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INFLUENCE OF HEAT RECOVERY MECHANICAL VENTILATION SYSTEM PARAMETERS ON BUILDING ENERGY CONSUMPTION – A CASE STUDY

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Abstract: Building energy consumption represents one of the significant challenges of modern energy policy, particularly in the European Union, where buildings account for a significant share of total energy consumption. Ventilation systems are an important factor in the energy balance of buildings, especially in buildings with highly airtight envelopes. With increasing energy efficiency requirements, the application of mechanical ventilation systems is becoming increasingly important for ensuring adequate indoor air quality and comfortable living conditions. By integrating heat recovery units, ventilation heat losses can be significantly reduced by using the heat from exhaust air to preheat fresh air. The aim of this paper is to analyze energy losses in mechanical ventilation systems with heat recovery and to assess the influence of individual system parameters on their energy performance.

Key words: Building, Ventilation System, Heat Recovery, energy losses, energy efficiency.

1 INTRODUCTION

In recent decades, increasing attention has been devoted to reducing energy consumption in buildings while maintaining adequate thermal comfort and indoor air quality. Buildings represent a significant share of total energy use, mainly due to heating, cooling, ventilation, and other building services. According to Eurostat, residential, commercial, and public buildings accounted for approximately 40% of total energy consumption in the European Union in 2024 [1]. Therefore, improving building energy efficiency has become an important aspect of energy conservation and sustainable development. The Energy Performance of Buildings Directive (EPBD)

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promotes measures for improving building energy performance, including efficient ventilation systems. In addition, Commission Regulation (EU) No. 1253/2014 establishes ecodesign requirements for ventilation units and defines minimum efficiency requirements for heat recovery systems [2].

Heating, ventilation, and air-conditioning (HVAC) systems play an essential role in providing comfortable and healthy indoor conditions by controlling temperature, humidity, and air quality. However, adequate ventilation can result in significant energy losses, particularly during periods with large differences between indoor and outdoor temperatures. Mechanical ventilation provides better control of the required airflow and indoor air quality, but conventional systems may significantly increase heating and cooling loads due to the continuous exhaust of conditioned indoor air.

Mechanical ventilation systems with heat recovery offer an effective solution for reducing these ventilation-related energy losses. They recover a part of the thermal energy from exhaust air and transfer it to the incoming outdoor air, thereby reducing the energy required for heating or cooling [3]. During the heating season, heat is transferred from warm exhaust air to cold outdoor air, while the reverse process can occur during cooling periods. This approach is particularly beneficial in well-insulated and airtight buildings, where controlled mechanical ventilation is essential for maintaining adequate indoor air quality. Heat recovery ventilation systems have been investigated extensively, with research focusing on heat exchanger configuration, materials, geometry, airflow rate, temperature difference, and humidity. System performance depends on both heat exchanger characteristics and operating conditions. In particular, airflow rate and the temperature difference between indoor and outdoor air significantly affect heat recovery efficiency [4].

An important challenge in ventilation design is achieving an appropriate balance between indoor air quality and energy consumption. Insufficient ventilation can deteriorate indoor air quality, whereas excessive ventilation increases heating and cooling demands. Furthermore, increasing airflow can increase fan energy consumption and affect heat recovery performance. Consequently, the selection of appropriate ventilation parameters is essential for achieving both adequate indoor conditions and low overall building energy consumption [4, 5].

Numerical building energy simulation provides an effective method for analyzing the interaction between ventilation system characteristics and overall building energy performance. EnergyPlus is widely used for detailed simulation of building energy consumption and HVAC systems [6, 7]. Such simulations enable the assessment of different ventilation configurations and operating parameters without the need for extensive experimental testing.

Therefore, the aim of this study is to investigate the influence of the parameters of a heat recovery mechanical ventilation system on building energy consumption. Particular attention is given to the effect of ventilation operating conditions on the heating and cooling energy requirements of the building. The results are intended to contribute to a better understanding of the role of heat recovery ventilation in improving building energy efficiency and to support the selection of appropriate system parameters.

2 MODEL OF THE ANALYZED BUILDING

Residential building, modeled in EnergyPlus software is shown in Figure 1. It is a family building, located in the city of Kragujevac (Serbia). The altitude of the city of Kragujevac is about 200 m, and it is located at 44°1N and 20°55E. The city has a

moderate continental climate with different seasons (summer, autumn, winter and spring).

