Power saving of an Energy Recovery Ventilator system in Atlantic Canada

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Abstract—**Over the recent years, the use of energy recovery ventilator (ERV) system has become a main international trend, encouraged by its high efficiency in maintaining a healthy indoor air quality (IAQ) and in saving power consumption in industrial, commercial and residential buildings.**

In this paper, an investigation of an air-to-air exchanger with an ERV core is presented in order to evaluate its energy saving performance in heating mode. This study has been carried out for a sample house based on a real home located in New Brunswick, Canada. Two scenarios with extreme climatic condition are described and discussed. Significant power saving was demonstrated and considerable amount of heat is recovered using an ERV system.

Keywords— **Energy recovery ventilator, sensible heat, energy saving, latent heat, mechanical ventilation systems, indoor air quality.**

I. INTRODUCTION

In the last few years, improving the indoor air quality (IAQ), which is vital for human health, has emerged as a tremendous concern worldwide [1-2]. According to U.S. Environmental Protection Agency [3] and Health Canada [4], poor IAQ was ranked as one of the most reasons for higher rates of infections, epidemic respiratory diseases, and so on.

Air exchange and ventilation are, undoubtedly, the most effective solutions to maintain an acceptable IAQ and to ensure comfortable and healthy occupied spaces by diluting airborne contaminants [5-7].

A closer glance at ventilation systems reveals that their pivotal role is to remove stale air from dwellings and supply fresh one [8]. However, in cold weather regions or in humid and hot climates, energy losses by ventilation systems without heat recovery are important [6-7].

Furthermore, energy consumption by the Heating, Ventilation and Air Conditioning (HVAC) sector has reached about 40% of the global energy consumption, all over the world [7], [9].

Canada is not an exception. Indeed, HVAC of buildings and houses accounts more than 22% of this country overall energy use and approximately 21% of its total greenhouse gases (GHG) emissions [10]. With the substantial need of comfort and the requirement of 100% fresh air ventilation, these ratios could be even higher [7].

Therefore, colossal efforts have been recently put on tackling this issue and finding adequate solutions in order to dwindle the amount of energy used by HVAC systems [11-13]. In this respect, advanced efficient techniques have been brought to light and applied in the houses and buildings.

As reported in the literature, air-to-air heat exchanger is one of the most promising technologies which is used so as to simultaneously provide a healthy indoor environment, thermal comfort and reduced energy demand [5-14].

Indeed, air-to-air heat exchangers are ranked into heat recovery ventilators (HRV) and energy recovery ventilators (ERV). These ventilation systems employ a counter-current, cross-flow or co-current flow heat exchanger between the inlet and outlet air streams [14]. HRVs are used to recover sensible heat and transfer it from one airflow to another, while ERVs, apart from the sensible heat, can transfer latent heat [15].

Due to their capability in recovering heat or/and moisture, these systems are widely used to reduce the cooling or heating requirements and subsequently to provide significant energy saving in houses and buildings [16].

As stated by Fehrm et al [17], the use of heat recovery system can lead to energy consumption reduction, roughly up to 20%. In [18], authors shed light on the efficiency of energy recovery systems that provide a considerable energy saving, up to 23%. Other researchers [16], [18-20] put great emphasis, in their works, on proving the high efficiency of these ventilation systems in providing comfortable and healthy indoor environment, while saving energy with ratios as much as 60%.

Even though the numerous numbers of studies that addressed the important role of air-to-air heat exchangers in reducing houses and buildings energy consumption, this topic still represents a big engineering and research challenge.

In this context, the ultimate purpose of this study is to assess the impacts of an air-to-air exchanger with ERV core on energy consumption. The thermal and energy consumption behaviors of the house, with and without the presence of an ERV system, are investigated in this work.

The remainder of this paper is presented in three sections. Section II described the ERV system and its modeling. In section III, the house ventilation system and its Simulink model

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are presented. Moreover, all simulation results are rigorously discussed, for each scenario.
At the end, Section IV summarized the major conclusions of this study.

II. ERV SYSTEM MODELING

To investigate the effects of ERV systems on the energy consumption behavior, an accurate and appropriate modeling of the ERV system is necessary.

