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Compact climatization system for mechanical ventilation with heat recovery

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TOPIC: Experimental heat and mass transfer processes

1. Introduction

Nearly zero energy (NZEB) or PASSIVHAUSS buildings [1, 2] are characterized by a very low energy consumption to meet the needs of air climatization (cooling and heating). Although in the design philosophy of these buildings, air conditioning and heating systems would be unnecessary, in some climatic regions, mainly due to user requirements, equipment such as geothermal or aerothermal heat pumps is usually installed [3].

This type of house is conceived from the design stage to achieve high energy efficiency. The orientation of the building and distribution of windows and facades are studied in detail to reduce the building's energy demand by taking advantage of solar radiation in winter and avoiding overheating during summer. Another important aspect is the excellent insulation of the building envelope, reducing heat losses to the environment.

Recently, to reduce energy consumption in air conditioning by interior air renovation, either heating or cooling, the implementation of mechanical ventilation systems with a Heat Recovery Unit (HRU) is being used [4, 5]. This solution ensures high levels of indoor air renewal without hardly increasing the heating and cooling demand in summer and winter. Although this technology has been present in ventilation systems for large spaces or buildings for several years [4], its use has become popular in homes thanks to the passivhaus certification, whose buildings are required to incorporate this ventilation system to guarantee air quality inside the building. Currently, more and more manufacturers include compact ventilation systems with heat recovery in their catalogues, to be implemented in single-family houses, but also in smaller residential flats.

Thanks to HRU, it is estimated that energy savings can exceed 35% [6], compared to conventional ventilation systems. However, although these units have a high efficiency greater than 90% in many designs, not all sensible heat can be recovered from the extracted airflow, requiring small heating and cooling systems to maintain comfortable conditions inside the dwelling.

The low heating demand that these buildings require is a small inconvenience when experts are designing the air conditioning installation that adjusts to the real needs of the building. Currently, there are few devices that can provide low heating and cooling powers, making the expert to install devices with power above the real needs, in most cases, small gas boilers or heat pumps are chosen.

In this work, the design of an air conditioning system for its use in mechanical ventilation systems with HRU is presented. This system allows the generation of a thermal flow (heat or cold) using several thermoelectric modules (TEM). It treats a compact and easily installable system in commercial HRU designs. The results obtained from the different tests carried out on the prototype are also shown, to estimate the efficiency of the system.

2. Prototype design

The proposed technology makes it possible to compensate, in the same device, the heating and cooling demand for the building, been coupled in series with the HRU, as it is scheduled in figure 1. The air flows at the HRU outlet are heated or cooled by TEM. In this work, the use of these modules is proposed since are devices that, without moving parts, can generate cold or heat, compactly with acceptable efficiency.

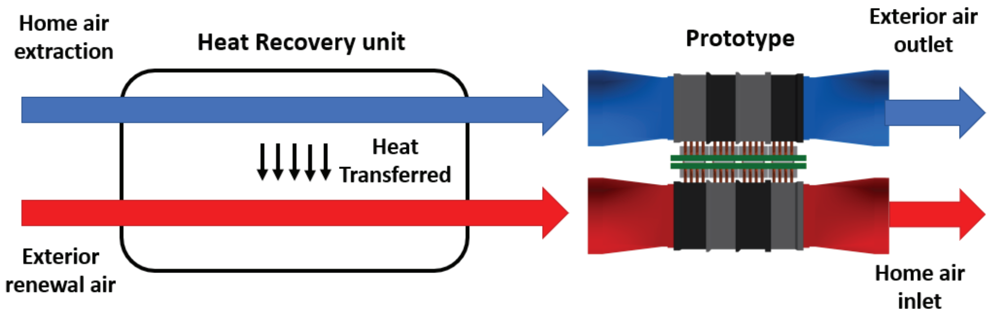

Figure 1. Scheme of operation of the compact air conditioning system for mechanical ventilation with heat recovery.

TEM generates a temperature difference when an electrical current is applied and can reverse operation by changing the polarity of the electrical current. Since two airflows are available at HRU: extraction and air renewal, the use of TEM is an ideal alternative. One airflow will warm up while the other will cool down, ensuring proper TEM operation.

