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# Investigation of Cooling Energy Saved by Air-to Air Heat-and Energy Exchangers in Different Climate European Countries

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## Abstract

*The object of this research study was to investigate the energy saved of 5 different constructed air-to air heat-and energy exchangers in three in different weather (high, moderated and low temperature regions) European countries. Using the ambient temperature, enthalpy duration curves, detailed mathematical expressions are presented to determine the annual energy saved by air-to-air heat recovery and energy recovery units. The three different climate cities are: Palermo (Mediterranean zone), Krakow (temperate zone) and Helsinki (cold climate). The investigated heat recoveries (only heat transferring between the air-streams) were the fixed-plate heat exchanger, the run around coil and the heat-pipe technology. Energy exchangers (heat and moisture transferring between the air-streams) were also investigated with higher moisture transfer effectiveness by the rotor with sorption and with lower the rotor without sorption. The results of the calculations show that the largest energy saved can be performed during the cooling period by the energy exchanger with sorption. Based on the results the amount of the cooling energy saved is 16-17 % in Helsinki, 31-32% in Krakow and 43 % in Palermo compared to ventilation systems without any heat or energy recovery unit.*

**Keywords - cooling energy saved; air-to air heat and energy exchangers; energy consumption of ventilation system**

## 1. Introduction

The demands in the building sector regarding energy conservation have been growing for many years in the whole world. Generally less energy use for HVAC systems is required but without compromising a comfortable and acceptable indoor environment. Decreasing the energy consumption in different endues sectors, especially in buildings [1], is one of the main energy concerns of the European Union (EU) countries. People nowadays spend about 90% of their time in indoor spaces [2]. This means that, without any indoor air is treating and fresh air supplying, people are subject to an unhealthy and uncomfortable environment for prolonged periods. With fresh air demand increasing, energy consumption also increases in order to condition this required fresh air. Due to the increasing indoor air quality (IAQ) standard, the ventilation loads represent about 20–50% part of the total heating demand for new and retrofitted buildings [2,4,9,10,11,12], depending on the building's insulation,

compactness, air change rate, indoor heat sources, indoor set points and outdoor climate. Therefore, there is a need for residential buildings and their systems to provide a comfortable and acceptable indoor environment. This is often accomplished through the use of heating, ventilation, and air conditioning systems, particularly in the summer (cooling) and winter (heating) seasons. Nearly 87% of residential homes in the United States of America use air conditioning, including 89% of single family homes, and 84% of multi-family homes [13]. In more extreme hot climates air conditioning penetration is nearly 100%. Air conditioning penetration is lower in many other parts of the world, but is predicted to grow worldwide by 72% between 2000 and 2100, particularly in the face of predicted climate change. Worldwide, the use of central heating is also predicted to increase by 34% by 2100 [14]. Since HVAC systems impact energy use, thermal comfort and indoor air quality, it is important to understand how and when these systems operate. However, there is limited information available on the operational characteristics, and specifically on runtimes and energy consumption of these HVAC systems.

With new building codes, EU countries also intend to reduce the total energy consumption in buildings by making the buildings well-insulated and tighter [2–7]. The first retrofit options to be considered for existing buildings are the improvement of the thermal insulation and air tightness. Improving the building envelope increases the relative part of the energy consumption due to ventilation. The usage of mechanical ventilation system equipped with an air-to-air recovery heat-and energy exchanger is a solution to ensure a high global energy performance of the building and reach the requirements in terms of IAQ [15]. In these systems, indoor air extracted from the building is used to pre-heat (in winter) or pre-cool (in summer) the fresh air flow rate coming from the outdoor environment. While such exchangers have been on the market for many years, only a few modeling works are presented in technical and scientific literature. Only the parameters having an impact on the energy performance of heat recovery ventilation have been investigated deeper in the last years. Mardiana and Riffat [16] list physical characteristics of the main components: heat exchanger and fans that influence the efficiency of heat or energy recovery. Roulet et al. [17] discuss the effect of leakages and shortcuts on heat recovery unit and show that the conventional methods to determine the heat recovery efficiency are not sufficient to outline the global performance of ventilation systems; and propose a method based on the specific net energy savings to characterize the energy performance. Manz et al. [18] investigate the same effect on a single room ventilation system and define a heat recovery efficiency based on heating load reduction. External parameters like the climate location also play a key role in the determination of the performances of ventilation systems [19]. Based on the above mentioned facts it is easy to see that the calculation of energy consumption and energy saved of ventilation systems is a complex design problem requiring many pieces of information such as outdoor weather condition, indoor set point temperature and relative humidity, mass flow rate of ventilation air, effectiveness of the exchanger, technique to add auxiliary heating and cooling. The calculations needed to evaluate the operating energy consumption involve functions of these parameters integrated over time and are quite complex (ASHRAE 2000). Several

studies on heating energy consumption of ventilation systems operated with heat-and energy recovery units have been done, but investigation of cooling energy saved of these systems have been not taken much attention in the literature [20-27].