In fact, there are several kinds of air-to-air heat exchanger which are presented in the literature: rotary wheels [13], [21], heat pipes [22], run around systems [23], plate type heat exchangers [5-10], [14], etc. Among these various technologies, plate type heat exchangers draw more attentions because of their noticeable benefits. These systems are simple and compact, have a high efficiency, have no moving parts and have no cross-over issues [20]. Thus, in this study, the authors have been interested by this kind of air-to-air heat exchanger.

Simply put, a plate type heat exchanger is a compact system that consists of alternating plates brazed together and a stack of fins in order to form flow channels. Without mixing physically, two different airflows pass each other. However, the heat or/and moisture is drawn from one air stream into the other.
Fig. 1 depicts the structure of the fixed plate energy recovery exchanger used in this study.

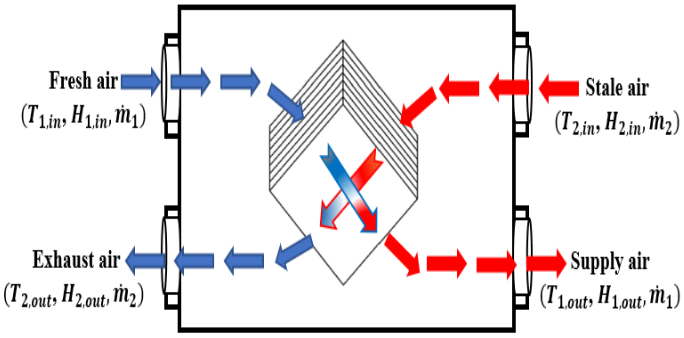

Fig. 1 Fixed plate energy recovery exchanger

As mentioned above, the ERV core exchanges both latent and sensible heat. The thermal effectiveness of the ERV core can be introduced in two ways: the sensible and latent effectiveness. According to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) [24], these parameters are respectively given as:

$$\varepsilon_S = \frac{\dot{Q}_S}{\dot{Q}_{S\_max}} \qquad (1)$$

$$\varepsilon_L = \frac{\dot{Q}_L}{\dot{Q}_{L\_max}} \qquad (2)$$

Where: $\dot{Q}_S$, $\dot{Q}_L$ are the actual sensible and latent heat transfer that can be, respectively, expressed as:

$$\dot{Q}_s = \dot{m}_1 c_p |T_{1,out} - T_{1,in}| = \dot{m}_2 c_p |T_{2,in} - T_{2,out}| \qquad (3)$$

$$\dot{Q}_L = \dot{m}_1 h_{fg} |H_{1,out} - H_{1,in}| = \dot{m}_2 h_{fg} |H_{2,in} - H_{2,out}| \qquad (4)$$

Where: $T_{1,in}, T_{1,out}$ are respectively the inlet and outlet temperatures of fresh air; $T_{2,in}$ $T_{2,out}$ are the inlet and outlet temperatures of stale air; $H_{1,in}, H_{1,out}$ represent respectively the inlet and outlet absolute humidity ratios of fresh air; $H_{2,in}, H_{2,out}$ are respectively the inlet and outlet absolute humidity ratios of stale air. $\dot{m}_1$, $\dot{m}_2$ are the primary and secondary air mass flow rates; c_p is the specific heat capacity of air and h_{fg} represents the specific latent heat of vaporization of water.

Moreover, the possibly maximum sensible heat transfer is defined by Eq (5) and Eq (6) represents the possibly maximum latent heat transfer [24-26], [16]:

$$\dot{Q}_{s\_max} = c_p \dot{m}_{min} |T_{2,in} - T_{1,out}| \qquad (5)$$

$$\dot{Q}_{L\_max} = h_{fg} \dot{m}_{min} |H_{2,in} - H_{1,out}| \qquad (6)$$

Where: $\dot{m}_{min}$ is the lower mass flow rates of both streams:

$$\dot{m}_{min} = min\{\dot{m}_1, \dot{m}_2\} \qquad (7)$$

Substituting Eq (3) and Eq (5) into Eq (1), the sensible effectiveness can be written as:

$$\varepsilon_S = \frac{\dot{m}_1 c_p (T_{1,in} - T_{1,out})}{c_p \dot{m}_{min} (T_{1,in} - T_{2,in})} \qquad (8)$$

Similarly, substituting Eq (4) and Eq (6) into Eq (2), the sensible effectiveness can be represented as follows:

$$\varepsilon_L = \frac{\dot{m}_1 c_p (H_{1,in} - H_{1,out})}{h_{fg} \dot{m}_{min} (H_{1,in} - H_{2,in})} \qquad (9)$$

For balanced air streams, the sensible and latent efficiency are respectively expressed by Eq (10) and Eq (11) [24-26], [16]:

$$\varepsilon_S = \frac{T_{1,in} - T_{1,out}}{T_{1,in} - T_{2,in}} \qquad (10)$$

$$\varepsilon_L = \frac{H_{1,in} - H_{1,out}}{H_{1,in} - H_{2,in}} \qquad (11)$$

III. CASE STUDY AND RESULTS

All simulations are carried out using MATLAB/Simulink environment version R2018b.

