NUMERICAL SIMULATION OF INDOOR AIR QUALITY - MECHANICAL VENTILATION SYSTEM SUPPLIED PERIODICALLY VS. NATURAL VENTILATION.

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ABSTRACT

Building integrated renewable energy sources e.g. photovoltaic system is one of the promised solution for improving energy efficiency in building. However such kind of the system is restrained by irregular power supplied and necessity to convert current from direct to altering form. Therefore, very often the electrical energy generated by photovoltaic system cannot be effectively utilised to supply building devices, e.g. components of HVAC or lighting system. The other problem is energy storage during the day to be successfully used during the night.
The paper is devoted to analysed numerically overall effectiveness of two types of ventilation system: low-power, direct current mechanical ventilation and natural ventilation. Both systems were applied for office building, generally occupied during a day. A comparison of both system were conducted for the whole calendar year.
Mechanical system considered in the paper is fully supplied from the photovoltaic panels integrated with façade cladding system. Panels covers a total opaque area of external wall, transferring solar energy into electricity with constant performance 15%. The proposed, low-power, mechanical ventilation system can be treated as an alternative for natural ventilation, because both are free from exploitation costs. On the other hand the effectiveness in providing proper indoor air quality of both systems is expected to be different. Efficacy of natural ventilation strongly depends on environmental conditions, while efficiency of proposed mechanical system can productively work during the day only.
Taking into account the changeably character of both ventilation systems work a dynamic simulation methods were proposed to analysed their effectiveness. The model of one office zone, occupied during a day were modelled in ESP-r system. The geometry of the room was discretized by control volume elements. The air flow inside the room was defined by a nodal network method. In the case of natural ventilation the window cracks and openings characterized the inlet, while outlet was defined as a ventilation chimney. On the other hand, while mechanical system is considered the inlet and outlet were defined as a mechanical ventilation devices.
Presented results shows the effect of both system on indoor air quality and thermal comfort. The results are limited to the period of occupancy only, during the whole calendar year.

KEYWORDS

Mechanical, natural, thermal comfort, photovoltaic, efficiency, simulation.

1 INTRODUCTION

Building integrated PV, e.g. façade system can be one of the renewable sources of electricity in zero or plus energy buildings. In the first place PV power should be used by any devices providing proper indoor environment conditions according to the main idea of sustainability building. Therefore, any technical building systems that use electrical energy for heating, cooling, ventilation and/or domestic water to satisfy energy needs can be supply directly from renewable electricity sources.

Photovoltaic is one of the most promised technology, because of easy installation, building integration and cost effectiveness. On the other hand, the periodical, changeable character of its operation generates the following two problem. Renewable energy is providing during the day only and in some characteristic periods of time the supply exceeds the demand. Therefore, the proper size and arrangement of electrical network components including battery, can provide an appropriate and effective operation of the whole system. One of the most precisions method of system design is dynamic numerical simulation using relatively short, e.g. one hour time step. For the purpose of this work the numerical model were developed using ESP-r (Energy System Performance) software.

The main goal of presented work was to investigate the effectiveness of proposed mechanical ventilation system supplied from photovoltaic modules under local, moderate weather conditions. It was assumed that analysed office building is occupied from 8:00 to 16:00, while façade ventilation unit is furthermore active one hour before and after that time. Outside working hours, the ventilation system is switch off. The only source of electrical energy for mechanical ventilation is energy from PV panels and reserve energy stored in battery. For the purpose of presented analysis different amount of panels was considered taking into account solar irradiation according to Typical Meteorological Year, TMY weather file. The effectiveness of solar energy conversion (15%) and stored (85%) were considered in analysis.

The second objective of the study was devoted to compare effectiveness of natural and proposed mechanical system supply from PV. Both systems works at no cost but theirs effectiveness depends on local climatic conditions: wind and temperature for natural or solar radiation for mechanical ventilation. Comparison of both systems were done based on the following parameters: air flow rates in analysed room (pollutant removal efficiency) and comfort indices (user thermal sensation).

