MODELLING OF HYBRID VENTILATION SYSTEM IN BUILDINGS USING ENERGYPLUS SOFTWARE

Danijela Nikolic[1], Milorad Bojic[2], Jasmina Skerlic[3], Jasna Radulovic[4], Dragan Taranovic[5]

Summary: *In the modern world today, the significant part of the total energy consumption is related to the building, so research and development of methods for improving energy efficiency in buildings are very important. A significant part of energy consumption in buildings relates to building ventilation. A hybrid ventilation system employs both, the natural and mechanical ventilation, at different times of the day. High energy savings can be achieved with heat recovery mechanical ventilation system, by using the special type of heat exchangers (HEs) - air-to-air heat exchangers. This paper presents a method of modelling the hybrid ventilation system in buildings by using EnergyPlus software. One illustrative example is provided.*
Keywords: *mechanical ventilation, natural ventilation, buildings, EnergyPlus software*

1. INTRODUCTION

Heating, ventilating and air conditioning systems (HVAC) are essential for the maintenance of a comfortable and healthy indoor environment for building occupants. In developed countries the HVAC systems consume around a third of the total energy consumption of the whole society [1]. On the other hand, energy saving in buildings is being strictly regulated by official requirements and local authorities. In a modern building, the ventilation losses may become more than 50% of total thermal losses [2]. Taking into account the above facts, the improvement of the efficiency in buildings ventilating systems to reduce their environmental impact constitutes a key issue. The purpose of ventilation is to provide acceptable indoor quality and thermal comfort.

Hybrid ventilation system provides a comfortable internal environment using both natural ventilation and mechanical ventilation system, but using different features of these systems at different times of the day, or in different seasons. A hybrid system has an intelligent control system that can switch automatically between natural and mechanical modes in order to minimize energy consumption [3].

[1] Assistant, Danijela Nikolić, Kragujevac, Faculty of Engineering, (danijelan@kg.ac.rs)
[2] Full professor, Milorad Bojic, Kragujevac, Faculty of Engineering, (milorad.bojic@gmail.com)
[3] Researcher, Jasmina Skerlic, Kragujevac, Faculty of Engineering, (jskerlic@gmail.com)
[4] Full professor, Jasna Radulovic, Kragujevac, Faculty of Engineering, (jasna@kg.ac.rs)
[5] Assistant, Dragan Taranovic, Kragujevac, Faculty of Engineering, (tara@kg.ac.rs)

Natural ventilation is the process of supplying and removing air through an indoor space by natural means, without the use of a fan or other mechanical system. There are two types of natural ventilation occurring in buildings: stack ventilation and wind driven ventilation. Wind driven ventilation design in buildings provides ventilation to occupants using the least amount of resources. Stack effect is temperature induced. When there is a temperature difference between two adjoining volumes of air the warmer air will have lower density and be more buoyant thus will rise above the cold air creating an upward air stream [4]. Most often natural ventilation is assured through windows. The natural ventilation is the simplest and cheapest option to cool the building, but it is also the most difficult to control [5].

Mechanical ventilation with heat recovery is often considered as one of the key elements of a low energy residential building in cold winter regions [6]. The air-to-air heat recovery heat exchangers (HR HE) commonly used in these HVAC systems. In air-to-air plate of heat exchangers the exhaust air from the building passes through one side of the HE while the fresh air from outside the building flows in a cross or counter-current flow through the other side of the HE. On that way, the outdoor fresh air can be heated by exhaust, inside air heat.

In this paper, it is analyzed the hybrid ventilation system in building, with HR unit – flat plate HE in mechanical ventilation system.

2. SIMULATION SOFTWARE - ENERGYPLUS

In this study, the simulation software EnergyPlus (Version 7.0.0) was used. EnergyPlus is made available by the Lawrence Berkley Laboratory in USA [7]. Its development began in 1996 on the basis of two programs: DOE-2 and BLAST. The software serves to simulate building energy behaviour and use of renewable energy in buildings. The software has been tested using the IEA HVAC BESTEST E100-E200 tests [8].

3. MATHEMATICAL MODEL

A hybrid ventilation system in Energyplus has an intelligent control system AvailabilityManager:HybridVentilation which serves two purposes [9]: it prevents simultaneous natural ventilation and HVAC system operation, and it allows users to examine various strategies to maximize natural ventilation in order to reduce heating/cooling loads. This availability manager works with the AirflowNetwork model to provide controlled natural ventilation. The weather data are uses from EnergyPlus`s own data base with weather files. This files have hourly or sub-hourly data: dry-bulb temperature, dew-bulb temperature, relative humidity, barometric pressure, wind direction, wind speed, rain, snow etc.

