Air Handling Unit with Heat Pump

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Abstract. The paper focuses on the design, implementation and measurement of parameters of an air handling unit (AHU) with the Peltier cells. This is a small local modular AHU for fresh air flows of 50 to 200 m³/hr. The unit is designed for ventilation of residential and administrative buildings. Computer simulations were utilized designing the unit (including CFD), and many measurements were performed. The design of the AHU uses the Peltier effect, which transfers the heat from the exhaust air drawn from the room to the fresh supply air (heating mode). In reverse, the unit then allows for pre-cooling of the supply air (cooling mode). The air handling unit with the Peltier element does not achieve the high efficiency of the compressor cycle units, but is much simpler and has longer life expectancy.

1. Introduction

The air-handling units with heat recovery currently have great potential in the Central European markets. New office buildings mostly have a well-resolved ventilation concept. The situation is worse in case of new residential buildings where forced ventilation is often designed without heat recovery and advanced systems are used only in a minority of buildings. However, the worst situation is with older buildings that, although they have undergone insulation and window replacement, often do not address the ventilation system at all. This condition has a negative impact not only on the energy consumption and the building structures, but also on the quality of the indoor environment.

The proposed AHU is primarily intended for the refurbishment of the existing buildings. Its installation should be quick and without any major interventions into the building structures.

2. The Peltier cell

The basic element of the unit is the Peltier cell. It is a semiconductor component, mostly plate-shaped (side length from 20 to 80 mm and thickness approx. 4 mm). The element itself consists of a matrix of interconnected P and N semiconductors, covered by non-conducting ceramic plates on both sides. The element exploits the Peltier effect when, after connecting the cell to a DC circuit, one side of the semiconductors (and the ceramic plate attached) heats up and the other cools down.
The Peltier cells are commonly available in a wide range of output power (cooling power from about 5 to 300 W). At the maximum permitted input power, the temperature difference between both element sides can reach about 70 K. In figure 2 there is the characteristic of the Peltier cells used in the AHU, an element designated TEC1-12715 with dimensions 50 x 50 x 4 mm. The element achieves the cooling output of about 150 W at 15 A and 16 V.

The negative properties of Peltier cells is the efficiency drop at higher temperature differences Δt between the cold and the hot side of the cell. In figure 2 it is clear, that the cooling coefficient EER, defined as the ratio of the electrical input to the cooling output, reaches its maximum of about 4 at Δt of 10 K, and it drops to about 2 at Δt of 20 K. Beyond that the drop is even faster, the EER being only 0.1 at Δt of 60 K. For high efficiency of Peltier cells-based devices it is therefore necessary to ensure low Δt on the elements both by the operating conditions and by the device design.
In recent years, many papers have been published in the field of utilization of Peltier cells in buildings. Their use focused on the following areas:

- in a photo-voltaic solar concentrating collector [1],
- as an active element in the building envelope that would generate energy from the surrounding environment [2], [3]
- in large-scale radiation soffits for building interiors [4]
- in condensing units for obtaining water from air humidity [5],
- in the heat exchanger for heat recovery from sewage effluent [6],
- in the water – water heat pump [7],
- in the air handling units for heating and cooling [8].

In most of the solved cases, the limiting factor for the real implementation of the device was the low efficiency of the Peltier cell at high temperature differences.

3. Concept of the Proposed Air Handling Unit (AHU)

The basic elements of the AHU are two heat recovery exchangers in series. The first heat exchanger (marked passive) consists of a common counter flow exchanger. The second exchanger contains the Peltier elements (active exchanger). During the winter operation of the unit, first a part of the extract air heat is transferred to the passive exchanger, and then the exhaust air enters the active exchanger, where it is further cooled and transfers another part of its heat into the supply air. In winter, the unit can bring supply (fresh) air with the required temperature to the interior. By simply reverse-polarizing the Peltier cells, the unit can be put into the summer mode, when conversely the supply air is cooled. The winter and summer operation of the unit is illustrated in figure 3. The proposed unit should allow modular stacking of up to 4 active heat exchangers (each with a fresh air flow rate of 50 m$^3$/hr) to one basic element with a passive exchanger, fans, and control.