2 METHODOLOGY

To conduct the analysis of indoor air quality, the computational model had to be subjected to a dynamic simulation, requiring the use of a suitable model of air flow. In order to determine the appropriate coupling phenomena of the heat and mass transfer, an Air Flow Network method was applied. In the presented approach, all of the components are defined by the nodes representing the volume of solids or the volume of air and the associated heat capacities [6]. The thermal model is based on the finite-volume discretization heat balance method, in which elements of the building structure, zones and associated systems are represented via nodes. Nodes with different physical parameters are connected by the flow path and they are remaining in the thermodynamic equilibrium state. A system of nonlinear differential equations characterise the properties and the form of the flow and they are describing the network connection. The flow through each connection is performed in such a manner that the amount of air flowing into and flowing out of each zone remains at equilibrium (as the principle of conservation of mass).

3 SIMULATION MODEL

3.1 Geometry and materials

The simulation was performed for the model of a single office room. Climate database was built on the basis of meteorological data type WYEC (Weather Year for Energy Calculation, Version 2) [5], developed for the city of Lodz. The room has been defined based on the actual area dimensions (depth x width x height) 5.8 x 3.0 x 3.6 m. All partitions were designed with the assumption of good thermal insulation of the area. The mineral wool with a thickness of 200 mm was used as a basic insulation material and it was located on the inside of both vertical and horizontal partitions. Window with dimensions of 1.2 x 1.2 m and a thickness of 0.01 m oriented to the west was located at the central part of the outer wall. In order to obtain accurate simulation results, the area of the room was divided into 3 zones with finite volumes equal 19.44 m^3 and 21.6 m^3.(Figure 1). The article authors assumed that the work spot is placed in the central part of Zone A.

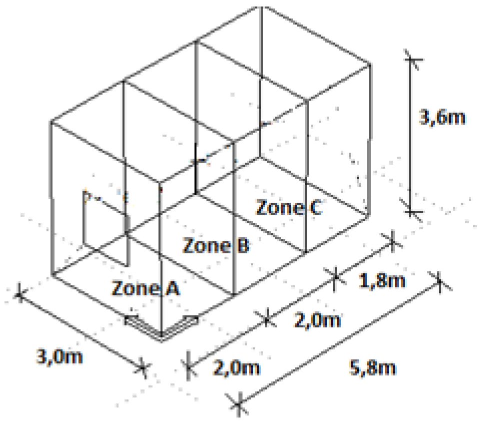


Figure 1: Model geometry

3.2 Computational assumptions

For the purposes of the article indoor air quality evaluation was made by using two thermal comfort indices: PMV and PPD. The parameters necessary for their designation were adopted in accordance with the standards for the required parameters of the proposed internal environment [4]. It was assumed that during cooling season (from October to March) the thermal resistance of clothing is I_{cl} = 0.5 clo (clothing in the form of thin trousers and a shirt with short sleeves), the activity level of 1.2 met = 70 W/m^2 (the characteristic value for office work). During the heating season (from April to September) thermal resistance of clothing assumed equal to 1.0 clo (shirt, pants, jacket). The level of activity remains unchanged and the air velocity was taken as the average air velocity value for each month.
Analyses were performed with the assumption the zone is occupied by one person from Monday to Friday from 8:00 ÷ 16:00. The total heat load being defined as 215 W/person [3], where 100 W is derived from the equipment room (electronic devices). It was assumed that solar irradiation is sufficient light source from 8:00 ÷ 15:00, and therefore heat gain from artificial lighting assumed equal to 10 W/m^2 between 15:00 ÷ 16:00.

3.3 Air Flow Network

The Air Flow Network is designed by five nodes (three internal - A, B and C and two external - 1 and 2, where the flow is caused by the effects of wind pressure on the surface elevation) (Figure 2). Wind pressure distribution coefficient is specified as for the partially exposed walls in the inlet node (1), while in the outlet node (2) as for the roof with inclination angle of less 10 ° [1]. It was assumed that the distance from the roof to the floor of the considered room is 15.0 m The flows in the nodes are a function of pressure and the properties of the components to which the nodes are attached. The area of the hole and the coefficient of discharge are two features of the components that were crucial for the analysis.

