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Experimental Performance Analyses of a Heat Recovery System for Mechanical Ventilation in Buildings

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Abstract

Nowadays the increasing trend to make buildings more and more energetically efficient leads to an improvement of the thermal performance of the elements such us walls, windows and doors, making the envelope a strong barrier between the indoor and outdoor environment, also for air infiltrations. If this circumstance results useful for energy consumption reduction, it constitutes a problem for indoor air quality and comfort.

Mechanical ventilation systems are often provided, and, at the aim of abating the thermal (or cooling) loads linked to the inlet of air from the external environment, heat recovery systems became more and more popular; for high values of air mass flow treated, many national regulations make the installation of heat recovery systems compulsory.

An experimental test bench was built at the Thermal Engineering Laboratory of the University of Perugia, aimed at evaluating the performance of air heat recovery devices. The first measurements were carried out on a commercial plate-type heat exchanger, made of polystyrene. This plastic material is characterized by a low value of thermal conductivity, but its easiness of workability allows to increase the heat exchange surface, overcoming also issues linked to the weight and the cost of the product.

The flow-rates, the pressure drops, and all temperatures of interest for the heat exchanger were acquired. The energy efficiency index of the heat recovery system was assessed with several tests conducted with different boundary conditions of the indoor and outdoor ambient, as well as different air flow rates.

Results were compared with data gathered from the manufacturer, highlighting the points of contact and the differences between the experimental outcomes and the company information sheet, providing further details that are commonly not available.

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Keywords: Mechanical ventilation; efficiency; test bench setup

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1. Introduction

The building sector is induced by the energy saving policies to reduce the energy consumptions with significant improvement of the insulation envelope. As a consequence, the air tightness increases, reducing the air exchange into the rooms and causing negative effects for the building and for the inhabitants, with mold formation and raising of the air pollution.

Nomenclature

η	efficiency
T	temperature
Subscript	
11	suction from indoor environment
12	inflow in the indoor environment
21	suction from the outdoor environment

In order to avoid the negative effect of the lack of external air in the building, several companies propose efficient mechanical ventilation system that are usually characterized by a heat recovery system. These devices can avoid the arbitrary action of the windows opening and pursue the energy saving objective with a pre-heating of the cold external air with the warm and exhaust internal air, in winter conditions. Several solutions exist with different efficiencies and costs.

The most common heat recovery systems are constituted by a double flux ventilation that allows the external air to enter into the rooms and to extract the inner air from the buildings polluted ambients, like kitchens and bathrooms. The heat recovery systems heats up the external air with the exhaust air during the extracting process. Some devices have the possibility to humidify and dehumidify the external air. The core component of the system is the heat exchanger, which works with two main different configurations: rotary heat exchanger and plate heat exchanger.

For the sake of brevity more attention has been paid to plate heat exchanger devices, directly linked with the experimental work. Several authors studied these systems with different materials and geometries of the heat exchanger. In particular, Manz et al. [1] studied experimentally and numerically an aluminum system for residential applications, realizing a test bench and analyzing the heat recovery performance. A deep experimental and analytical analysis was carried out by Gendebien et al. [2] and Fernández-Seara et al. [3] on a heat exchanger made with several corrugated plates made of synthetic materials. The plastic material is generally characterized by a low thermal conductivity value, but it allows to create geometries suitable to increase the surface for the thermal heat exchange. The study carried out by [2] focused on the performance of the device in different conditions of humidity. Several different materials were used by Zhang et al. [4] analyzing the effect in the efficiency due to the variation of mass-flow rate, temperature and humidity. A particular heat recovery system was designed by Kragh et al. [5], in order to optimize the heat recovery for the very cold climate.

In general, plate heat exchangers work with the two fluids unmixed, exchanging heat through the walls of the exchanger. The devices can be constituted by different materials; aluminum has an high thermal performance, but other materials, like plastic membrane can also be used: they are characterized by lower thermal conductivity than aluminum but they allow to reduce the thickness and weight, creating particular shapes to increase the heat exchange surfaces.

In the present work a test bench is built to analyze the performance of a controlled mechanical ventilation (CMV) system with air-to-air counter-flow heat recovery, analyzing characteristics that are not commonly available.

2. Description of the CMV analyzed

The tested controlled mechanical ventilation system is showed in the figure 1. The model works with two fluxes (circuit 1: suction from outside and introduction into the rooms; circuit 2: suction from the room and extraction outside) with a nominal mass flow rate of the air equal to 300 m^3/h. Two fans guarantee the two fluxes (constant flow rate of 300 m^3/h and nominal speed of 3200 rpm): introduction of the external air and emission of the exhaust internal air. The fluxes need a filtering section to avoid impurities inlet in the device and in the room.

