units equipped with indirect evaporative cooling (IEC) usually treat the air exhausted from the indoor space with direct evaporative cooling (DEC), which cools and humidifies the air exhausted from the indoor space. By using this process, the cooling capacity of the heat recovery unit can be significantly increased. As the cooling capacity of the heat recovery unit increases, the mechanical cooling energy demand decreases. The aim of the paper is to describe the operation of indirect evaporative cooling and its impact on the low-temperature mechanical cooling system of the air handling unit. The paper shows that using the IEC procedure, the cooling power delivered by the mechanical cooling system varies with the reduction of the latent heat energy demand of the cooling calorifier in addition to the direct cooling energy reduction, which is an indirect result of the IEC process.

2. Materials and methods

This article focuses on air handling units with 100% fresh air supply (see figure 1). These units provide the required amount of fresh air to the occupied zone and are also involved in indoor air conditioning. As the amount of fresh air supplied varies with the number of occupants and the occupancy of the rooms, the air handling system only provides supplementary cooling and heating capacity to the rooms. Other mechanical systems (fan-coil, VRF, etc.) also provide cooling and heating for the premises. In



evaporative air cooling, the air is forced through a humidifier unit. Heat and mass transfer occur at the same time between the moved air mass and the large surface area of the water. The energy required for evaporation comes from the medium adjacent to the water surface (air), so the temperature of the air decreases as a function of the amount of water evaporated.

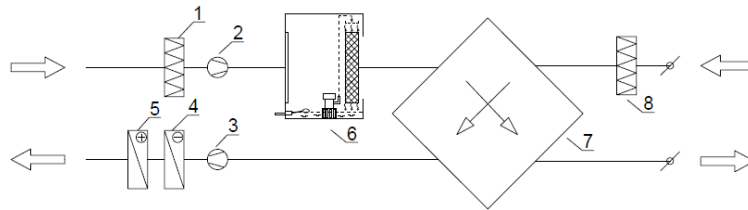


Figure 1. AHU with IEC (1: air filter; 2: exhaust air fan; 3: supply air fan; 4: cooling heat-exchanger; 5: heating heat-exchanger; 6: IEC unit; 7: heat recovery unit; 8: air filter)

The energy removed from the medium is returned to the mixture together with the evaporated mass, so that the enthalpy of the water vapor-air mixture changes only slightly during the process (see figure 2). If no heat from an external source is added to or removed from the system during the process, which means that the process is adiabatic, the enthalpy of the medium increases with the heat of the evaporated water [6]:

$$\Delta h = \Delta x * c_v * t_v \quad (1)$$

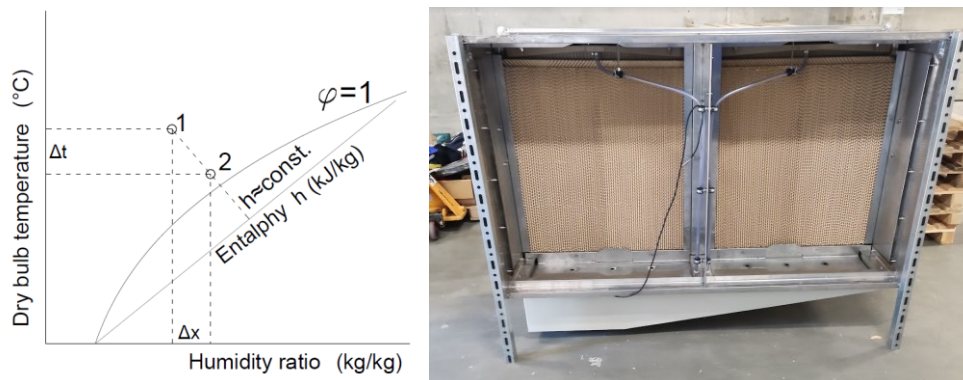


Figure 2. Evaporative Cooling process in Molliere h-x diagram; IEC unit

(1: exhaust air; 2: exhaust air after DEC)

Since the mass fraction of evaporating water vapor is small compared to air, it is assumed for practical calculations that the enthalpy of the air-water vapor mixture does not change, then the temperature change during evaporative cooling can be determined as a function of the initial temperature and the evaporated water:

$$t_2 = \frac{-r_0 * \Delta x}{c_p + c_{pv} * \Delta x} + t_1; (t_2 = t_{DEC}) \quad (2)$$

The cooling capacity that can be achieved by a heat recovery unit (HRU) depends on the temperature difference between the two media and the heat recovery efficiency of the unit. If the indoor air temperature is above the condensation temperature of the outdoor air, there is no phase change in either medium during the heat exchange [7]. The cooling capacity of the heat recovery unit can then be determined as follows:

$$\eta = \frac{t_{sup} - t_{out}}{t_{exh} - t_{out}} [-] \quad (3)$$

$$t_{sup} = \eta * t_{exh} + (1 - \eta) * t_{out} [^{\circ}C] \quad (4)$$

$$Q_{hr} = \Delta h * \dot{m} = c * \Delta t * \dot{m} = c * \eta * (t_{out} - t_{exh}) * \dot{m} [kW] \quad (5)$$