![Figure 3. Winter and summer operation of the unit](image)

Furthermore, the unit is designed to allow, apart from the commonly published concepts in the literature

- Increase the air flow through the hot side of the active heat exchanger in the summer mode. This measure allows better heat transfer from the hot side of the Peltier elements, thus decreasing their $\Delta t$. The measure increases the cooling coefficient EER.
- The unit can be switched to the circulation mode. This mode can be utilized in winter when it is not necessary to bring fresh air into the interior, but the demand for heating persists (absence of persons in the building). The passive exchanger is disconnected in this mode and the interior air circulates only through the hot side of the active exchanger, similarly for the exterior air.
4. Unit Design Concept
The active exchange has been identified as the decisive component with a significant influence on the total unit efficiency. A great deal of time was devoted to its optimization, addressing:

- Exchanger material,
- Exchanger geometry,
- Optimum number of Peltier cells,
- Optimization of heat transfer from the Peltier element to the heat exchanger material,
- The completion procedure for the active exchanger.

During the optimization, large number of calculations was performed including CFD simulations. At the same time, measurements on exchanger samples were performed. Finally, a compact aluminium plate heat exchanger with a large heat transfer surface was determined as an optimum. The side of the exchanger adjacent to the Peltier elements should exhibit good flatness and allow the use of small thickness (about 0.1 mm) of heat conducting paste (with $\lambda$ below 4 W/m*K).

During optimization, it has been found that finding a supplier of the desired heat exchanger is much more difficult than its design. Normally supplied heat exchangers do not have optimum geometry and the price of custom piece production for prototype units was unacceptable. In the end, the measured exchanger samples were a compromise.

5. Simulation and Measurement Examples

5.1. CFD simulation of the active exchanger

**Exchanger parameters:**
- 2 x aluminium heatsink with dimensions 150 mm x 75 mm and length of 500 mm,
- fin thickness 1 mm, air gap 2 mm,
- heat exchange surface of one heatsink 1.75 m$^2$,
- 9 x Peltier cell TEC1-12715, 3 rows of 3 elements,
- heat conducting paste 0.1 mm ($\lambda = 5$ W/m*K),

**Air flow parameters:**
- air flow 85 m$^3$/hr,
- temperature $T_{\text{ETA}} = 15$ °C (extract air), $T_{\text{ODA}} = 10$ °C (outdoor air). It corresponds to the passive heat exchanger efficiency of 66.6% and $T_{\text{interior}} = 20$ °C and $T_{\text{exterior}} = 5$ °C.

**Model:** 3D model in the ANSYS Fluent software including a Peltier element model.

![Figure 4. Cross-section of the aluminium heatsink](image)
Figure 5. Distribution of temperatures along the cross-section

Table 1. Simulation results

| $T_{\text{ETA}}$ extract air ($^\circ$C) | $T_{\text{EHA}}$ exhaust air ($^\circ$C) | $T_{\text{ODA}}$ outdoor air ($^\circ$C) | $T_{\text{SUP}}$ supply air ($^\circ$C) | $\Delta T$ cold (K) | $\Delta T$ hot (K) | flow rate (m$^3$/hr) | power input (W) | cooling power (W) | heating power (W) | COP heating | EER cooling |
|--------------------------------------|---------------------------------------|-------------------------------------|-------------------------------------|----------------|----------------|-------------------|----------------|----------------|----------------|-------------|-------------|
| 10                                   | 4.5                                   | 15.0                               | 26.0                               | 5.5            | 11.0          | 100                | 188            | 187            | 374            | 1.99        | 0.99        |
| 10                                   | 5.8                                   | 15.0                               | 22.6                               | 4.2            | 7.6           | 100                | 118            | 143            | 260            | 2.21        | 1.21        |

Table 2. Temperatures of Peltier cells

| row | power input 188 W | power input 118 W |
|-----|-------------------|-------------------|
|     | hot side ($^\circ$C) | cold side ($^\circ$C) | hot side ($^\circ$C) | cold side ($^\circ$C) |
| 1   | 33.5              | 4.9               | 25.8              | 5.6               |
| 2   | 30.6              | 2.8               | 24.9              | 4.0               |
| 3   | 27.0              | -0.1              | 23.4              | 2.5               |

It is clear from the results that for power input of 188 W (corresponding to approx. 4 A), the COP was about 2, at 118 W the COP increased to 2.2.

For input of 188 W, the $\Delta t$ on elements of the individual rows reached values of 38.8 K, 27.8 K and 20.9 K, with the temperature differences of the output air $\Delta t_{\text{air}}$ 21.5 K.