A. House ventilation system description

In this study, a typical home from New Brunswick, as shown in Fig. 2, is used in the simulations.

This two-storey home has a living room and a kitchen, which are considered as one space, two bedrooms, a bathroom, a garage and a basement that includes a third room. Each space was modeled as a thermal zone that was supposed to have a homogeneous temperature.

The air temperature in the three spaces are respectively assumed to be 15 °C, 20 °C and 18°C.

Fig. 2 House plan based on planned5d template (https://planner5d.com)

In general, the incoming fresh air from outside passes through the air-to-air exchanger and then delivered to each room. The stale air gathered from the home is expelled outside (Fig. 3). In this study, only the heating mode was considered. Consequently, passing through the ERV unit, the sensible and latent energy are transferred from the warm air (i.e. the exhaust air) to the cold one (i.e. the fresh air).

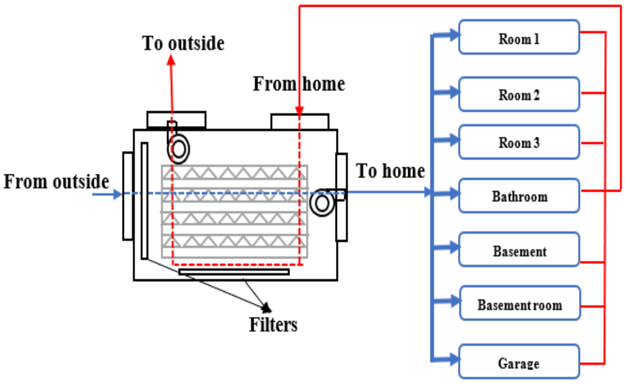

Fig. 3 General scheme of mechanical ventilation with an ERV

To assess the impacts of the air-to-air exchanger on the home energy consumption, two scenarios are taken into consideration:

- Scenario 1: The house energy consumption behavior without the presence of an ERV exchanger
- Scenario 2: With an ERV exchanger

In the following section, space 2 (living room and kitchen), which is assumed to be the most occupied space in a day, is selected for the assessment.

The other rooms, garage and basement are indirectly ventilated and air-heated through the mass and heat transfer in between. These heat exchanges are presented in Fig. 4. The impact of the fresh air supplied to this room, the thermal and energy consumption behaviours are analysed.

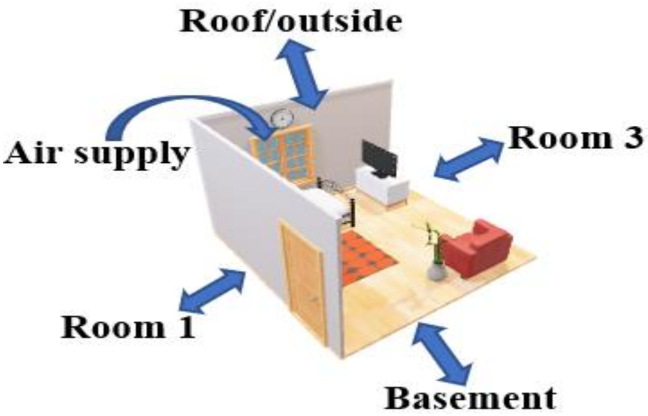

Fig. 4 Present study’s methodology

The global model of this investigation is implemented in Matlab/Simulink using a set of block diagrams representing the previous mathematical equations. The Simulink model of room 2 is illustrated in Fig.5.