For the technology and design validation, a first prototype has been built, whose design is shown schematically in Figure 2. As can be seen in the image, the design is symmetrical and modular. In this way, the number of different elements is reduced, and it is possible to scale the equipment to the needs of each home.

In the middle of the device (3) the TEMs are arranged, where both faces are in contact with respective 10 mm thick aluminium plates. This element allows the heat to be distributed more uniformly, avoiding the presence of hot points that can damage the TEM. Heat is transferred to both airflows through heat sink blocks (4), made up of several heat pipes and aluminium fins. These elements are characterized by their rapid response and good operation at partial loads. The last component of the system is the ducts through which the air circulates. Due to the rectangular design of commercial heat sinks, a circular to rectangular transition element (1-2) is included with the standard dimensions for ventilation ducts. All ducts were made by 3D printing.

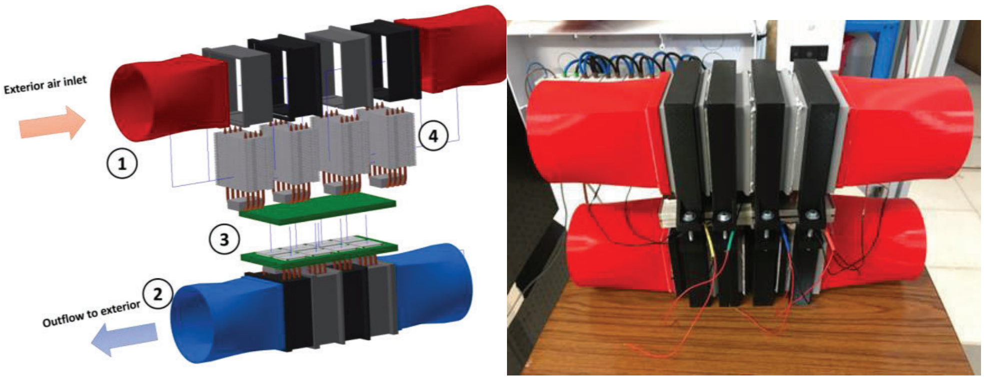

Figure 2. Prototype elements distribution (left). Real constructed Prototype (right)

The proposed design is completely modular, to be able to make the equipment flexible to the needs of its application. The built prototype has a total of 4 modules with a nominal thermal power of 200W each. One Farnell TEM model MCTE1-19913L-S [7] has been placed in each module. The nominal voltage is 24Vdc and can generate a nominal heat flux of 200W.

3. Experimental facility

To carry out the energy characterization experimental test of the designed prototype, an experimental facility was built that allows the real operating conditions to be artificially reproduced and to control and regulate its working parameters. In figure 3 the scheme of the experimental facility is shown.

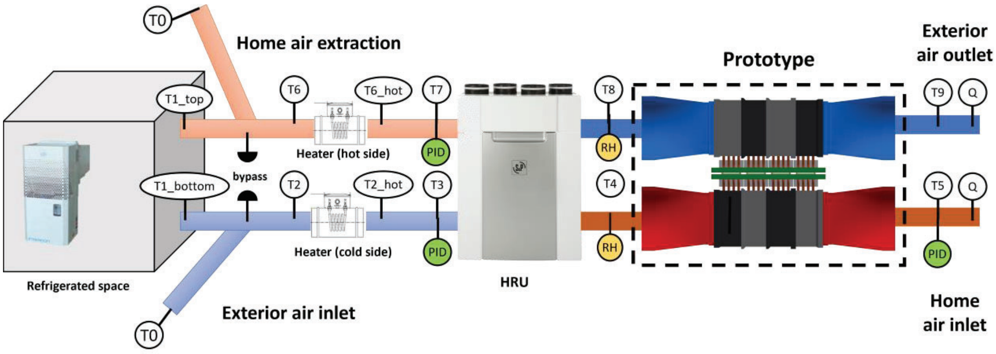

Figure 3. Scheme of the experimental facility.