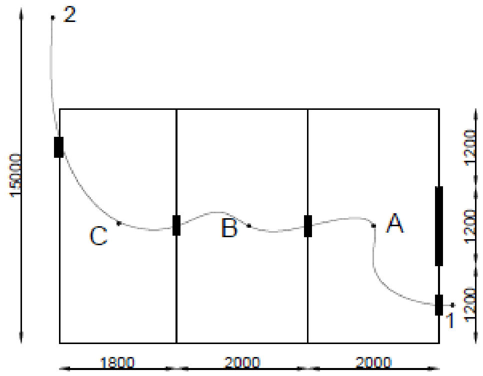


Figure 2: The Air Flow Network in the model

3.4 Adopted ventilation systems

For the purposes of the article two different types of ventilation systems was modelled to compare the indoor air quality - low-power, direct current mechanical ventilation and natural ventilation. Both systems were applied for an office room described above.
Mechanical system consists of the ventilation unit with constant volume of supply air at the level of 90 m^3/h which works from 7 am to 5 pm to fully ventilate the room before and after it is being occupied. It is fully supplied from the photovoltaic panels integrated with façade cladding system. Building integrated photovoltaic components were implemented into ESP-r by Clarke *et al.* [2] as a multi-layer construction model. Photovoltaic facade consisted of outer glazing, PV element, resin binder and back sheet glazing. Photovoltaic material was formed as a layer of number of solar cells. The PV properties were determined in form of specific components using 'special material' database. The 13 PV panels, 0,72 m^2 surface area each, covers a total opaque area of external wall that equals 9.36 m^2. It was assumed that panels are transferring solar energy into electricity with constant efficiency 15%. Whole system is supplied with a battery which efficiency is equal to 85%. It was assumed that the battery can accumulate up to 1320 Watts of the power.
In the case of natural ventilation the window cracks and openings characterized the inlet, therefore its efficiency strongly depends on environmental conditions. In both cases the outlet was defined as a ventilation chimney.

4 RESULTS

Simulations were performed for the whole calendar year with the time step of 60 minutes. Results were presented in the form of monthly averaged and daily distribution for selected weeks of summer and winter.

4.1 PV energy supply

The energy comes from PV panels needs to cover the power demanded by a ventilation unit which stands at the level of 37 Watts. Efficiency of proposed mechanical system supplied from the photovoltaic panels strongly depends on intensity of solar radiation throughout the year. Periods when the solar radiation intensity is the highest and the lowest can be distinguished. According to climate database two occupancy weeks were highlighted: week with the highest and the lowest values of solar radiation intensity – respectively from 23rd to 27th of June and from 8th to 12th of December.

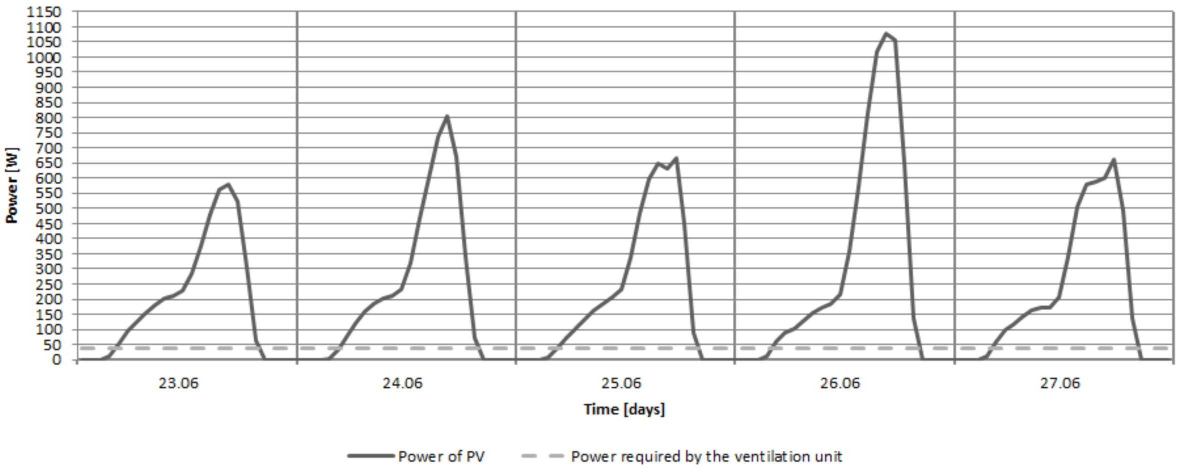


Figure 3: Power generated from PV panels during week the highest values of solar radiation intensity

