# ANALYSIS OF AN AIR-TO-AIR HEAT EXCHANGER DESIGNED FOR THE MECHANICAL VENTILATION SYSTEM OF A HOUSE

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*This paper deals with the analysis of a heat recovery unit which is a part of the heating, ventilating and air conditioning (HVAC) system of an experimental house built inside the campus of Politehnica University of Bucharest. This work presents an algorithm used to determine the thermal efficiency of the air to air plate heat exchanger which is the most important component of the mechanical ventilation heat recovery (MVHR) unit and the analysis of the experimental data.*

**Keywords:** heat recovery, theoretical thermal efficiency, temperature transfer efficiency.

## 1. Introduction

An important amount of energy is used to heat, to cool, to ventilate, to light the buildings and to operate the appliances and the office machines. A very important percent of the total energy used by a country is used in buildings from residential and commercial sector. During the design and development process of the building projects is necessary to adopt solutions that lead to the reduction of primary energy consumption for heating, cooling and lighting through climate-responsive design and conservation practices. These are possible by employing renewable energy sources such as geothermal energy, passive solar heating and photovoltaics.

Heating, ventilation and air conditioning (HVAC) are three different functions often combined in the modern buildings. The heating system is designed to add thermal energy to a space of a building, the ventilation system is intended to introduce or/and to remove air in/from the inhabited space (to move air without changing its temperature) and the air conditioning system is designed to remove

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thermal energy from the space [1]. The purpose of the entire HVAC system is to provide interior comfort conditions for the building occupants. Today is not enough to heat or to cool the space but also to renew the inside air by bringing more outdoor fresh air. This is a practice that increases monthly utility costs by increasing the amount of energy for heating, cooling and humidifying/dehumidifying.

One of the solutions to reduce the primary energy consumption of a building consists in using applications for air-to-air energy recovery. A mechanical ventilation heat recovery (MVHR) unit allows the transfer of sensible and/or latent heat between two air streams: fresh air introduced into the building and the exhausted air rejected outside. The device is usually a component of the HVAC system and its main role is to precondition the outdoor fresh air required for the ventilation of the building and to give a substantial energy reduction [2]. The air-to-air heat recovery is a basic technique in achieving the standard of low [3] and very low energy buildings such as: the passive house, zero energy building [4],[5].

## 2. System description

As experimental purpose, two low energy houses (fig. 1) having a common wall are built inside the campus of the University Politehnica of Bucharest and their certification as passive houses is intended. A passive house, which is a low energy house, has to fulfill two important requirements: heating energy consumption must be lower than 15 kWh/m$^2$/year and total primary energy consumption must be under 120 kWh/m$^2$/year [6]. The houses have a very good insulation, large windows in the southern side and small windows in the northern side.

Fig. 1. Politehnica House

The two houses are architecturally identical, with a usable surface of 140 $m^2$ each, but they have implemented different HVAC solutions. Both systems are based on renewable energy sources and heat recovery. The subject of this paper is the study of the heat recovery system installed in the one of the houses, called "East House". The HVAC solution adopted for this house consists of a mechanical ventilation heat recovery (MVHR) unit connected to an earth to air heat exchanger (EAHX) (fig. 2) and supplementary infrared radiant panels. The domestic hot water is provided by a water tank connected with a solar panel. The HVAC system of the second house (West House) also uses geothermal and solar energy for space heating and hot water production. An MVHR unit identical with the one on the first house assures heat recovery from the exhausted air.

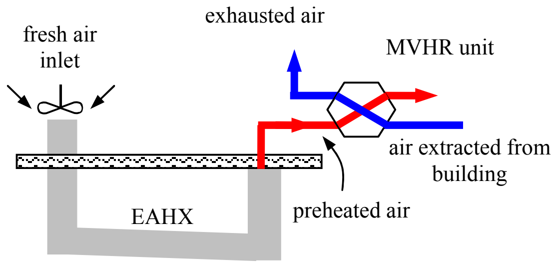


Fig. 2. Integration of the MVHR unit in the ventilation system

The EAHX system is made from a high density polyethylene pipe of 38 m long with an exterior diameter of 200 mm and a tightness of 7.8 mm. The pipe is buried in the ground, at a 2m depth. As it is known, compared to outdoor air temperature, the ground temperature varies by only a few degrees during one year. This system allows the pre-heating of the ventilation air in the winter and its cooling during the summer, the heat of the ground is brought inside the house with the help of this geothermal system.