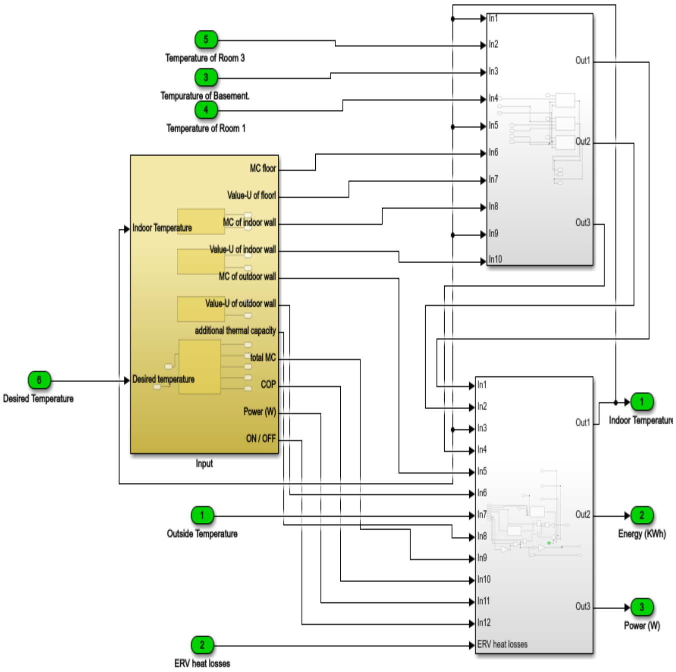

Fig. 5 Simulink model of room 2

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So as to represent the heat exchange between the living room and the first bedroom, the Simulink model used in this study is depicted in Fig.6.

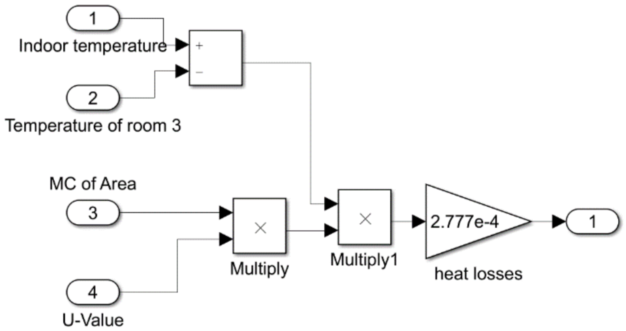

Fig. 6 Simulink model of heat exchange between the living space and the first bedroom

Fig.7 highlights the Simulink model of the heat exchange between the living space and the second bedroom.

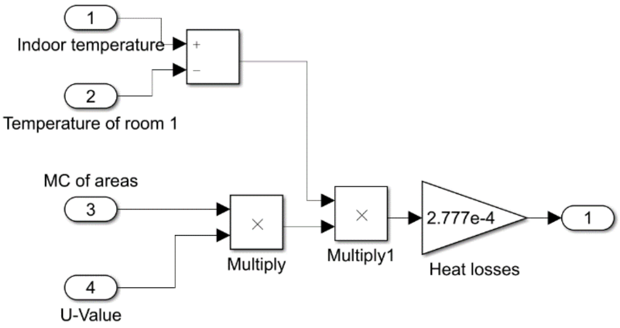

Fig. 7 Simulink model of heat exchange between the room 2 and room 1

For its part, the heat exchange between the living room and basement is expressed relying on the Simulink model illustrated in Fig.8.

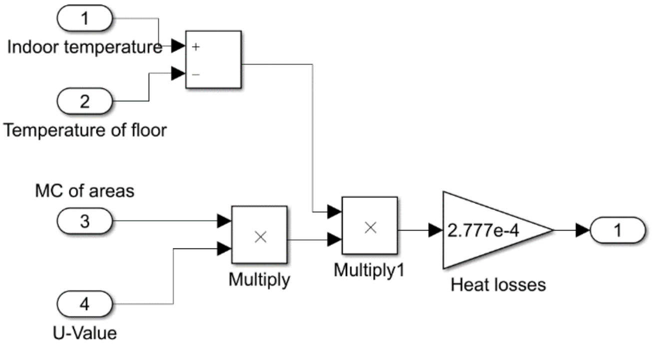

Fig. 8 Simulink model of heat exchange between the room 2 and basement

Real climate data of the region of Moncton, New Brunswick are received from the Meteorological Service, Environment and Climate Change Canada [27] and used to perform the simulations.

The profiles of outdoor air temperatures and relative humidity ratios of January 2018 are illustrated in Fig.9.