5.2. Measurement of the Active Exchanger

Exchanger parameters:

- 2 x aluminium heatsink with dimensions 102 mm x 128 mm and length of 600 mm,
- fin thickness 1.5 mm, air gap 2.5 mm,
- heat exchange surface of one radiator 1.75 m$^2$,
- 9 x Peltier element TEC1-12715, heat conduction paste $\lambda = 6$ W/m.K,
Air flow parameters:
- different temperatures and flows,
- also the state roughly corresponding to the simulation has been measured (the input temperatures had small deviations)

**Figure 6.** View of the individual heatsinks of the active module, the bottom heatsink has already the Peltier cells installed. The space between the elements is thermally insulated and overlaid with aluminium foil. On the right there is the insulated module ready for measurement.

**Table 3.** Measurement results

| T_{\text{ETA}} extract air (°C) | T_{\text{EHA}} exhaust air (°C) | T_{\text{ODA}} outdoor air (°C) | T_{\text{SUP}} supply air (°C) | ΔT cold (K) | ΔT hot (K) | flow rate (m³/hr) | power input (W) | cooling capacity (W) | heating capacity (W) | COP heating | EER cooling |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|-------------|-------------|-------------------|-----------------|------------------|------------------|-------------|-------------|
| 7.6                             | 2.8                             | 13.3                            | 23.5                            | 4.8         | 10.2        | 100               | 185             | 170              | 353              | 1.91        | 0.92        |
| 7.6                             | 3.8                             | 13.1                            | 20.3                            | 3.8         | 7.2         | 100               | 116             | 135              | 249              | 2.15        | 1.16        |

The measurement results show that a good match with the simulation was achieved. Heating COP and cooling EER coefficients differ by max. 0.1.

On the sample of the active heat exchanger, a large number of measurements were performed for different boundary conditions. Figures 7 and 8 show the results from the state when room temperature air T_{\text{int}} (24 °C) is fed to both sides of the heat exchanger.

**Figure 7.** Temperature progression depending on input power (96 W, 143 W, 168 W)
6. Measurement of the Complete Unit

A sample of the unit containing passive and one active module was measured. For the active module, a budget aluminum heatsink with dimensions 50 x 100 mm and a total length of 800 mm was used. The heatsink contained 10 fins 4 to 3 mm thick and with a total heat transfer surface of 0.72 m². 8 Peltier elements were used in the module.

The measurement was performed for different boundary conditions on a test line for small air handling units. The measurement results for flow of 50 m³/hr and winter temperature conditions are listed in Table 4.

The results show that the unit achieves total heating coefficients COP in the range 2.9 to 6.9 in the ventilation mode, for outdoor air temperatures from -6 to 11 °C. The actual heat coefficients of the active heat exchanger range from 1.03 to 1.84. The active module in this unit is beneficial for the overall unit efficiency at outdoor temperatures above -6 °C. When heatsinks with better parameters are used, this point can be expected to move to temperatures to -10 °C.

**Figure 8.** Course of COP and EER (corresponding to the conditions from figure 7)

**Figure 9.** Heatsink geometry used in the active heat exchanger

**Figure 10.** AHU ready for measurement (the passive heat exchanger is under the blue thermal insulation, the active one under the white insulation)
Table 4. Measurement results

| $T_{\text{int}}$ (°C) | $T_{\text{ext}}$ (°C) | $T_{\text{SUP}}$ supply air (°C) | Current (A) | Voltage (V) | Power (W) | Total Heating Capacity (W) | COP (Peltier) | COP (Total) |
|-----------------------|-----------------------|-------------------------------|-------------|-------------|-----------|---------------------------|--------------|------------|
| 20.8                  | -5.9                  | 29.0                          | 4           | 51.6        | 206       | 595                       | 1.02         | 2.9        |
| 21.1                  | 0.6                   | 26.3                          | 3           | 38.6        | 116       | 438                       | 1.23         | 3.8        |
| 21.2                  | 4.9                   | 22.9                          | 2           | 25.8        | 52        | 307                       | 1.42         | 5.9        |
| 21.2                  | 11.1                  | 23.1                          | 1.5         | 19.6        | 29        | 203                       | 1.84         | 6.9        |

7. Conclusion
The paper summarizes the initial development phase of the AHU with the Peltier element; both the simulation and measurement results are presented. The results show that the total efficiency of the unit is negatively affected by the Peltier element property – low efficiency at high temperature differences at the element. To reduce the temperature necessary, good heat transfer from the element to the air stream must be ensured. This required use of good quality heatsinks with a large heat transfer surface. A good efficiency also requires specification of the operation conditions of the device. From the results so far, it is apparent that the presented concept of the AHU with the Peltier cell is expedient to operate up to the outdoor air temperature of about -10 °C.

Acknowledgment
This work was supported by the National Sustainability Programme (NPU), Project No. LO1605 – University centre for energy-efficient buildings.

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