The building has three floors and an area of 120 m^2. Each room represents one zone, so there are 6 conditioned zones in 3 levels and 5 non-conditioned zones (3 corridors, staircase and roof). On the ground floor there is a living room, a corridor, a laundry room and a staircase, which, as a zone, extends across all three levels of the house vertically. The second level contains of hall, a bedroom and a kitchen, and the third level cotains a bathroom, hall and one more bedroom.

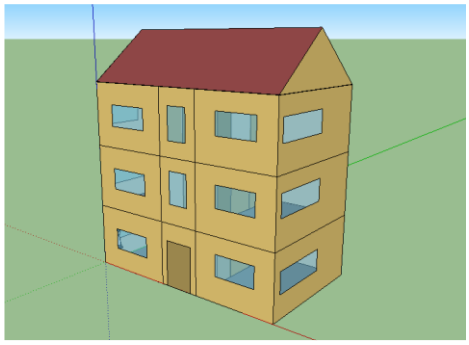
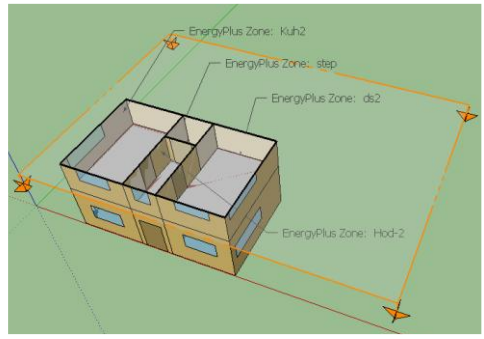
a)  b) 

Figure 1. *Modelled building: a) Schematics b) Cross-section of the second floor*

The envelope of the building is made of hollow brick, polystyrene thermal insulation layer and lime mortar. In this investigation, the polystyrene thickness was 0.15m, with thermal conductivity is 0.037 W/mK the [8]. The windows are double-glazed with air gap of 13 mm. Air temperatures in the heated zones are set to 22^0C from 07:00-09:00 and from 16:00-21:00, and to 18^0C from 09:00-16:00. The simulated building has a district heating system.

Heat recovery mechanical ventilation system (HRV) is also implemeted in analyzed model. This system in our area are primarily useful in the winter period. His function is the using of the waste heat of the indoor air to preheat the cold fresh air that is introduced inside the building. HRV system use a counter-current heat exchanger, which consists of two ventilation channels placed next to each other. One carries cool fresh air, the other carries moist, stale but warm air. These two air currents move in opposite directions through the heat exchanger, which allows the outgoing air to transfer most of its heat to the incoming air current without mixing them with each other. Duct fans can be activated automatically or manually, depending on the new temperature and air humidity. The incoming air stream can also have a by-pass line. In certain periods of the year, it is thermally more efficient for the incoming air stream to bypass the recuperator - heat exchanger.

EnergyPlus software includes the airflow network model, which simulates the operation of an air distribution system. This comprehensive model is utilized to simulate thermal conduction and air leakage losses in constant volume air distribution systems, applicable to residential or light commercial buildings. The airflow network model can also simulate the heat and moisture gains or losses from the system's ductwork.

Figure 2 shows a schematics of the heat recovery mechanical ventilation system with air-to-air heat exchanger (HE), the outdoor air mixer (OA MIXER) and the outdoor air splitte (OA SPLITTER) [9]. The heat exchanger (HE) is a key element of a

ventilation system, enabling heat transfer between incoming outdoor air and outgoing exhaust air. Its performance is defined by effectiveness, specified in the input file.