3.1 EnergyPlus Model for natural ventilation

EnergyPlus contains two models for natural ventilation. The “Design Flow Rate” model is based on environmental conditions modifying a design flow rate. The “Wind and Stack with Open Area” model is based on equations defined in ASHRAE Handbook [7]. These two ventilation objects can be used alone or in combination to determine ventilation air.

3.2 EnergyPlus model for mechanical ventilation system with HR unit

A special part of EnergyPlus contains the Airflow network model, which may simulate the performance of an air distribution system, including supply and return leaks, and calculate multizone airflows driven by outdoor wind and forced air during HVAC system operation [10]. This model can simulate the heat and moisture gains or losses from the air distribution system itself (ductwork). Fig. 1 represents simplified schematics of the mechanical ventilation system with the HR unit - air-to-air heat exchanger (HE) and the outdoor air mixer (OA MIXER).

Heat Exchanger. This component models an energy transfer between the supply air stream and the exhaust air stream. The energy transfer is guided according to the effectiveness values that are specified by the user in the input data file. At this HEs, the exhaust air from the building passes through one side of the HE while the fresh air from outside the building flows in a cross or counter-current flow through the other side of the HE.

Outdoor Air Mixer. The outdoor air mixer is the most common component used in an outdoor air system. The outside air mixer splits the return air of primary air system into relief and re-circulated air streams. Then, it mixes the outside air stream with the re-circulated air stream to obtain the mixed air stream.

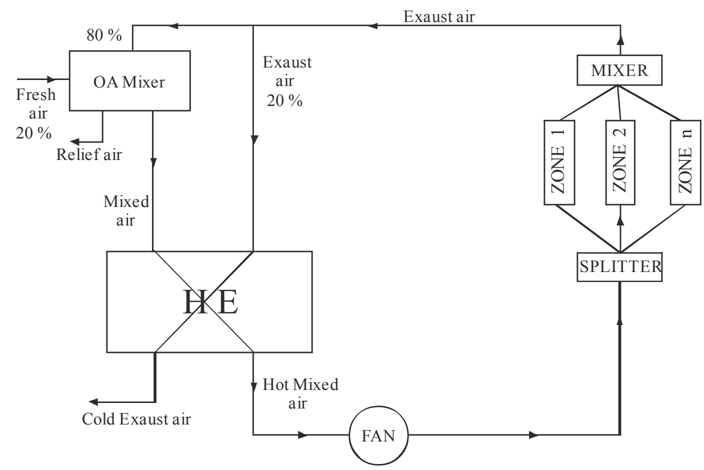

Fig. 1 *Simplified mechanical ventilation system with HR unit*

3.3 Characteristic values

The airflow network [7] model consists of three sequential steps: (1) pressure and airflow calculations, (2) node temperature and humidity calculations, and (3) sensible and latent load calculations. These equations will not be presented here.

Ventilation by Wind and Stack with Open Area. For this model, the ventilation air flow rate is a function of wind speed and thermal stack effect, along with the area of the opening being modeled. The equation used to calculate the ventilation rate driven by wind is:

$$Q_W = C_W A_{opening} F_{schedule} V$$

where: Q_w = Volumetric air flow rate driven by wind (m^3/s), C_w = Opening effectiveness (-), $A_{opening}$ = Opening area (m^2), $F_{schedule}$= Open area fraction (user-defined schedule value), V=local wind speed (m/s).
The equation used for calculating the ventilation rate due to stack effect is:

$$Q_S = C_D A_{opening} F_{schedule} \sqrt{2g\Delta H_{NPL}\left(\left|T_{zone} - T_{odb}\right| / T_{zone}\right)}$$

where: Q_S = Volumetric air flow rate due to stack effect (m^3/s), C_D = Discharge coefficient for opening (-), $A_{opening}$ = Opening area (m^2), $F_{schedule}$ = Open area fraction (user-defined schedule value), ΔH_{NPL}= Height from midpoint of lower opening to the neutral pressure level (m), T_{zone} = zone temperature (K), T_{odb} = local outdoor dry-bulb temperature (K).

The total ventilation rate calculated by this model is

$$V_{WindAndStock} = \sqrt{Q_S^2 + Q_W^2}$$

Sensible, total and latent HR rates.