The object of this research study was to investigate the energy saved of five different constructed air-to-air heat-and energy exchangers in three in different weather European countries in cooling period. Using the ambient temperature and enthalpy duration curves, developing a novel approach to describe the changing of the cooling air condition parameters during the cooling period, detailed mathematical expressions were worked out to determine the energy consumption of the ventilation systems and the energy saved by air-to-air heat-and energy recovery units during the cooling period. The three different climate cities are: Palermo (as Mediterranean zone), Krakow (as temperate zone) and to Helsinki (as cold climate region). The investigated heat recoveries that are suitable only for heat transfer are the fixed-plate heat exchanger, the run around coil and the heat-pipe technology. Energy exchangers, that were also considered, allow both heat-and moisture transfer with higher moisture transfer effectiveness by a sorption rotor and with lower without sorption coating. Using the developed method it is easy to see that during the selection of heat-and energy recovery units when a ventilation system is designed, the energy saved of the units have to considered not only for heating, but also for cooling period depending of the climate location. The results by the developed method show that before the selection of the heat-and energy recovery unit into an air handling unit, their energy saved has to investigate not only for the heating, but also for the cooling period depending on the climate zone.

## **2. Methodologies**

The energy saved of different heat-and energy recovery technologies were investigated in three different climate cities (Palermo as a hot, Krakow as temperate, and Helsinki as a cold climate city) in cooling period. The energy saving investigation for the heating period in these three cities have been already investigated in a previous study [49]. During our investigation a steady air volume flow rate was assumed to 1000 m<sup>3</sup>/h, and the air density was assumed to constant 1,2 kg/m<sup>3</sup>. For heat recovery systems, that are suitable only for heat transfer, temperature controlling was considered during calculations, which means the heat exchanger works only when outer air temperature is higher than the exhaust temperature delivered from the conditioned space. In case of energy recovery systems that are suitable for both heat-and moisture transfer, enthalpy controlling was considered, thus energy exchanger operates until enthalpy of ambient air decreases to the exhaust air enthalpy value. During our research a comparative energetic investigation was performed for the heat-and energy recovery systems most commonly applied in HVAC practice. Among heat recovery technologies that transfer only heat energy, cross flow plate heat recovery, run around coil heat recovery and heat pipe heat exchangers were investigated. Among energy recovery systems that are suitable for both heat and moisture transfer rotary energy recovery unit with sorption and non sorption coating were investigated. The object was to predict the energy savings in the different cases for cooling season. The heat and moisture transfer

effectiveness values for each exchangers were selected (Table 1) based on VDI 2071 standard.

Table 1. Heat-and moisture effectiveness values of the investigated heat-and energy recovery units

Type of the investigated heat- and energy recovery	Heat transfer effectiveness	Moisture transfer effectiveness
-	$\eta_h [-]$	$\eta_m [-]$
Cross flow plate heat recovery	0,6	0
Run around coil heat recovery	0,4	0
Heat pipe heat exchangers	0,3	0
Rotary energy recovery unit with sorption coating	0,8	0,65
Rotary energy recovery unit with non sorption coating	0,8	0,15

Air handling process for sizing state is plotted to diagram Mollier h-x is in Fig. 1. As the ambient air (to) passes the cooling coil the air temperature is decreased to the cooling temperature (tc) and finally the air is heated up by a re-heater to the supply air temperature (ts) to provide the required indoor air parameters (ti;  $\phi_i$ ) in cooling season

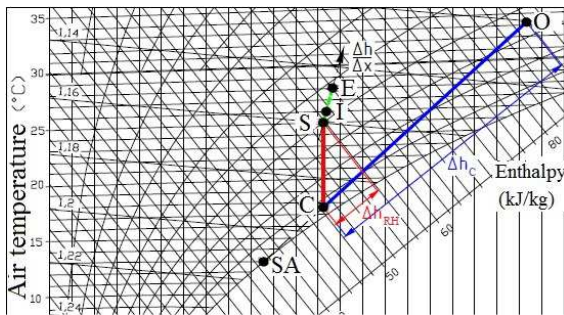


Fig. 1 Air handling process without heat-and energy exchanger in diagram h-x, in cooling period, Palermo

To determine the energy consumption of the system ambient air enthalpy duration curve was used. Fig. 2 shows the areas that are proportional with the energy consumption of the cooling („C”) and the re-heater („RH”).