If evaporative cooling is used before heat recovery (IEC), the state of the exhaust air is changed, which modifies the heat recovery process according to the following equation:

$$t_{DEC} = \frac{-r * \Delta x}{c_p + c_{pv} * \Delta x} + t_{exh} [^{\circ}C] \quad (6)$$

$$t_{sup} = \eta * t_{DEC} + (1 - \eta) * t_{out} = \eta * \left(\frac{-r * \Delta x}{c_p + c_{pv} * \Delta x} + t_{exh} \right) + (1 - \eta) * t_{out} [^{\circ}C] \quad (7)$$

$$Q_{hr+IEC} = c * \eta * (t_{out} - t_{DEC}) * \dot{m} = c * \eta * \left(t_{out} - \left(\frac{-r * \Delta x}{c_p + c_{pv} * \Delta x} + t_{exh} \right) \right) * \dot{m} [kW] \quad (8)$$

From the above relations, it can be seen that with the application of IEC, the heat recovery power increased according to the following equation:

$$\Delta Q = Q_{hr+IEC} - Q_{hr} = c * \eta * \frac{r * \Delta x}{c_p + c_{pv} * \Delta x} * \dot{m} [kW] \quad (9)$$

The improved heat recovery cooling performance obtained by using the IEC process directly reduces the cooling energy demand of the air handling unit (see figure 3).

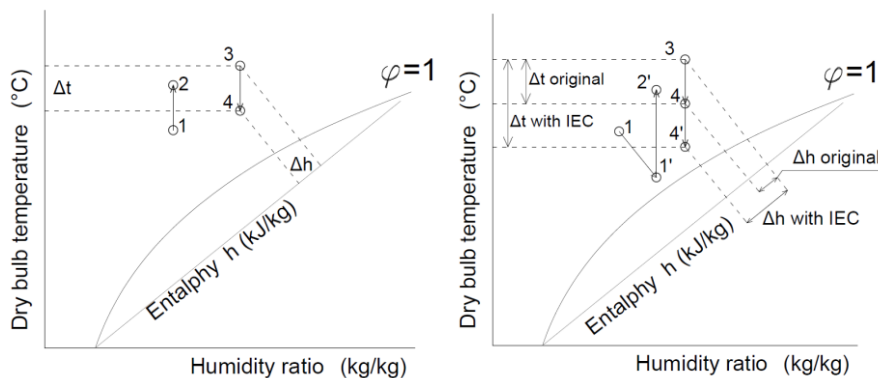


Figure 3. Original heat recovery unit cooling process; Heat recovery cooling process with IEC in Molliere h-x diagram (1: exhaust air; 1': exhaust air after DEC; 2: exhaust air after HRU; 2': exhaust air after HRU in IEC case; 3: fresh air; 4: fresh air after the HRU; 4': fresh air after HRU in IEC case)

The air handling units are often controlled to maintain a given supply temperature. In summer conditions, if the air does not reach the required supply temperature after the heat recovery, the cooling calorifier is responsible for setting the required supply temperature. The average temperature of cooling heat exchangers is often lower than the condensation temperature of the air. If the air is cooled with a calorifier at a temperature below the condensation temperature, condensation will still occur when the set temperature of the air is not at the condensation temperature. The air would then be able to absorb the condensate produced on the heat exchanger fins, but due to the rate of the process, it cannot fully absorb it, so the treated air will dry. The latent heat energy required for condensation comes from the cooling system. If the cooling calorifier is required to produce a lower sensible cooling capacity, the

condensation rate is also reduced. If the calorifier has quality control, the average temperature of the heat exchanger will also increase under part-load conditions, which will further reduce the amount of latent heat removed by condensation (see Figure 4).

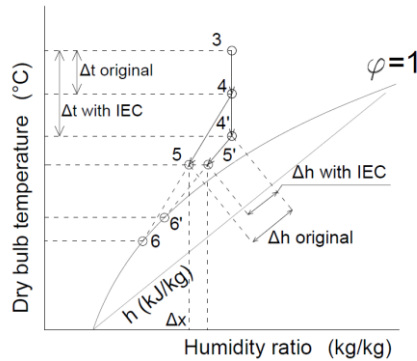


Figure 4. The secondary effect of IEC process. Supply air parameters changing after cooling heat exchanger (3: fresh air; 4: fresh air after the HRU; 4': fresh air after HRU in IEC case; 5: Cooled fresh air for the supply air temperature; 5': Cooled fresh air for the supply air temperature in IEC case; 6: Average temperature of cooling heat exchanger; 6': Average temperature of cooling heat exchanger in IEC case)

The change in the operation of the cooling calorifier and the resulting change in the amount of cooling energy is a secondary effect of the IEC, which further reduces the amount of energy used by the air handler.

3. Results and discussion

A simulation model was used to determine the working point of the heat exchanger. The simulation is based on the basic equation describing the heat exchanger performance:

$$Q = U * A * \Delta t_{log} [kW] \quad (10)$$

Due to the quality control of the calorifier, the degree of turbulence of the media does not change significantly, so the thermal energy emitted by the calorifier varies as a function of the logarithmic mean temperature.