Fig. 3. The air to air heat exchanger of the MVHR unit

The MVHR unit, specially designed for the mechanical ventilation system of the passive houses, works at air temperatures between -20 and +40°C and normal air humidity. The unit is compact and it is incorporated into the air ductwork. It consists of a plastic made plate heat exchanger (fig. 3), two fans, filters and a frost protection system. The heat exchanger is made of corrugated plates that form between them channels for the two air streams. To ensure an effective heat transfer between the two air streams, each channel is divided in 8 small channels. The geometrical characteristics of the MVHR unit heat exchanger are presented in table 1. The exhausted air and the fresh air flow in cross current direction. At very low air temperatures, the automatic frost protection prevents formation of the ice particles on the heat exchanger surface plates.

*Table 1*

**Geometrical characteristics of the heat exchanger:**

| Property | Symbol | Value | UM |
|---|---|---|---|
| Channel height | $H_o$ | 0.002 | m |
| Channel width | $l_o$ | 0.018 | m |
| Plate thickness | $\delta_p$ | 0.002 | m |
| Channel length | L | 0.35 | m |
| Number of channels | $n_c$ | 416 | - |
| Number of active plates | $n_p$ | 51 | - |
| Surface of one plate | $S_p$ | 0.2 | $m^2$ |
| Total heat exchange surface | S | 10.2 | $m^2$ |

The two radial fans identical and synchronized included in the MVHR unit are designed to circulate and control the airflow. In order to avoid the formation of overpressure or underpressure inside the house, the air flow of the two streams must be equal. In order to obtain more energy savings and also to meet the hygiene and comfort conditions, the MVHR unit is connected to an earth to air heat exchanger. The fresh air is taken from the outside of the building and is introduced inside the earth to air heat exchanger where it is preheated in the winter and cooled in the summer.

### 3. Thermal efficiency of the heat recovery unit

The efficiency of the MVHRV unit heat exchanger is calculated with the NTU method, a traditional solution in solving the heat exchangers problems [7]. NTU stands for number of heat transfer units. The logical scheme of the calculation model is presented in fig. 3. The first step consists of initialization of the fresh air temperature at the outlet of the MVHR. The values of the fresh air temperatures (inlet and outlet) are used to calculate the enthalpies $h_{2i}$ and $h_{2o}$, the thermodynamic and thermophysical properties ( $c_p$ - specific heat, $\rho$ - density, $\lambda$ - thermal conductivity, $\eta$ - dynamic viscosity, $Pr$ – Prandtl).

