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Effect of indirect evaporative cooling of working parameters of air handling units

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Abstract. The specific energy consumption of air handling units has significantly decreased due to the tightening of ErP requirements. The efficiency of heat recovery devices used in air handling units has substantially improved. One possible way to further reduce cooling energy demand is the application of indirect evaporative air cooling. The study presents the impact of indirect evaporative cooling on the operation of an air handling unit. With fixed technical parameters, the increase in the operating time and cooling energy output of the heat recovery unit was analyzed based on long-term meteorological data. The results show that indirect evaporative cooling can be effectively applied in the Central European continental climate. The study also examines how the cooling energy gain achievable through indirect evaporative cooling depends on the indoor air conditions.

1. Introduction

In Central Europe – including Hungary – a warming trend can be observed during the summer period. One possible technical solution to reduce the cooling energy demand of air handling units is the application of indirect evaporative air cooling. By employing this method, the performance and useful operating time of heat recovery units can be increased. According to Eurostat data, the number of cooling degree days (CDD) in Hungary has significantly increased during the period from 1979 to 2023 [1]. The rise in the number of cooling degree days suggests that heat stress during the summer has intensified in recent years. This means that maintaining comfort parameters in enclosed spaces is associated with an increasing demand for cooling energy. Building energy consumption accounts for 40% of total energy use in Hungary, of which approximately two-thirds is devoted to meeting heating and cooling needs [2]. Since the energy consumption of buildings has a significant impact on overall energy usage, building energy efficiency improvements and the optimization of building operations have become key areas of development.

Our research focuses on reducing the mechanical cooling energy demand of air handling units (AHUs). In order to improve the energy efficiency of AHUs, manufacturers have implemented significant developments, enhancing the efficiency of both heat recovery devices and fans used in these systems. By increasing the efficiency of heat recovery, the primary energy demand for heating and cooling during the operation of AHUs can be significantly reduced. One possible method for further reducing mechanical cooling energy consumption is the application of the indirect evaporative air-cooling process. Based on tests carried out in the Air Technology



evaporative air cooling, not only can the amount of cooling energy saved by the heat recovery unit be increased, but its useful operating time can also be extended.

Under Hungarian climatic conditions, our goal was to identify the potential extent of energy savings. Our investigations were carried out using data from the Agrometeorological Station of the University of Debrecen – Kismacs. The study was based on measured data from the period 2009–2021. The temperature frequency curve determined from this data is illustrated in Figure 2.

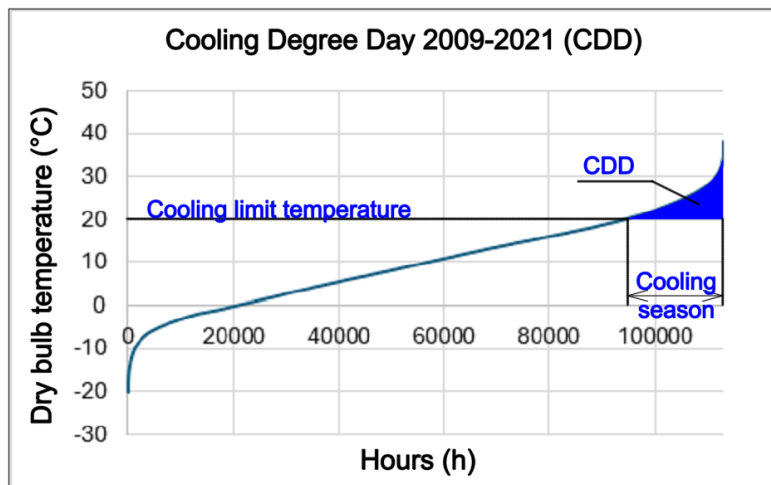


Figure 2. Temperature frequency curve in Debrecen (2009-2021), handled cooling degree days (CDD) by the air handling unit

The extent of energy savings largely depends on the technical design of the mechanical system, its operational characteristics, and the desired indoor comfort level. In order to focus on the assessment of Hungarian climatic conditions, the properties of the mechanical system under investigation were fixed (Table 1). Based on the fixed parameters, the length of the cooling season and the cooling temperature difference are shown in Figure 2.