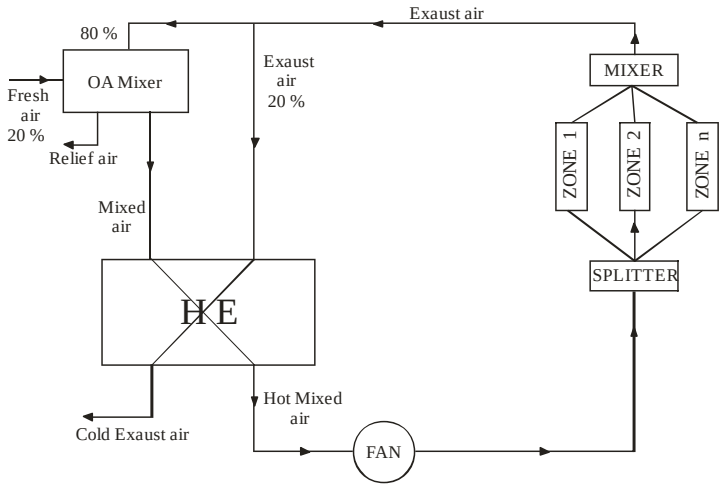


Figure 2. *EnergyPlus model for Heeat Recovery Ventilation System*

The Outdoor Air Mixer (OA Mixer) regulates the distribution of return air into recirculated and relief streams. It then combines the recirculated air with outdoor air to obtain a mixed air stream for further treatment and distribution.

An Air Loop is the central air-handling part of an HVAC system, responsible for circulating and conditioning air. It consists of two main sections: the primary air system and the zone equipment. The primary system includes fans, heating and cooling coils, outdoor air control components, and associated equipment. Zone equipment delivers conditioned air to individual spaces through devices such as air terminals, fan-coil units, baseboards, and window air conditioners.

A Splitter separates one incoming air stream into two or more outgoing streams while maintaining the same thermodynamic properties, including temperature, pressure, enthalpy, and humidity ratio. The total incoming mass flow rate equals the sum of the outgoing flow rates.

The sensible and latent air-to-air heat exchanger is typically used for exhaust or relief air heat recovery in EnergyPlus simulations. The input requires no geometric data, but this data can be changed by software user. Performance is defined by specifying sensible and/or latent effectiveness (75% and 100%) of the nominal (rated) supply air flow rate in both heating and cooling conditions (Table 1).

Table 1. *Operating Conditions for Defining Heat Exchanger Performance*

Parameter	*Heating*	*Cooling*
Entering supply air temperature:		
Dry-bulb	*1.7°C*	*35°C*
Wet-bulb	*0.6°C*	*26°C*
Entering exhaust air temperature:		
Dry-bulb	*21°C (70°F)*	*24°C (75°F)*
Wet-bulb	*14°C (58°F)*	*17°C (63°F)*

In this study, the simultaneous operation of the district heating system and the heat recovery mechanical ventilation system was simulated. The operation of the

systems were simulated during the heating season, for the month of January, every day from 6 a.m. to 10 p.m. The simulations were performed with the air flow of 1.4 m^3/s, and fan pressure drop of 100 Pa. For conditioned zones, the number of air changes was between 1 and 1.6, which corresponds to ASHRAE recommendations. The heat exchanger in an HRV mechanical ventilation system is defined by two parameters - the hydraulic diameter (Rh, m) and the pipe length (L, m), so this parameters were varied to analyze their impact on the total building energy consumption (Etot, GJ) and heating energy consumption (Edh, GJ).

3 RESULTS AND DISCUSSION

3.1 Different values of HR hydraulic diameter

The analysis initially assessed the impact of the heat exchanger's hydraulic diameter on both, the energy required for space heating and the buildings total energy consumption. To ensure consistent simulation conditions, the length of the pipes through which the supply and exhaust air streams flow was L=1 m. Table 2 summarizes the obtained simulation results.

Table 2. *Heating energy consumption and total building energy consumption for different hydraulic diameter of heat exchanger ih HRV system*

Rh (m)	*0.03*	*0.05*	*0.075*	*0.1*	*0.15*	*0.2*	*0.25*	*0.3*	*0.5*
Edh (GJ)	*16.05*	*15.47*	*14.82*	*14.54*	*14.42*	*14.41*	*14.4*	*14.4*	*14.4*
Etot (GJ)	*16.69*	*16.09*	*15.42*	*15.12*	*15*	*14.99*	*14.98*	*14.98*	*14.98*

Figure 3 gives the graphical presentation of the obtained results from Table 2.