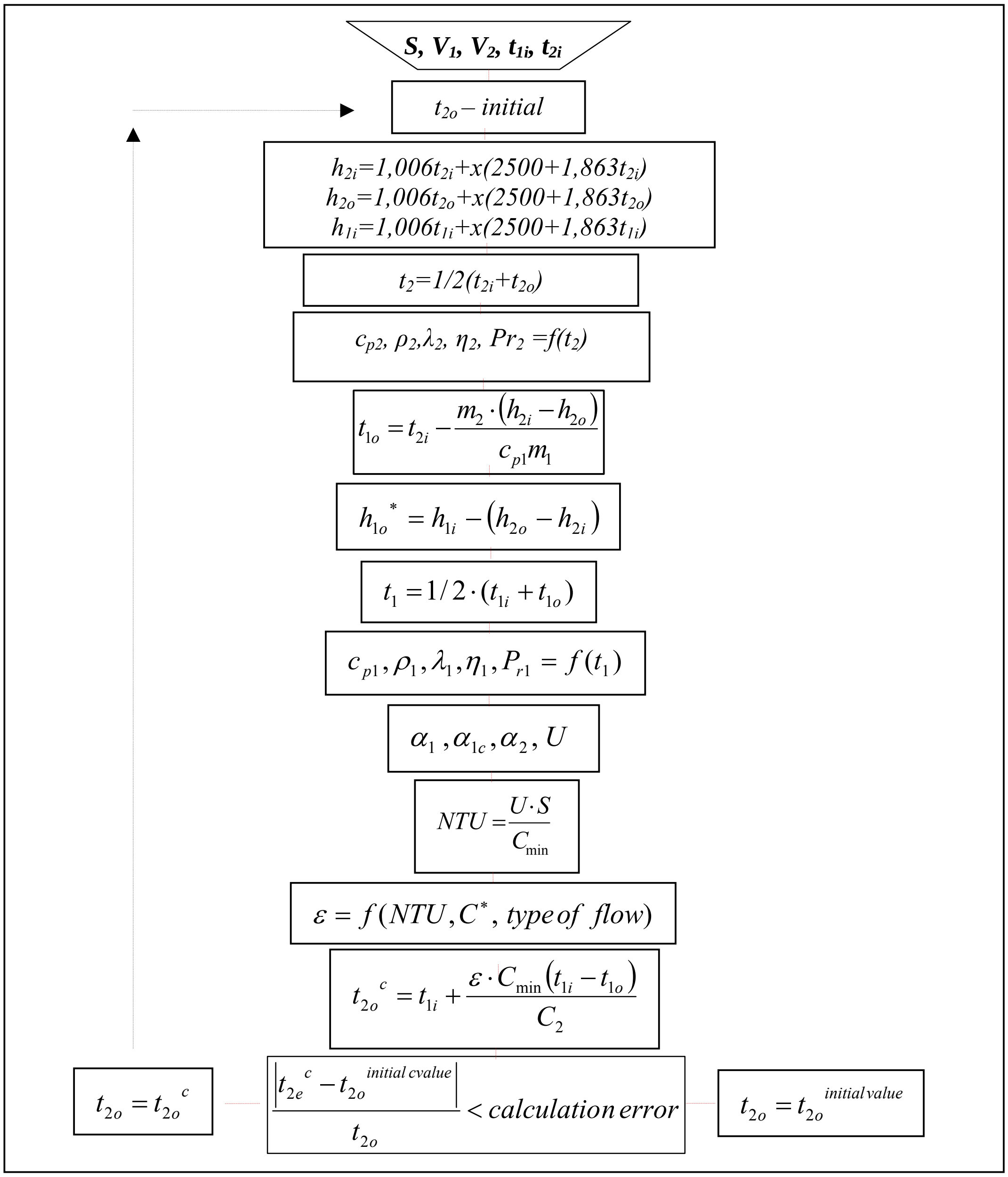


Fig. 4. Scheme of the calculation algorithm

The value of $h_{1o}^*$ (exhausted air enthalpy at the outlet of the MVHR) is found after an energy balance on the heat exchanger:

$$h^*_{1o} = h_{1i} - (h_{2o} - h_{2i}) \tag{1}$$

The analysis of the heat exchanger continues with the determination of the overall heat transfer coefficient:

$$U = \frac{1}{\frac{1}{\alpha_1} + \frac{\delta_p}{\lambda} + \frac{1}{\alpha_2}} \quad \left[W/m^2.K\right] \tag{2}$$

Where:

- $\alpha_1$ represents the heat transfer coefficient of the exhausted air;
- $\alpha_2$ is the heat transfer coefficient of the fresh air;
- $\lambda$ is the thermal conductivity of the plates;

The cross sectional areas of the air flows fresh air and exhausted air are equal. The Reynolds numbers values correspond to a laminar flow between the walls. The Nusselt numbers (depending on the fluids properties) are then calculated according to [8].

The heat transfer coefficients from the fluid to wall:

$$\alpha_1 = c_h \frac{Nu_1 \cdot \lambda_{a1}}{D_h} \quad \text{and} \quad \alpha_2 = \frac{Nu_2 \cdot \lambda_{a2}}{D_h} \quad [W/m^2.K] \tag{3}$$

Where:

- $c_h$ is the correction factor;
- $Nu_1$ and $Nu_2$ are the Nusselt numbers of the air flows;
- $\lambda_{a1}$ and $\lambda_{a2}$ represents the thermal conductivity of the fluids;
- $D_h$ is the hydraulic diameter of the space between the walls;

Exhausted air heat transfer coefficient is different from the one of the dried exhausted air due to a correction factor $c_h$ which takes into account the latent heat. The correction factor is calculated with the next expression [9]:

$$c_h = \frac{h_{1i} - h_{1o}^*}{c_p\left(t_{1i} - t_{1o}\right)} \tag{4}$$

The value of $h_{1o}^*$ is found after an energy balance on the heat exchanger:

$$h^*_{1o} = h_{1i} - (h_{2o} - h_{2i}) \tag{5}$$

Finally, the expression used to calculate the exhausted air heat transfer coefficient is:

$$\alpha_{1c} = c_h \cdot \alpha_1 \tag{6}$$

The NTU depends on the minimum heat capacity coefficient. The next step is to settle whether the exhausted air or the fresh air is the minimum fluid. In our case the fluid with a smaller heat capacity coefficient is the hot fluid:

$$C_{\min} = \rho_1 \dot{V}_1 c_{p1} \qquad [W/K] \tag{7}$$

It is now possible to develop the expression for the efficiency of the heat exchanger:

$$\varepsilon = \exp\left[\frac{\exp\left(-NTU \cdot C^* \cdot n\right) - 1}{C^* \cdot n}\right] \tag{8}$$

Where: $C^* = \dfrac{C_{\min}}{C_{\max}}$ and $n = NTU^{-0.22}$.