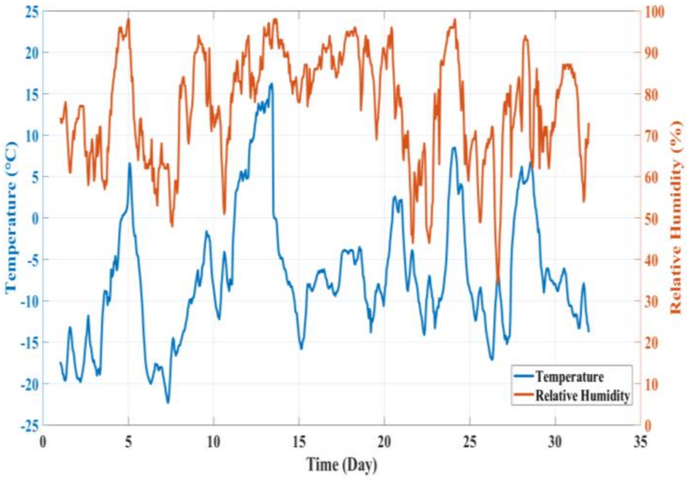

Fig. 9 Real data of outdoor air temperatures and relative humidity ratios in Moncton region, January 2018 [27]

B. *Experimental results*

First of all, the fresh air supply was accomplished using a regular air-to-air exchanger without an ERV.

The assessment of the thermal and energy consumption behaviors is considered in this study. The simulations are conducted based on the monthly climate data. However, only results for one day are presented in this paper.

Fig. 10 represents the profiles of thermal behaviour of the room. As shown in this figure, the heat is mostly turned on (room temperature is raised) until the temperature reaches the current room temperature. The heat is turned off just once for a short time during the same period (temperature is decreased).

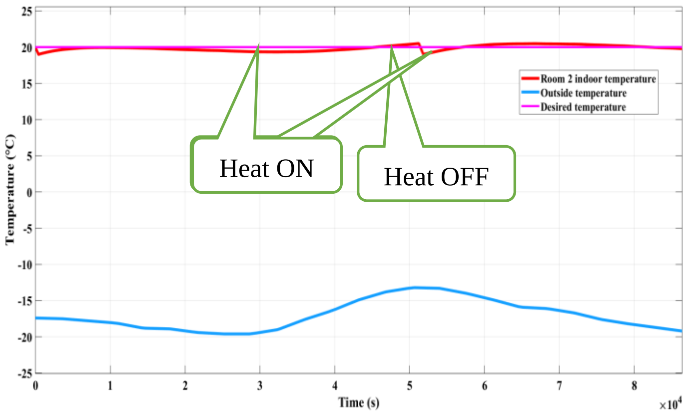

Fig. 10 Thermal behaviour of room 2

In Fig.11, the energy consumption profiles for the room and the house are presented. As can be seen, without an ERV, the energy consumption is evaluated to **35.49 kWh** and the total house energy use reaches, for its part, **81.44 kWh**. According to NB Power Business Rates (effective August 1, 2018), and based on the first 5000 kilowatt hours price, the amount of the power consumption related to the air exchanging is more than 138$ monthly. The total power consumption in the home is close to 318$ monthly.

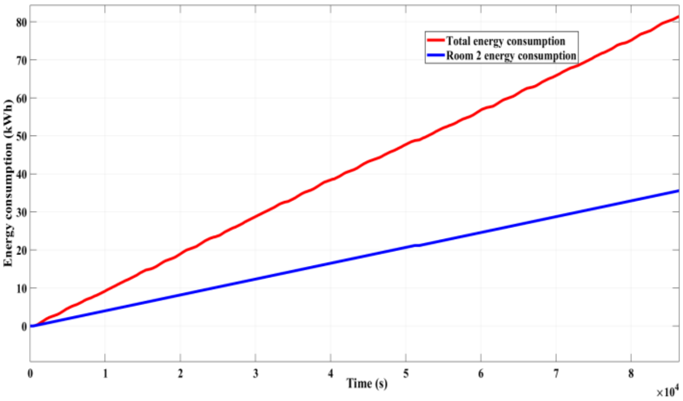

Fig. 11 Profiles of energy consumption of room 2 and total energy use

To evaluate the impacts of an ERV based air-to-air system on the home energy consumption, a **50%** efficiency unit is used. The daily profiles of thermal behaviour and energy demand are respectively illustrated in Fig. 12 and Fig. 13. As depicted in Fig.12, the heat is turned off more often during the same period which implies an energy saving.