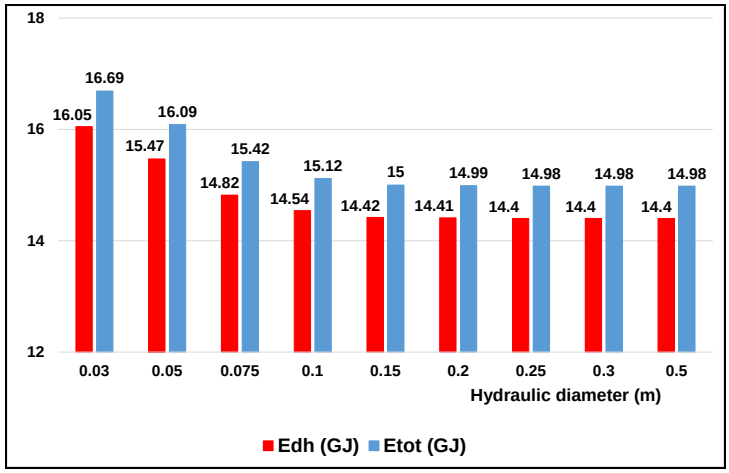


Figure 3. *Heating energy consumption and total building energy consumption for different hydraulic diameter of heat exchanger in HRV system*

Based on the obtained results, it can be concluded that with the increase in the value of the hydraulic diameter Rh of the heat exchanger in the heat recovery mechanical ventilation system, there is a decrease in the energy required for district heating of the building (Edh) and the total energy consumed by the building (Etot), during the simulation month of January. It can be concluded that increasing the value

of the hydraulic diameter above 0.2 m has no effect because the heating energy consumption, as well as the building total energy consumption remains unchanged.

With the increase of the hydraulic diameter Rh of the heat exchanger, the effective heat exchange surface increases, which means that a larger amount of energy is transferred from the warm exhaust air to the fresh supply air. As the same amount of air flows through the system at a reduced speed, it moves more slowly and heats up more, thus reducing the required amount of energy consumed by the district heating system. With the reduction of heating energy, the total energy consumption of the building is automatically reduced.

3.2 Different values of HR pipe length

Another simulations were carried out with the aim to analyze the impact of different values pipe length form air supply/exhaust on heating energy consumption and total building energy consumptio. In all simulations, the hydraulic diameter was assumed to be Rh = 0.05 m. Other parameters remained unchanged compared to the previous simulations. The data obtained are presented in Table 3.

Table 3. *Heating energy consumption and total building energy consumption for different pipe length for air supply in HRV system*

L (m)	0.1	0.3	0.5	0.75	1	3	5	10	15
Edh (GJ)	16.11	16.08	16.02	15.89	15.47	15.38	15.25	15.08	14.76
Etot (GJ)	16.75	16.72	16.66	16.53	16.09	16	15.87	15.69	15.35

Figure 3 shows the graphical presentation of the obtained results from Table 3.

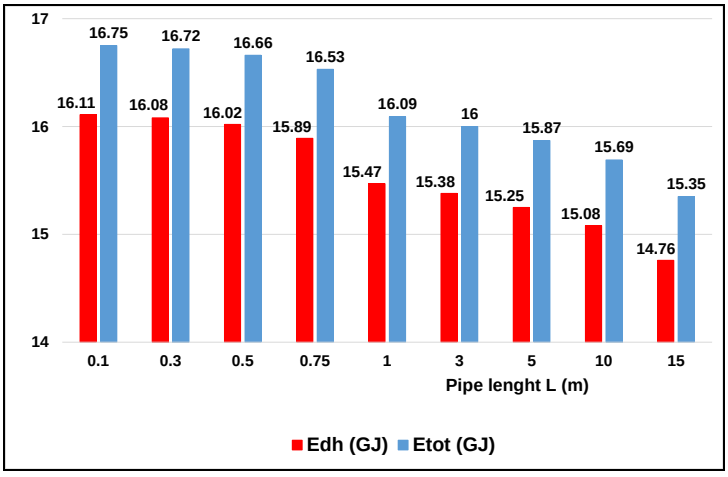


Figure 4. *Heating energy consumption and total building energy consumption for different pipe length for air supply in HRV system*

When pipe length L of the air supply in the HRV system increases, there is also an decrease in the energy required for district heating, as well as the total energy consumed by the building, during the simulation month of January.