Table 2 shows the results obtained after applying the NTU method. The efficiency of the MVHR unit which is also called theoretical thermal efficiency is about 0.64.

*Table 2*

**Properties of the two air flows at the inlet of the HRV unit**

| Property | Symbol | Value | UM |
|---|---|---|---|
| **Exhausted air** | | | |
| Temperature | $t_{1i}$ | 23.27 | $^oC$ |
| Relative humidity | $\varphi_{1i}$ | 50 | % |
| Air flow | $V_1$ | 82.3 | $m^3/h$ |
| Enthalpy | $h_{1i}$ | 41.1 | kJ/kg |
| Temperature | $t_{1o}$ | 18.4 | $^oC$ |
| **Fresh air** | | | |
| Temperature | $t_{2i}$ | 15.39 | $^oC$ |
| Relative humidity | $\varphi_{2i}$ | 40 | % |
| Enthalpy | $h_{2i}$ | 30.5 | kJ/kg |
| Air flow | $V_2$ | 82.3 | $m^3/h$ |
| Enthalpy | $h_{2i}$ | 30.5 | kJ/kg |
| Temperature | $t_{2,o}$ | 20.36 | $^oC$ |
| Efficiency | **0.64** | | |

## 4. Analysis of the experimental data

Experimental data of the heat recovery unit are analyzed within this study. Measurements were conducted in April during the heating season. The measuring system includes temperature sensors such as Pt 100. The sensors are placed at every inlet and outlet of the MVHR. Hot wire flow meters are used to find out the two air flows. The flow meters type is KIMO, CTV 210-HN 300 and they work in the field 0-1m/s and 0-30m/s. They have an accuracy of±3% and a time base of 1.6s. All the sensors are connected to the KEITHLEY acquisition unit.

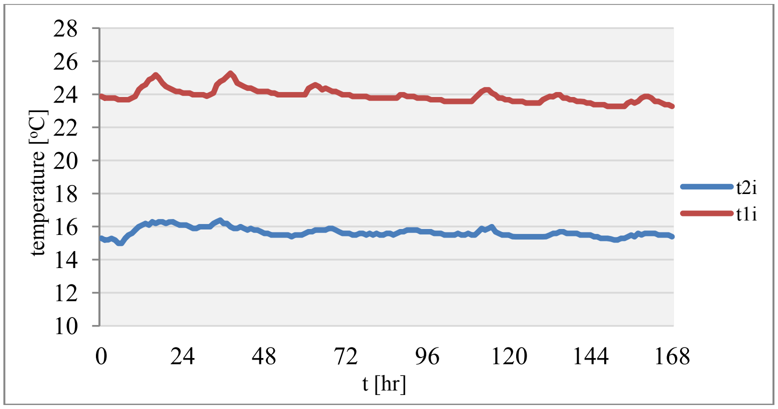


Fig. 5. The evolution of the air streams at the inlet of the MVHR

As it can be seen from fig. 5, the temperature of the two air flows at the inlet of the MVHR unit are kept relative constant during the week. The house is used only as a laboratory and there are no heat gains inside. Even though there are days when the outside temperature has a high variation of more than 15°C, due to the earth to air heat exchanger the fresh air temperature is kept around 15°C all the time during the week.