This facility is designed to generate 2 airflows at different temperatures, being able to simulate the extraction of air from the building interior and the air renewal. The extraction air will have the same temperature inside the building, between 19℃ and 25℃, while the renewal air will have that outside temperature, between −5℃ and 10℃ in winter and between 25℃ and 40℃ in summer.

To this end, there is a refrigerated large space where the air is cooled. After that, the air temperature is regulated by electric heaters. The setpoint temperature for both air flows is regulated by a PID controller. In summer conditions, where the outside temperature is higher, it is not necessary to cool the air and, therefore, the air is taken directly from the laboratory, which is later heated to the set temperature.

Both air flows are generated by the HRU model S&P Domeo 210 [6]. This unit has two fans that generate and regulate the flow circulating through the installation. Finally, the HRU outlets are connected to the prototype, where the renewal air is heated or cooled to the required temperature. Figure 4 shows the real caption of the experimental device.

Figure 4. Experimental facility.

The main objective of the experimental test carried out is to be able to know the real operation capacities of the installation under different conditions, and to estimate the energy efficiency of the system. To this end, the installation includes sensors for temperature, humidity, airflow and electricity consumption. All temperature, relative humidity, and TEM activation time measurement values are recorded every 30 seconds using a Campbell-Scientific CR1000X datalogger. Table 1 includes the specifications of the sensors used:

Table 1: Sensors implemented in the experimental feasibility.

Sensor	Model	Resolution
Temperature	Thermocouple K	± 0.5℃
Pressure	Testo 510	$\pm 1.5\%$
Humidity	Honeywell HIH-4010-003	$\pm 3.5\%$
Anemometer	PCE-007	$\pm 3\% \pm 0.1$
Voltmeter	Fluke 117	$\pm 0.5\%$
Amperemeter	UNI-T UT210D	$\pm 2\%$

The prototype's operation control is carried out by a PID, which regulate the temperature of the renewal air flow. This PID controls the activation of the TEMs. Due to the high installed power, each TEM is connected to a Solid State Relay (SSR). In figures 5 it is shown the electrical protection, DC power supply and SSRs (left image) and PID controller and datalogger (right image).

Figure 5. Electrical protection, DC power supply and SSRs (left) and PID controller and datalogger (right).

4. Results and discussion

In this work, the results of the first two tests carried out on the prototype are shown. In both cases, the outdoor temperature has been set at 7°C and the airflow was set at 80 m^3/h. In the first test, the objective was to compensate the heat not recovered in the HRU so that the temperature of the air at the outlet of the system would be the same as that inside the building at 21°C. In the second test, a scenario where the air temperature is slightly higher than that of the inside the building is analyzed. In this way, it is intended to compensate the heat losses of the building. To do this, the PID setpoint temperature was increased to 25°C. In the first test, only one TEM module was activated, while in the second test 2 modules were activated.