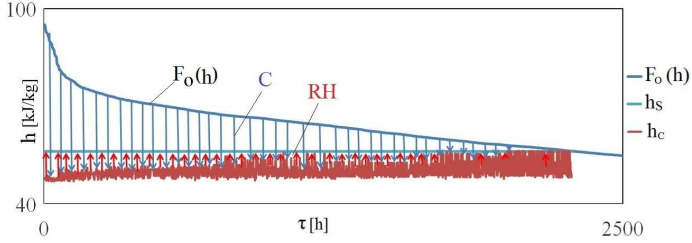


Fig. 2 Areas proportional to the energy consumption of cooling and re-heating without heat-and energy exchanger in Palermo in cooling period

Using the amount of energy determined with the areas on the ambient air enthalpy duration curve, the energy consumption of the ventilation system could be calculated by Equations (1-2).

Energy consumption of the cooling coil:

$$Q_C = \rho \cdot \dot{V} \cdot \int_{h_o}^{h_c} F_o(h) dh \quad [\text{MJ/year}] \quad (1)$$

Energy consumption of the re-heater:

$$Q_{RH} = \rho \cdot \dot{V} \cdot \int_{h_c}^{h_s} F_o(h) dh \quad [\text{MJ/year}] \quad (2)$$

### Determining the energy consumption of ventilation system operated with cross flow plate heat exchanger in Palermo in cooling period

Air handling process for sizing state is plotted to diagram Mollier h-x is in Fig. 3. As the ambient air ( $t_o$ ) passes the heat recovery the air temperature is decreased to the heat recovered temperature ( $t_{HR}$ ), then, passing the cooling coil, to the cooling temperature ( $t_c$ ) and finally the air is heated up by a re-heater to the supply air temperature ( $t_s$ ) to provide the required indoor air parameters ( $t_i$ ;  $\phi_i$ ) in cooling season.

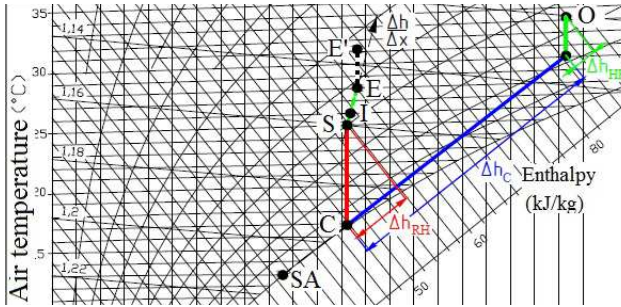


Fig. 3 Air handling process with cross flow plate heat exchanger on diagram h-x in cooling period in Palermo

Using the amount of energy determined with the areas on the ambient air temperature duration curve (Fig. 4), the energy consumption of the ventilation system for cooling period could be calculated by Equations (3-4).

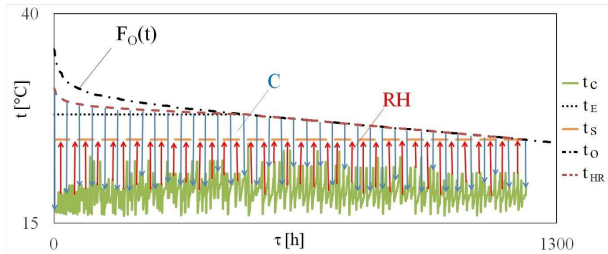


Fig. 4 Areas proportional to the energy consumption of cooling and re-heating with cross flow plate heat exchanger in Palermo in cooling period

Energy consumption of the cooling coil:

$$Q_C = c_{pl} \cdot \rho \cdot \dot{V} \cdot \int_{t_c}^{t_{HR}} F_O(t) dt \quad [\text{MJ/year}] \quad (3)$$

Energy consumption of the re-heater:

$$Q_{RH} = c_{pl} \cdot \rho \cdot \dot{V} \cdot \int_{t_c}^{t_s} F_O(t) dt \quad [\text{MJ/year}] \quad (4)$$

The determination method for energy consumption investigation looks almost the same for rotary heat exchangers technology.