Table 1. Main parameters of energetic calculation

Parameters	Value
AHU air mass flow (supply/exhaust air)	1/1 kg.s ⁻¹
Thermal efficiency of Heat recovery unit in AHU	82.4%
Evaporative efficiency of evaporative air cooler unit	73.7%
Exhaust air temperature	25 °C
Supply air temperature	20 °C

With the use of indirect evaporative cooling, the cooling capacity provided by the heat recovery unit can be increased. If no moisture transfer or condensation occurs during the cooling process, the change in the cooling degree days (CDD) by the air handling unit is proportional to the increase in cooling energy generated by the heat recovery unit. The cooling energy produced by the heat recovery unit (HRU) reduces the amount of cooling energy required from the cooling coil (CC). The temperature difference managed by the air handling unit can be expressed using Equation (1).

$$CDD_{AHU} = CDD_{CC} + CDD_{HRU} \quad (1)$$

Under the fixed parameters listed in Table 1, if the outdoor air temperature exceeds 20 °C, cooling power input is required to achieve the set supply air temperature. The heat recovery unit is only capable of generating cooling energy when the outdoor air (t_o) temperature exceeds the temperature of the exhaust air (t_{ex}) extracted from the interior (in our case, 25 °C). The handled part of the cooling degree days by the heat recovery unit during the examined period can be described using Equation (2), where η_{HRU} is the thermal efficiency of the unit.

$$CDD_{HRU} = z_{t_o > 25^\circ\text{C}}(\bar{t}_o - t_{ex})\eta_{HRU} \text{ [hK]} \quad (2)$$

If the exhaust air is treated with evaporative air cooling ($t_{ex,DEC}$), the temperature of the treated air can be determined using Equation (3), where ε is the effectiveness of evaporative cooling unit.

$$t_{ex,DEC} = t_{ex} - \varepsilon(t_{ex} - t_{ex,wb}) \text{ [}^\circ\text{C]} \quad (3)$$

If indirect evaporative air cooling is implemented, the exhaust air is treated with evaporative cooling before entering the heat recovery unit. In this case, the temperature difference managed by the heat recovery unit can be expressed by Equation (4), using the relationships given in Equations (2) and (3).

$$CDD_{HRU IEC} = z_{t_o < t_{ex,DEC}}(\bar{t}_o - (t_{ex} - \varepsilon(t_{ex} - t_{ex,wb})))\eta_{HRU} \text{ [hK]} \quad (4)$$

The additional temperature difference achieved by applying indirect evaporative air cooling can be described by Equation (5).

$$\Delta CDD_{HRU IEC} = CDD_{HRU IEC} - CDD_{HRU} \text{ [hK]} \quad (5)$$

By substituting Equations (2) and (3) into Equation (5), we obtain the relationship expressed in Equation (6).

$$\Delta CDD_{HV HRU} = z_{t_o < t_{ex,DEC}}(\bar{t}_o - (t_{ex} - \varepsilon(t_{ex} - t_{ex,wb})))\eta_{HRU} - z_{t_o > 25^\circ\text{C}}(\bar{t}_o - t_{ex})\eta_{HRU} \text{ [hK]} \quad (6)$$

The operation of the air handling unit was analyzed using Equations (1)–(6) and taking into account the fixed technical parameters listed in Table 1, based on meteorological data recorded between 2009 and 2021.

3. Results and discussion

The cooling degree days (CDD) of a conventional air handling unit equipped with a heat recovery system is illustrated in Figure 3a. Figure 3b. shows the cooling degree days (CDD) by both the heat recovery unit and the cooling coil. Upon examining the figures, it is evident that the useful operating time of the heat recovery unit (7187 hours), under the fixed parameters, is significantly shorter than the total cooling period (21734 hours). In this case, the heat recovery unit is able to contribute to CDD during only 33.07% of the cooling period. The total temperature difference bridged by the air handling unit (93102 hK) was covered by the heat recovery unit in the amount of 22.56% (21008 hK). Consequently, the cooling coil of the air handling unit must account for the remaining 77.44% of the temperature difference in order for the system to operate under the desired conditions.