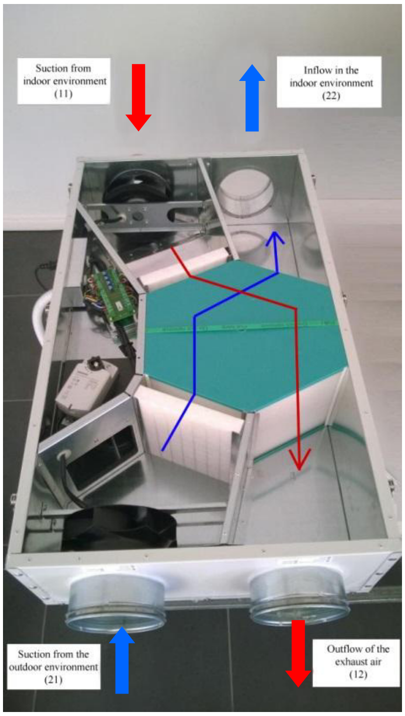

Fig. 1. The CMV system with the scheme of the circuits.

The hexagonal shaped heat exchanger is composed by a refined grid of little triangular channels, made of polystyrene. The grid is built to maximize the thermal exchange between the warm and cold fluid. The walls of each channel are in contact with the other fluid for avoiding the mixing.

The system is provided by a regulation device, aimed at setting three different speeds of the fans. Moreover, it is possible to bypass the heat exchanger and create the free cooling working conditions, introducing the external air without pre-heating. In order to guarantee the optimum working of the equipment, it was necessary to balance the two circuits mass flow.

3. Experimental setup

A test bench was built to test the CMV and simulate the performance; it was designed according to EN 308 [6] that prescribes indications for the procedures and the set-up of laboratory tests to realize efficiency tests for the heat exchanger and the whole CMV.

In order to avoid the air short circuit, the pre-heated external air was dispatched in the external environment, in a point far enough from the external suction point. Temperature, pressure and speed of the fluxes have been measured to characterize the whole machine.

T-type thermocouples were placed on each section of the heat exchanger, installing three temperature probes at different heights for each wall. Four additional temperature and humidity probes were added into the pipes to check the fluxes conditions just out of the CMV.

The differential pressure upstream and downstream of the heat exchanger was measured by means of an alcohol manometer.

Finally, the air speed was measured with a hot wire anemometer. The measure must be done at a certain distance of the obstacles and singularities and for the circle shape the measurements were carried out according to logarithmic method of Tchebycheff [7]. The speed measurements are performed along three diameters, with a shift of 60° and executing six measurements for each diameter (figure 2). With the average of the 18 values, it is possible to obtain the average speed of the flux and the mass flow rate. The measurements were performed for the two circuits, for the three different speeds of the fans and for the standard and free-cooling setup.

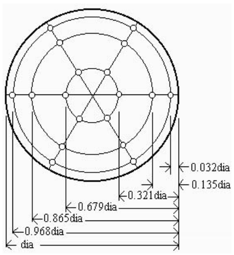

Fig. 2. Speed measurements point according to Tchebycheff method [7].

4. Measurement results and performance analysis

Table 1 shows the speed measurements and the calculation of mass flow rate for the two circuits. The velocity measurements were performed for three different fan speeds and with two configurations: the first one without the distribution plant and the second one taking into account the whole distribution plant. The last column is referred to the free-cooling mode only for circuit 1. As can be seen, the distribution plant has been designed to make the circuits balanced.

Table 2 shows the values of the differential pressure evaluated on the inlet and outlet faces of the heat exchanger.

The tests have been performed between November and December, with different external temperatures, being executed in different hours of the day. Table 3 shows the temperature and the relative humidity for the three tests. The inner temperature was kept to 20°C for the first two measurements, while for the third one it was increased up to 30°C, in order to create a higher difference temperature between indoor and outdoor. Figure 3 shows the trend of the temperatures on the four faces of the heat exchanger during the test n. 3.

Table 1. Speed measurements in the two circuits with different configurations

Velocity and volume flow rate	Circuit 1 without distribution plant	Circuit 2 without distribution plant	Circuit 1 with distribution plant	Circuit 2 with distribution plant	Circuit 1 Free-cooling mode (without distribution plant)
V_1 (m/s)	2,33	2,35	0,49	0,54	4,27
V_2 (m/s)	3,42	3,35	0,73	0,78	5,87
V_3 (m/s)	3,96	4,03	0,92	0,95	6,68
Q_1 (m^3/h)	160,2	161,3	34,1	37,1	293,9
Q_2 (m^3/h)	234,9	230,6	50,1	53,4	403,9
Q_3 (m^3/h)	272,0	277,3	63,1	65,6	459,7