### 3. Results

Fig. 5-8 show the predicted energy saved of the ventilating systems operating with different heat-and energy recovery technologies.

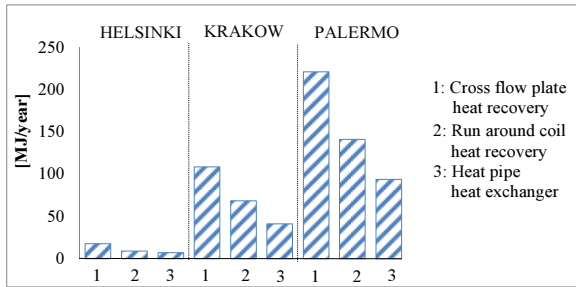


Fig. 5. Energy saved of the investigated heat recovery technologies in cooling period

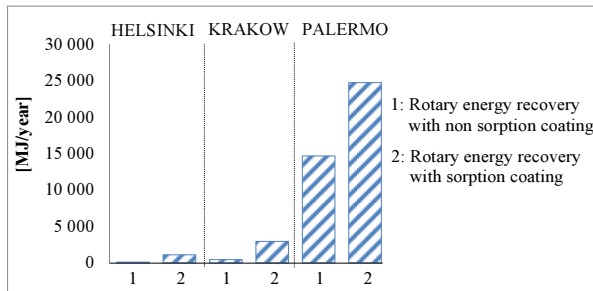


Fig. 6. Energy saved of the investigated energy recovery technologies in cooling period

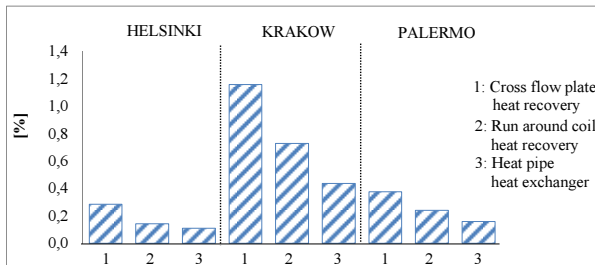


Fig. 7. Energy saved of the investigated heat recovery technologies correlated to consumption without heat recovery operation in cooling period



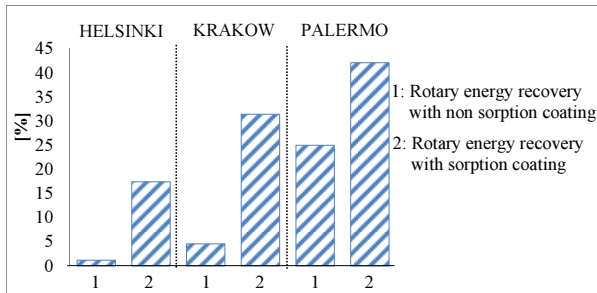


Fig. 8. Energy saved of the investigated energy recovery technologies correlated to consumption without energy recovery operation in cooling period

Based on the results the highest amount of energy saved can be reached with rotary energy recovery (especially with sorption coating) in cooling period. In Helsinki nearly 1100 MJ/year, in Krakow 3000 MJ/year, and in Palermo approximately 25 000 MJ/year energy can be saved in the cooling period. Naturally there are differences in the energy consumption of the different located cities; therefore it is worth taking into consideration even the percentage format of the savings beside the values themselves. The results show that highest percentage of energy saved can be reached in Palermo by 42%, followed by Krakow (31,5 %), finally Helsinki (17,5 %) (compared to the ventilation system without any heat-and energy recovery technologies).

#### 4. Conclusion

According to the above it can be concluded that in cooling period higher rate of energy saved can be performed in a Mediterranean climate area. In case of the heat recovery systems that transfer only for heat energy, the maximal energy saved is only some 100 MJ/year, in percentage it means only 1-2%. Its reason is the higher energy consumption of re-heating compared to the ventilation system without any heat-and energy recovery. Namely the cooling air temperature is lower related to the same ambient air condition parameters, by this way the re-heater has to heat up the air from a lower cooling air temperature value. It must be noted, that the values were not determined regarding the annual energy savings, only for the cooling period, thus the above results relevant only for this period. Selecting any heat- and energy recovery technology is worth for heating period, since the heating period is generally much longer than the necessary cooling hours' number especially in cold climates. Obviously the higher proportion cooling period compared to heating period, the much more it worth considering the energy saving for this period, for example in case of Palermo the energy saved by the heat-energy recovery can be significant even in the cooling period.

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