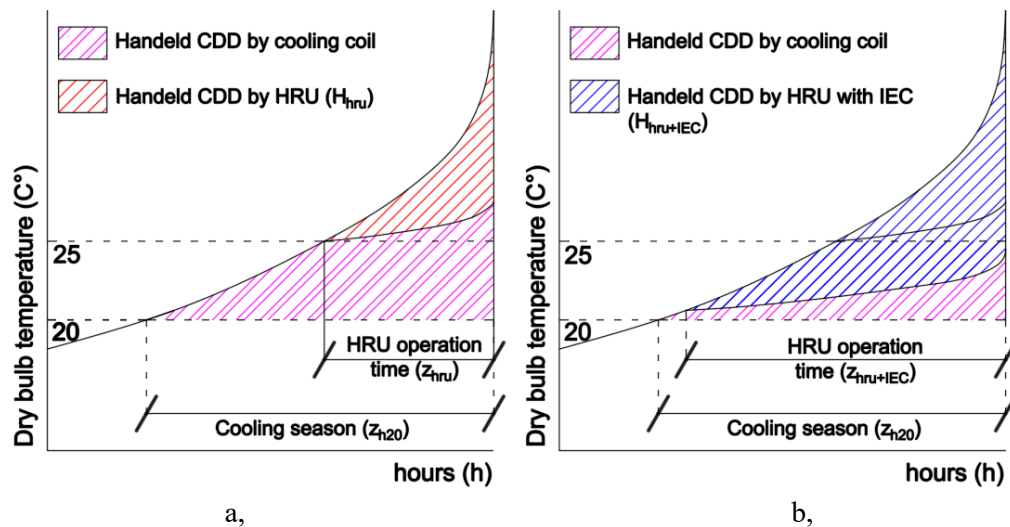


Figure 3. Temperature frequency curve in Debrecen (2009-2021) in the cooling season, a, the handled CDD by the heat recovery unit and the cooling coil in a conventional AHU; b, the handled CDD by the heat recovery unit and the cooling coil in AHU with indirect evaporative cooling

The air temperature achievable through evaporative cooling strongly depends on the initial condition of the air. For the previous calculations, the air temperature of the exhaust air from the interior was sufficient; however, to determine the wet-bulb temperature corresponding to the indoor air condition, the indoor humidity content must also be known. In the example case, air at 25 °C and 60% relative humidity has a wet-bulb temperature of 19.4 °C. If the evaporative efficiency of the evaporative cooling unit is 73.7%, the temperature of the exhaust air will decrease to 20.39 °C after the process.

In the case of conventional air handling operation, the useful operating time of the heat recovery unit was 7187 hours, which increased to 10998 hours with the application of indirect evaporative air cooling representing a 53% increase. In the conventional case, the heat recovery unit could cover a temperature difference of 21.008 hK, which increased to 53565 hK with the application of indirect evaporative cooling representing a 155% increase. With the combined use of the heat recovery unit and the indirect evaporative cooler, 57.53% of the total CDD is covered, compared to 22.56% previously. Figure 4 illustrates the change in the useful operating time of the heat recovery unit due to indirect evaporative cooling under various indoor humidity conditions. Based on Figure 4, it can be seen that under the fixed technical parameters, the heat recovery unit achieved the longest operating time at 25 °C and 40% relative humidity.

The figure also shows that indoor humidity has a significant impact on the magnitude of the CDD covered by the indirect evaporative cooling unit installed in the examined air handling system. If the indoor air is sufficiently dry, the indirect evaporative cooling process can generate adequate cooling capacity to achieve the desired supply air temperature (in this case, 20 °C) during a significant portion of the examined period (2009–2021), even without the use of a cooling coil in the air handling unit.