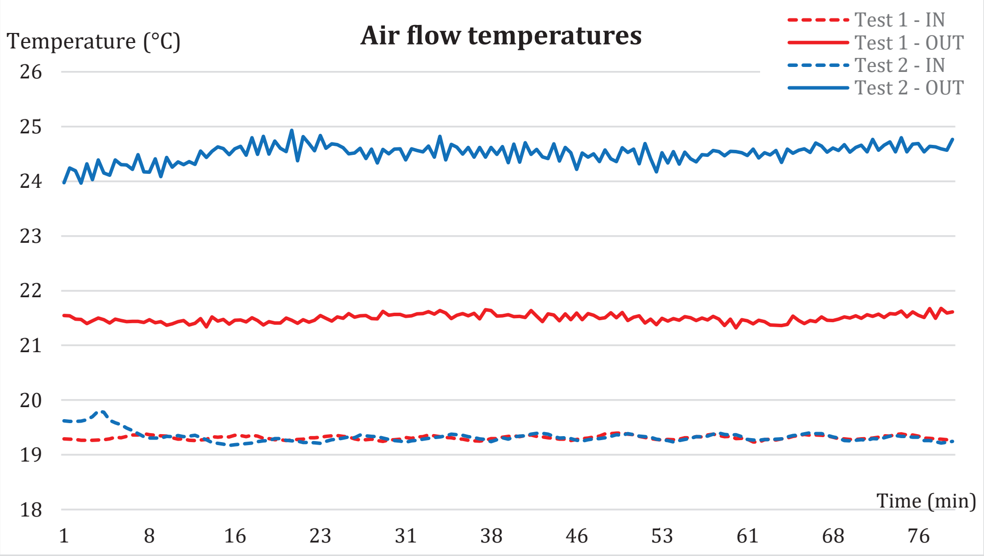

Figure 6. Measured air flow temperatures in test 1 and 2.

Figure 6 shows the temperatures measured in the renewal airflow. In both tests can be seen that the outlet temperature is homogeneous throughout the test length, managing to provide the necessary heat flux to maintain the defined temperature ranges. The temperature deviation at the prototype outlet is due to the reading error of the PID control itself.

When the temperatures in both airflows at different points of the installation are represented, as shown in figure 7, it is possible to analyze each process individually. In the HRU, the temperature difference of the airflow at the outlet concerning the inlet is 1.5 °C, reflecting the good efficiency of the system and its real utility.

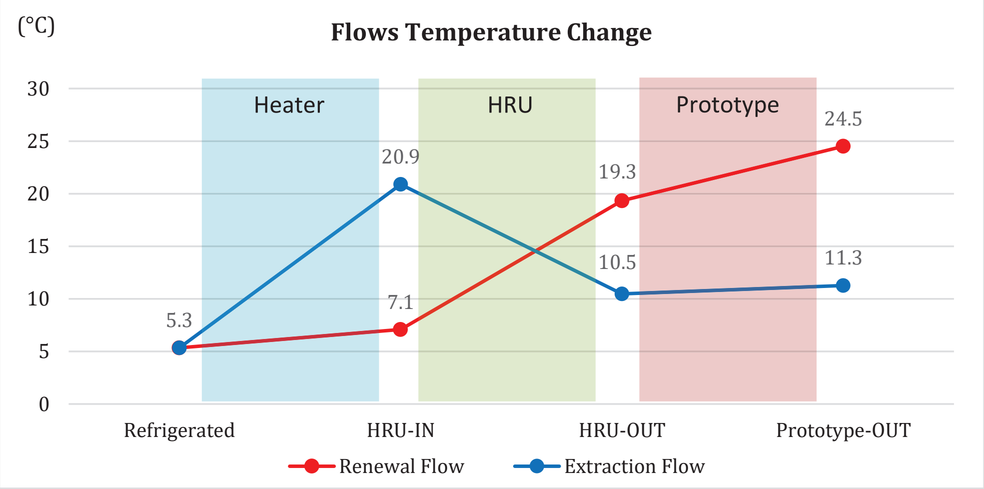

Figure 7. Temperature of the air flows at different points of the experimental feasibility. Values obtained from test 2.

On the other hand, when the prototype operation is analyzed individually, it can be verified the proper global operating, as has been previously observed. The prototype can heat the renewal air flow to the established temperature. However, the extraction flow undergoes a slight heating. Despite being in contact with the cold surface of the TEM, the flow heats up. This is produced because, during the time that TEM is turned off, there is heat transfer between the hot to the cold surface. In this way, this energy is dissipated and therefore the efficiency of the process is reduced. This phenomenon has been experimentally verified by analyzing the system when TEMs were disactivated while maintaining the air flows at different temperatures, observing a heat transfer between the air flows.

To avoid this process, a voltage regulator for the TEMs should be implemented, preventing TEM from turning off and therefore generating heat transmission between airflows.

When the global performance of the protype is analyzed, some differences are observed between both tests. To avoid the influence of heat transfer between airflows in the prototype, the number of activated TEMs has been adjusted in each test, so that the TEM activation time is similar. In both tests, it was close to 1/3 of the time. In test 1, an average efficiency of 73.3% is reached, while in the second test it increases to 87%. This variation may be due to measurement sensor errors in temperature (±0.5°C) and relative humidity (±3%). In the first test, the temperature increase is 2.3°C while in the second case it is 5.2°C.