By analyzing the obtained data and diagrams, optimal values of the heat exchanger's parameters can be chosen based on the review of the literature and on the analysis of the existing devices for using waste heat that are currently on the market, which are used in smaller family buildings. Since the available suitable devices

have a pipe diameter for air supply in the range of 0.15-0.2 m, and a pipe length in the range of 0.5-1 m, for further analysis of the entire model, a heat exchanger with the following characteristics has choosen: Rh =0.2 m and L=1 m.

3.3 Indoor air quality

For the observed configuration of the HRV mechanical ventilation system with the optimal characteristics of the HE, the following text presents some results that can be obtained by using EnergyPlus when simulating the operation of this system.

Figure 5 shows the amount of sensible heat exchanged in the heat exchanger during the simulation month of January. It can be concluded that the greatest sensible heat is exchanged during the day, when the GVK system is working. The need to introduce fresh air into the interior of the house is greater during the day than at night.

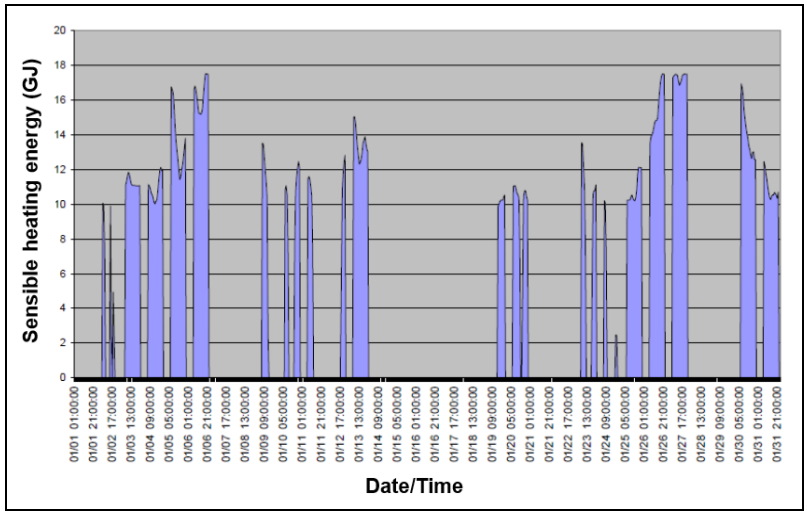


Figure 5. *Exchanged snsible heat during January*

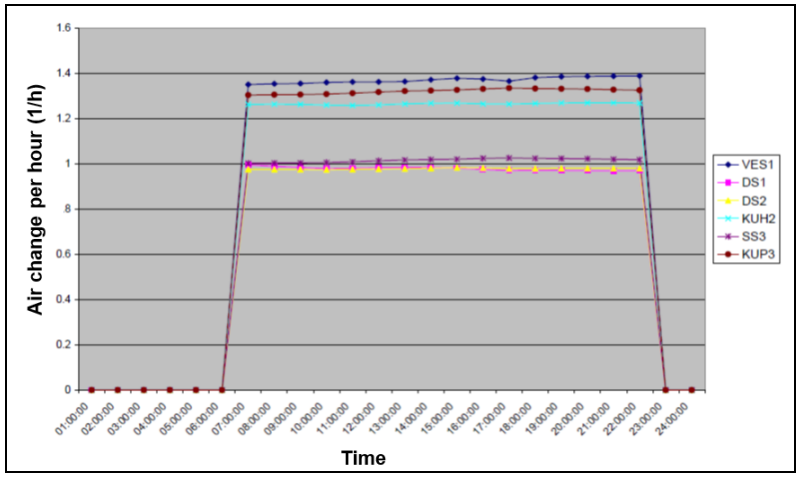


Figure 6. *Number of air changes per hour in conditioned zones, for January 5th*

Figure 6 shows the number of air changes per hour, calculated using EnergyPlus for January 5th. Values are presented for each conditioned room in the building. The obtained results coincide with the recommendations of the ASHRAE standard for the required number of air changes in the rooms.

CONCLUSION

In modern, energy efficiency buildings, ventilation system is necessary to ensure a comfortable and healthy interior. The right choice of ventilation system have to balance cost, maintenance and building energy consumption. This study shows the modeling of the HRV mechanical ventilation system in the EnergyPlus software and the effect of different heat exchanger's parameters on the heating energy needs and on the total building energy consumption. The use of an optimized HRV system reduces the energy required for building heating, and thus the total energy consumption, and, at the end the costs.

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