The required cooling energy is the sum of sensible and latent cooling energy:

$$Q = Q_{sens.} + Q_{latent} [kW] \quad (11)$$

$$Q = c * \dot{m} * \Delta t + \dot{m} * \Delta x * r [kW] \quad (12)$$

The latent heat flow affects the amount of total heat flow, which influences the required logarithmic temperature difference. The change in temperature difference affects the amount of condensate produced, which is responsible for the latent heat flow. Because of the dependence of the parameters, the system of equations can be solved iteratively. By incorporating the approximation equation into the simulation, we are able to determine the extent to which the primary and secondary effects of the IEC process are responsible for the reduction in cooling energy.

The simulation is based on data measured on 11.08.2021. At the University of Debrecen's Air-ventilation and air-conditioning laboratory, the air handling was equipped with IEC. The measurements were taken every minute between 9:00-18:00. The temperature in the laboratory was kept at 25°C and the IEC procedure was examined. During the measurement, a balanced ventilation of 1500 m³/h was applied. Using the measured data, we simulated that if the desired supply temperature is 20°C, then what cooling capacity should be provided by the cooling calorifier for cases without IEC and with IEC.

Figure 5 shows that the cooling power delivered by the cooling calorifier is significantly reduced by using IEC. Since the calorifier's physical parameters are unchanged, it can be adjusted to match the required cooling capacity by changing the water temperature. The reduction in cooling capacity has led to a significant reduction in the temperature difference, while the average water-side temperature of the heat exchanger has increased, which reduces the amount of condensation during cooling.

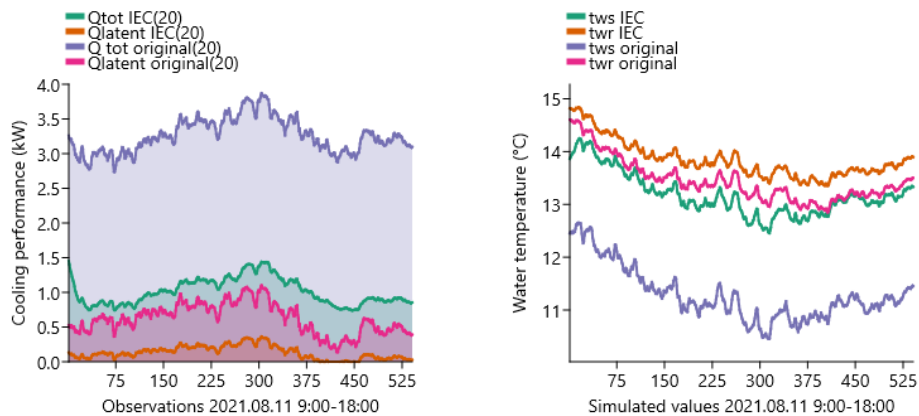


Figure 5. Simulated values based on laboratory measurements

The reduced mechanical cooling energy demand due to the primary and secondary effects of IEC is illustrated in Figure 6. Based on the results from the day of the measurements, it can be seen that 78.24% of the total cooling energy reduction was due to the primary effect and the remaining 21.76% was due to the secondary effect of the IEC process under the given operating conditions.

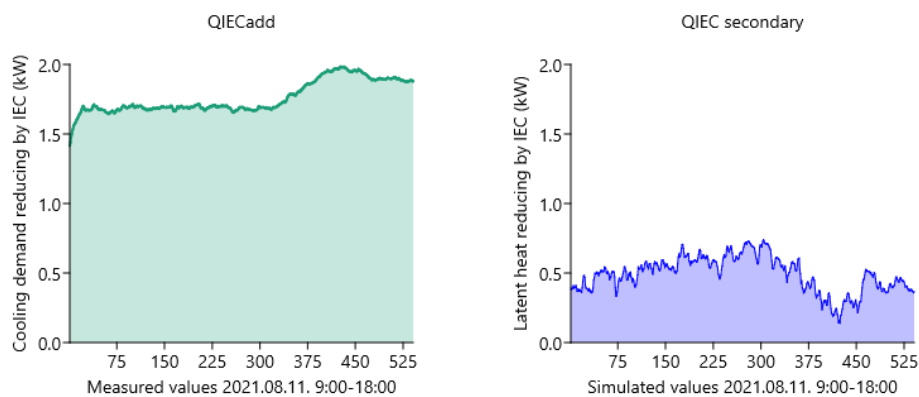


Figure 6. Cooling performance reducing by IEC: a, primary effect; b, secondary effect simulated values based on laboratory measurements

4. Conclusions

The paper describes the operation of air handling units equipped with the IEC system that handles 100% fresh air. The cooling energy that can be saved with IEC is divided into two components. The primary cooling performance is the cooling performance produced by the IEC process, which the mechanical cooling system does not need to produce. The secondary is the reduction in power demand caused by factors affecting the operation of the cooling calorifier, mainly due to the reduction in the latent heat energy required to generate the condensate. The primary and secondary effects were presented using a real measurement day and the secondary effects were simulated. The results show that secondary effects have a significant impact on the mechanical cooling energy demand consumed by the air handling unit, making the research on this topic of high importance.

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