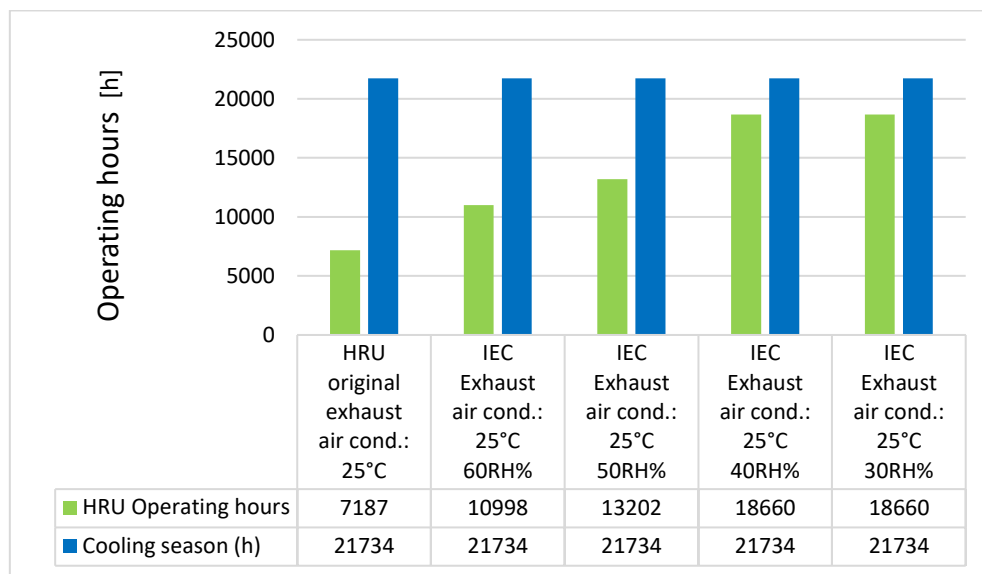


Figure 4. Useful operating hours of heat recovery unit, depending on inside air conditions

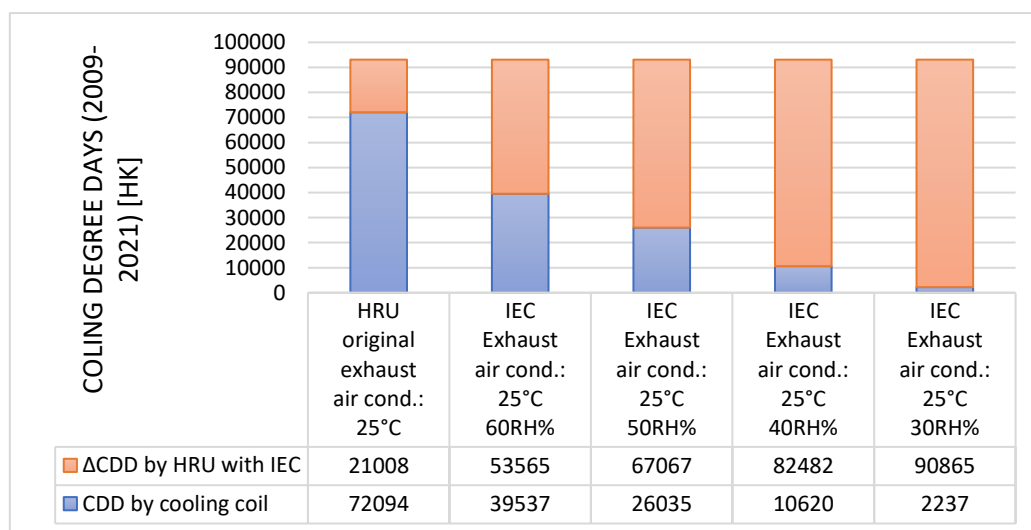


Figure 5. Handled CDD by the heat recovery unit and the cooling coil in the air handling unit, depending on inside air conditions

4. Conclusion

The aim of this study was to examine the applicability of the indirect evaporative cooling process under Hungarian climatic conditions. Using the results of previous laboratory measurements, the energy consumption of an air handling unit was analyzed through a representative system.

Based on the results of the investigation, the following conclusions can be drawn:

- The integration of indirect evaporative cooling, *ceteris paribus*, can significantly reduce the amount of mechanical cooling energy consumed by the air handling unit.
- The useful operating time of the heat recovery unit during the cooling season can be significantly increased, *ceteris paribus*, by incorporating an indirect evaporative cooler.

- The amount of cooling energy that can be recovered through the indirect evaporative cooling process strongly depends on the indoor air conditions, which must be taken into account during the energy design of the system.

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