Table 2. Pressure measurements in the two circuits (Pa)

	Circuit 1 – Circuit 2
P_1	135
P_2	230
P_3	304

Table 3. Internal and external conditions for the three tests

	External T(°C)	Internal T(°C)	RHexternal (%)	RHinternal (%)
Test 1	11,2	20	95	57
Test 2	9,7	20	59	35
Test 3	12,7	30	94	45

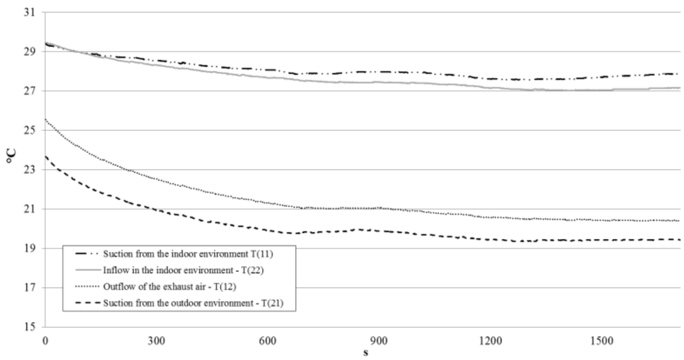

Fig. 3. Trend of the temperatures on the four faces of the heat exchanger.

Thanks to the measured parameters, it was possible to calculate the efficiency of the heat exchanger with the following expression [6]:

$$\eta = \frac{(T_{22} - T_{21})}{(T_{11} - T_{21})} \quad (1)$$

It could be noted that the expression of the efficiency is referred only to the sensible heat exchange between the two fluxes, without considering the energy used by the fans.

Figure 4 shows the trend of the three tests, varying the mass flow rate (different speed of the fans). The efficiency of the system resulted relatively high (around 90%), and it increases when the mass flow rate decreases. The efficiency reduction and the measured values on this work result in good agreement with the tests performed by the manufacturer on the heat exchanger (Fig. 4).

The performed tests have the mass flow rate of the two circuits quite far from the nominal value. The efficiency of the system decreases for the declared mass flow rate from the datasheet (300 m^3/h).Anyways a simple distribution plant significantly decreases the mass flow rate that the fans can guarantee representing a problem in the real building where the construction needs can lead the distribution plant to have a high degree of complexity.

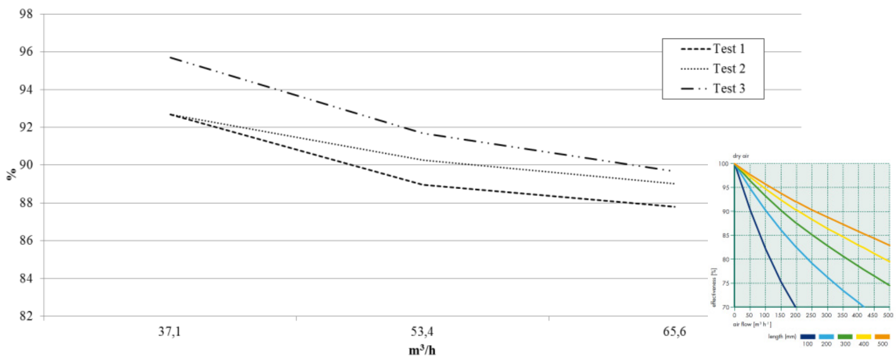

Fig. 4. The efficiency of the system with different mass flow rates and the efficiency trend according to manufacturer.

5. Conclusions

Ventilation in buildings assumed a significant role to avoid issues linked to mold and the quality of the internal environment.

A controlled mechanical ventilation system (CMV) with heat recovery has been analyzed in order to define the main characteristics and check the efficiency in different working conditions. A test bench setup has been designed, according to the Standards, and velocity, pressure and temperature measurements have been carried out. Generally, the efficiency of the heat exchanger results very high (around 90%) but it is strongly linked to the air mass flow rate in the two circuits.

The configuration of the distribution plant in the test bench (plenum and pipes) defined a mass flow rate quite far from the nominal value, leading to an increment of the efficiency. The higher values of the mass flow rate could determine low performance of the whole system. The test bench setup will be useful to study the innovative systems not yet available in the market. For instance, membrane heat recovery systems that allows to exchange also humidity between the two fluxes.

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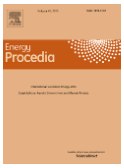

Biography

Giorgio Baldinelli is Permanent Researcher in Industrial Applied Physics at the Department of Engineering - University of Perugia. Lecturer of the course of Thermal Fluid Dynamic for the Masters of Science in "Mechanical Engineering" at the University of Perugia. Main research activities: energy and buildings, renewables; heat transfer, acoustic, energy planning, LCA.