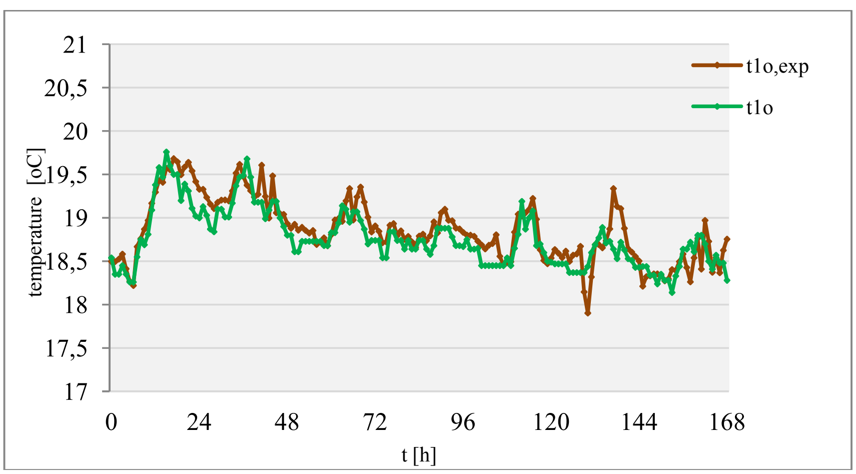


Fig. 6. Exhausted air temperature at the outlet of the MVHR

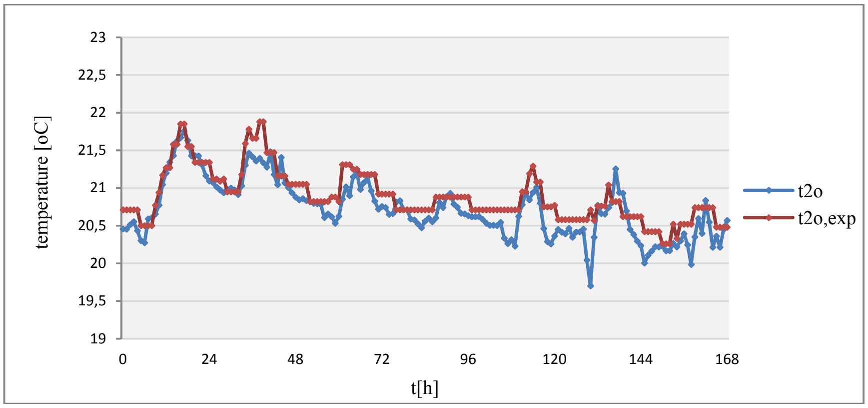


Fig. 7.Fresh air temperature at the outlet of the MVHR

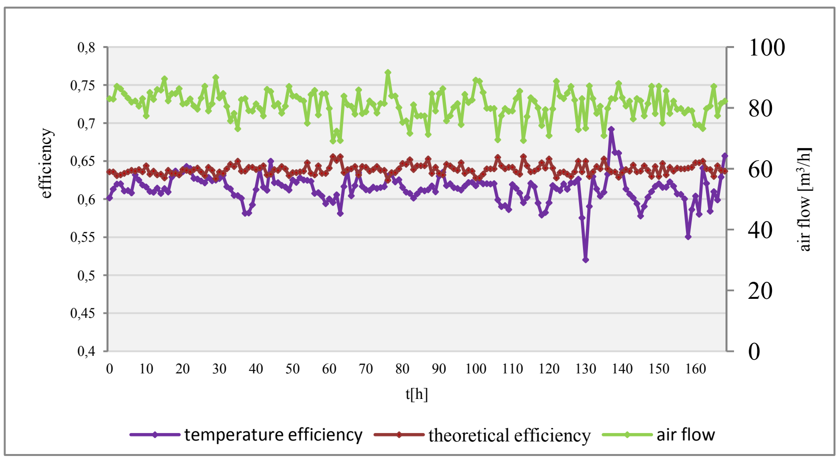


Fig. 8. Comparison between theoretical efficiency and experimental efficiency

According to the diagrams from fig. 6 and fig.7, there is only small difference between calculated values and those obtained after monitoring the system.

The thermal performance of the heat exchanger can be also evaluated with another parameter such as the temperature transfer efficiency. The definition equation is [10]:

$$\eta = \frac{t_{2o} - t_{2i}}{t_{1i} - t_{2i}} \tag{8}$$

The diagram from fig. 8, shows the difference between the theoretical efficiency calculated with the proposed algorithm and the temperature transfer efficiency calculated with the equation (8). The theoretical efficiency depends not only on temperature but also on the flow rates. Even if the flow rates should be constant they have a slow variation that produces changes on the efficiency.

## 5. Conclusions

The paper emphasizes the contributions of the MVHR unit to the heating process of the fresh air needed to ventilate the house and a method applied to calculate the efficiency. The comparison made between the theoretical and measured efficiency showed that the values of the efficiency calculated by NTU method are close to the temperature efficiency. The study showed that both parameters depend on the flow rates. When the air flow is increased they both decrease.

The experimental data correspond to a Spring day when the difference between the temperature of the ground and outside temperature are not so higher like in the winter. This fact makes the EAHX less important than the HRV unit. The most part of the thermal energy of the fresh ventilation air comes from the exhausted air.

## Acknowledgement

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