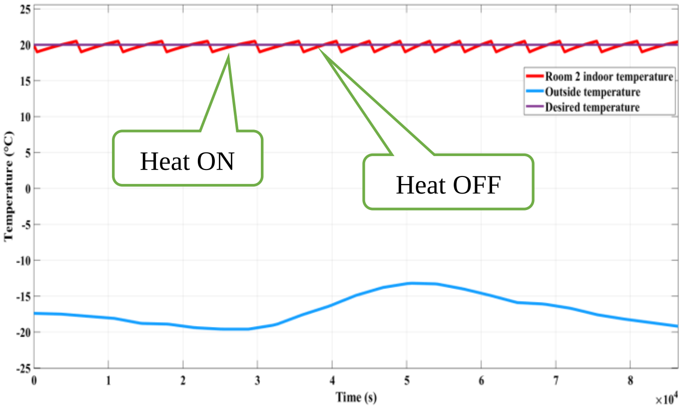

Fig. 12 Thermal behaviour of room 2 with the ERV

For the ERV scenario, it is noticed that the energy consumption in room 2 reduced from **35.49 kWh** to **31.36 kWh**, while the total energy consumption does not exceed **74.73 kWh**.

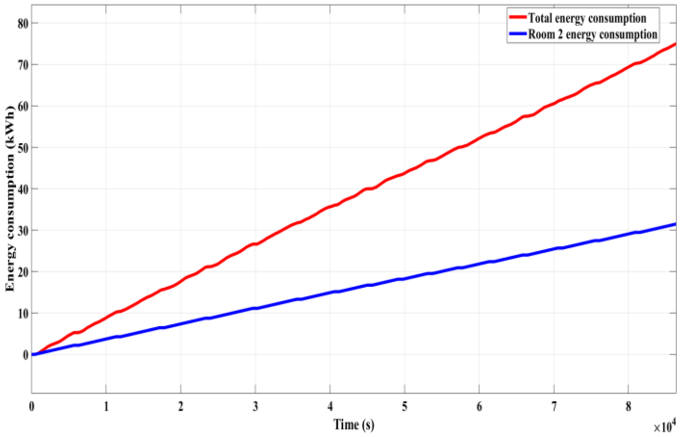

Fig. 13 Profiles of energy consumption of room 2 and total energy use, with the presence of ERV

Fig.14 shows the global house energy consumption for the two scenarios. It is obviously clear that the overall energy use is dwindled from **81.44 kWh** to **74.73 kWh**. Consequently, a significant energy saving by **8%** was obtained in a very cold day with temperature between -20ºC and -14 ºC. The amount of saving is more than 25$ monthly.

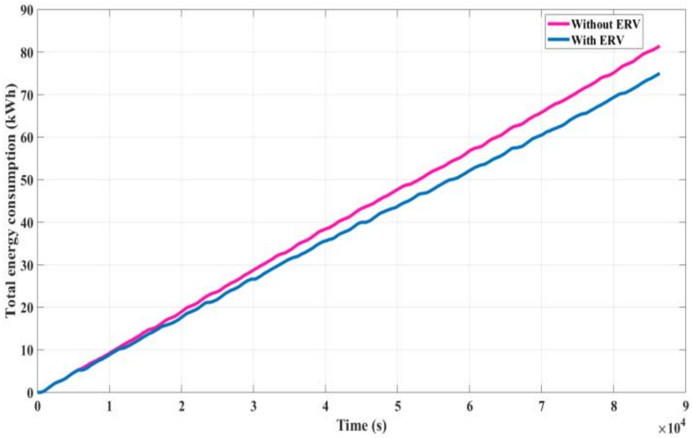

Fig. 14 Global energy consumption with and without the ERV

IV. CONCLUSION

Nowadays, air-to-air exchanger with an ERV core represents one of the promising mechanical ventilation technologies and is becoming substantially attractive to occupants in order to ensure a good and healthy IAQ. Due to their capability in recovering heat and moisture, these systems are widely used to reduce the cooling or heating requirements and subsequently to provide significant energy saving in houses and buildings. As demonstrated in this work, this kind of ventilation systems has an energy consumption impact. Two scenarios were investigated, with and without an ERV. All simulations are carried out using MATLAB/Simulink environment. To summarize, the obtained results showed clearly the efficiency of the test system on energy saving. A significant energy reduction by 8% in extremely operating condition was obtained.

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