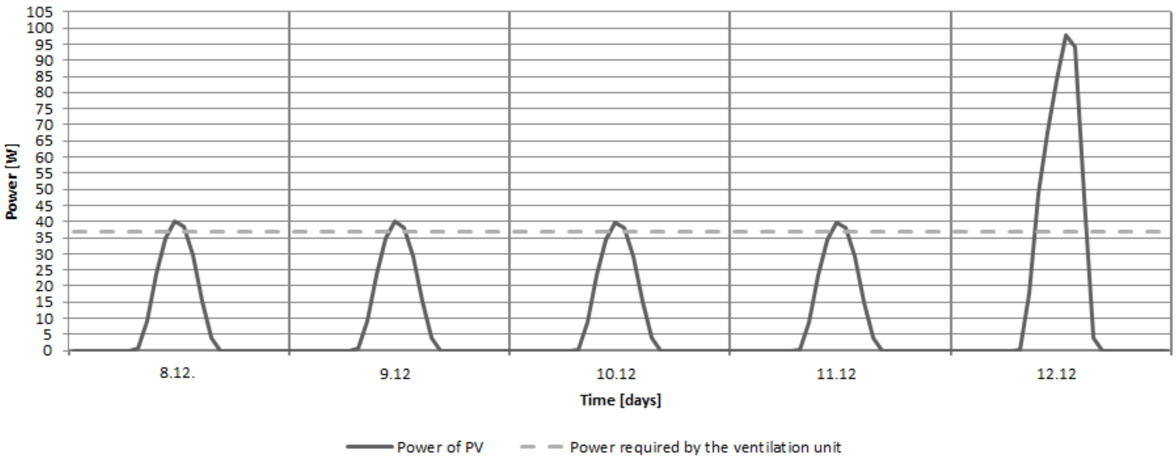


Figure 4: Power generated from PV panels during week the lowest values of solar radiation intensity

Figures 3 and 4 presents power generated from PV (including the battery efficiency 85%) during these weeks with an indication of power required by the ventilation unit.

The graphs shows that during the whole calendar year seasons in which the PV panels cover the whole energy demanded for efficient work of ventilation unit as well as those over which accumulated power there is required appear. Maximum value of the excess of the energy occurs on 26th of June and it equals 1040 W. The amount of the energy supplied by PV panels is not sufficient to provide work of the ventilation unit from 8th to 11th of December.

Amount of the energy that can be stored depends on the number (surface area) of PV panels. Figure 5 presents possible amount of the solar energy to be storage for different number of panels installed in the building, including energy consumption of ventilation unit.

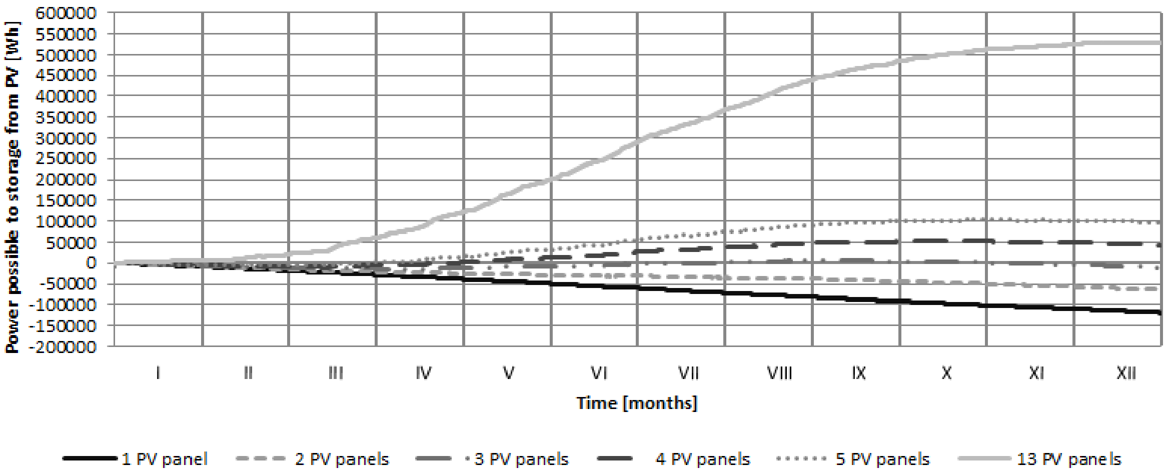


Figure 5: Power generated from PV panels during week the lowest values of solar radiation intensity

Figure 5 shows that installing from one to three PV panels cannot provide a sufficient powering of the ventilation unit from solar energy. Application of four PV panels on the building wall will cause the possibility energy storage in the second half of the year at the level of 50 kWh. However, the great amount of the solar energy cannot be stored and exploited due to the low capacity of the storage cell.