This values can be obtained by using next equations:

$$Q_{sensible} = \left(\dot{m}_{C_p,Sup}\right)\cdot\left(T_{SupAirIn} - T_{SupAirOut}\right)$$

$$Q_{Total} = \dot{m}_{SupAir}\cdot\left(h_{SupAirIn} - h_{SupAirOut}\right)$$

where $Q_{sensible}$ =sensible HR rate (W), Q_{Total} =total HR rate (W), $\dot{m}_{C_p,Sup}$ =heat capacity rate of the supply air stream (W/K), $T_{SupAirIn}$ =supply air inlet temperature (°C), $T_{SupAirOutn}$ = supply air outlet temperature (°C), $\dot{m}_{SupAir}$ =mass flow rate of the supply air stream (kg/s), $h_{SupAirIn}$ =supply air inlet enthalpy (J/kg), $h_{SupAirOut}$ =enthalpy of the supply air leaving the HE (J/kg).

4. RESULT AND DISCUSSION

Mechanical ventilation with a HR unit is modelled by EnergyPlus software. The mechanical ventilation is used in a house shown in Fig. 2. The house consists of living room, two bedrooms, kitchen, bathroom and two anterooms.

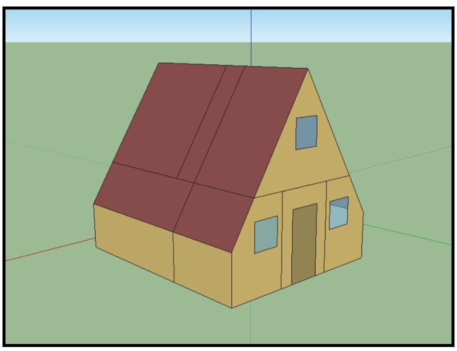

Fig. 2 *Modelled residential house*

Figure 3 represent the number of air change rate per hour by mechanical ventilation in each simulated zone calculated by EnergyPlus in 1st October as functions of time. The higher number of air change rate is for anteroom at the second floor, which has no windows.

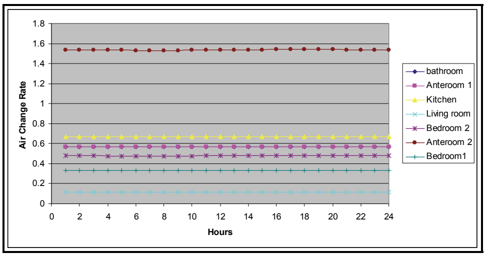

Fig. 3 *Number of air change per hour for mechanical ventilation for different zones calculated by EnergyPlus in 1st October as functions of time*

Figure 4 shows the sensible heating energy exchanged at HE during a simulation month October. The highest sensible heating energy is achieved during daily hours, when HVAC system operates. Then, the need to deliver fresh air inside the house is greater than that during night.

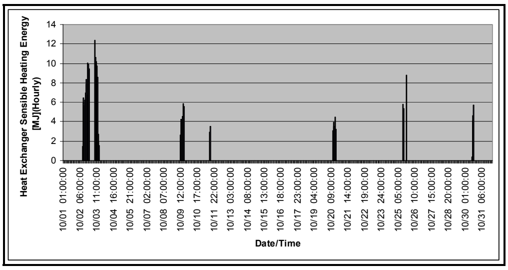

Fig. 4 *Sensible heating energy of HE during simulation month - October*

Figure 5 represent the natural ventilation sensible gain in the entire house, calculated by EnergyPlus during a simulation month – August. This value is calculated for each timestep when the outdoor dry-bulb temperature is higher than the zone temperature; otherwise, the sensible gain is set to 0. The higher value of sensible gain by natural ventilation is during the first days of August.

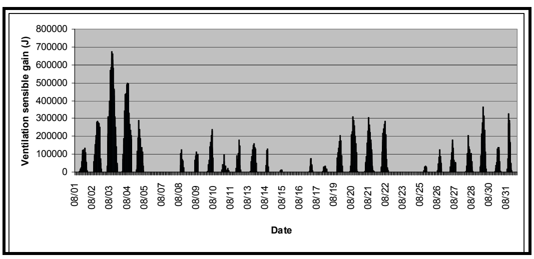

Fig. 5 *Hourly sensible heat gain due to natural ventilation, calculated during August*

5. CONCLUSION

This paper represents the modelling of hybrid ventilation in commercial and residential buildings by EnergyPlus software. This software has great capabilities for modelling buildings energy behaviour. Using EnergyPlus for modelling both, natural and mechanical ventilation, the energy used for ventilation and space heating can be reduced by varying a different factors. Using HR in a ventilation system, the energy used for ventilation and space heating can be reduced.

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