For its estimation, the energy consumption, provided by expression (1), and the heat absorbed by the air flow, by expression (2), were estimated.

$$Q_{TEM} = I \cdot V \cdot t_{ON} \tag{1}$$

$$Q_{air} = \dot{m} \cdot (h_{out} - h_{in}) \cdot \Delta t \tag{2}$$

$$\eta = \frac{Q_{TEM}}{Q_{air}} \cdot 100 \tag{3}$$

where I and V are the current and voltage of TEM respectively; t_{ON} is the TEM activation time in each measurement interval, $\dot{m}$ air mass flow, h_{out} and h_{in} are the inlet and outlet air enthalpies and Δt is the measurement interval.

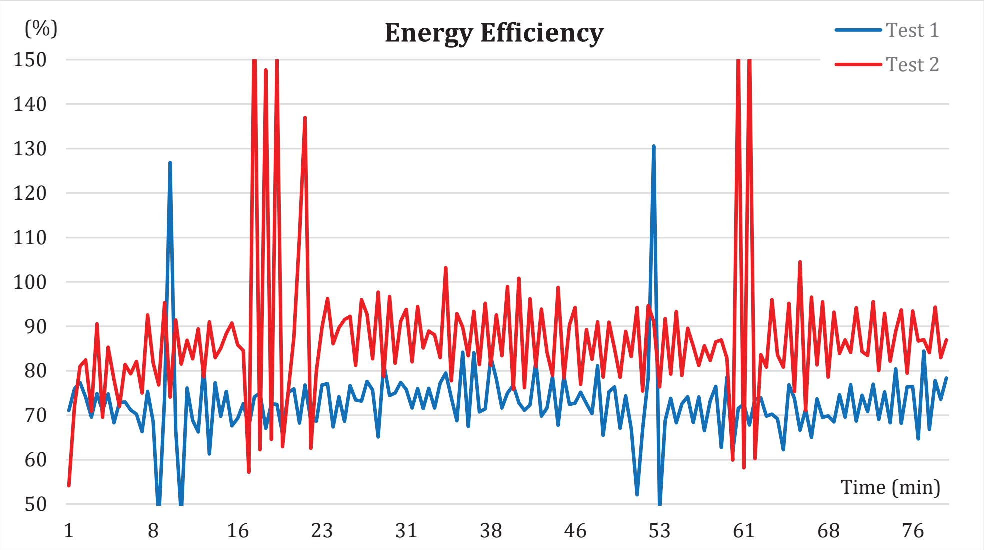

Figure 8. Prototype energy performance.

5. Conclusions

The air-conditioning system described can be integrated in a compact form, and with the possibility of being scaled by adjusting its capacity to each building energy demand, and to most commercial heat recovery designs. This element simplifies the design of the installations and reduces the total cost of the air-conditioning system for low-energy building.

An experimental installation has been designed for testing the prototype, which allows to simulate the exterior air inlet and building outflow. Since the temperature of both airflows can be adjusted and summer and winter scenarios can be tested. The installation measure continuously air temperature at different points, relative humidity, pressure losses, energy consumption and air flow rates of both flows.

The tests carried out have made it possible to validate the design. Although the system is capable of compensating for energy losses due to efficiency in the recuperator and, also, increase the temperature of the air entering the building, its efficiency is limited due to the heat that is transferred between the air flows when the TEMs are not activated. This aspect causes part of the energy provided by the TEMs to be dissipated by the exterior outlet flow. Therefore, relatively low efficiency has been observed in tests, with values below 90%.

The analysis of the results has also allowed to conclude that this low efficiency can be increased when the system power is regulated by varying the supply voltage of the Peltier cells. This reduces heat transfer between air flows when the TEMs are not in activated.

In the cooling tests, the recorded efficiency is even lower. When the TEMs have been activated in reverse, a longer activation time is required. This produces an overheating of the extraction air flow. Due to the high heat conduction through the TEMs, the renew air flow warms, producing a lost in efficiency.

Acknowledgements

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