4.2 Indoor air quality

Presented results for indoor air quality are restricted to the hours and days of the room occupancy – from 8 am to 4 pm and from Monday to Friday each week.

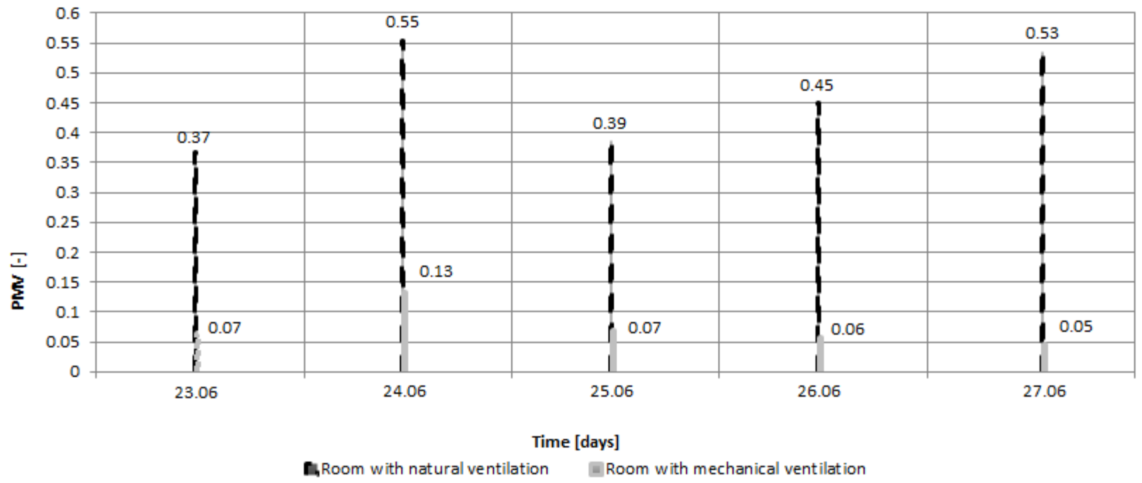
Mean values of interior temperature in Zone A, air velocity in Zone A, PMV and PPD rate for each month of the year for both models – room with natural and mechanical ventilation system are presented in Table 1.

Table 1: Monthly mean values indoor air quality indices in Zone A in both models – room with natural and mechanical ventilation system

	Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Temperature [oC]	Room with natural ventilation	20.0	20.0	20.0	20.6	22.2	23.0	22.7	23.6	21.8	20.1	20.1	20.0
	Room with mechanical ventilation	21.4	21.5	21.7	22.1	23.5	23.8	24.1	24.4	22.8	21.9	21.6	21.4
Air velocity [m/s]	Room with natural ventilation	0.005	0.003	0.004	0.003	0.003	0.003	0.003	0.002	0.003	0.005	0.003	0.005
	Room with mechanical ventilation	0.011	0.010	0.010	0.010	0.010	0.009	0.009	0.009	0.009	0.010	0.010	0.011
PMV [-]	Room with natural ventilation	-0.32	-0.29	-0.25	-1.11	-0.56	-0.27	-0.35	0.16	-0.69	-0.20	-0.24	-0.32
	Room with mechanical ventilation	-0.04	0.01	0.08	-0.66	-0.18	-0.04	0.05	-0.07	-0.43	0.16	0.06	0.00
PPD [%]	Room with natural ventilation	7.18	6.81	6.45	33.30	17.80	10.71	12.99	8.72	12.95	6.36	6.45	7.20
	Room with mechanical ventilation	5.83	5.91	6.17	16.96	10.67	10.61	10.22	7.40	12.29	6.03	6.04	5.98

The results presented in the Table 1 show that indoor air quality in room supplied in mechanical ventilation system is on higher level than in room ventilated by natural ventilation system. Differences between mean values of the interior .temperature reach to 1.8°C and differences between mean values of the air velocity are at the level of 0.006 m/s. Almost all monthly mean values of PMV in room with mechanical ventilation system are included in the interval -0.5<PMV<+0.5, mean value in April is the exception. The most unfavorable conditions of thermal comfort occur in period from April to September. The reason for this occurrence is insufficient cooling during the heating season.

Figures 6 and 7 presents daily mean values of PMV and PPD rates for week with the highest and the lowest values of solar radiation intensity – from 23rd to 27th of June and from 8th to 12th of December.



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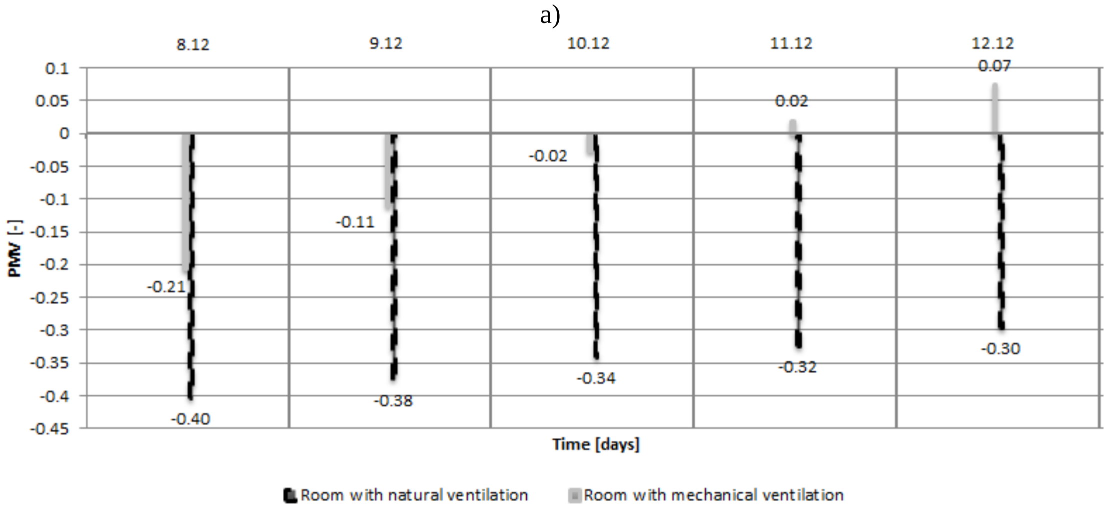

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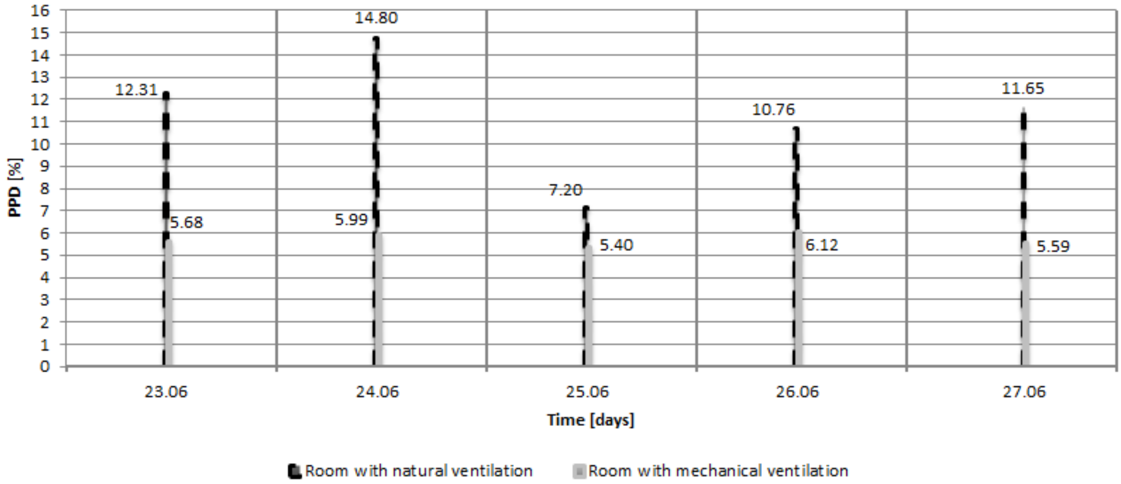
Figure 6: Daily mean values of PMV rate for a) 23rd to 27th of June b) 8th to 12th of December



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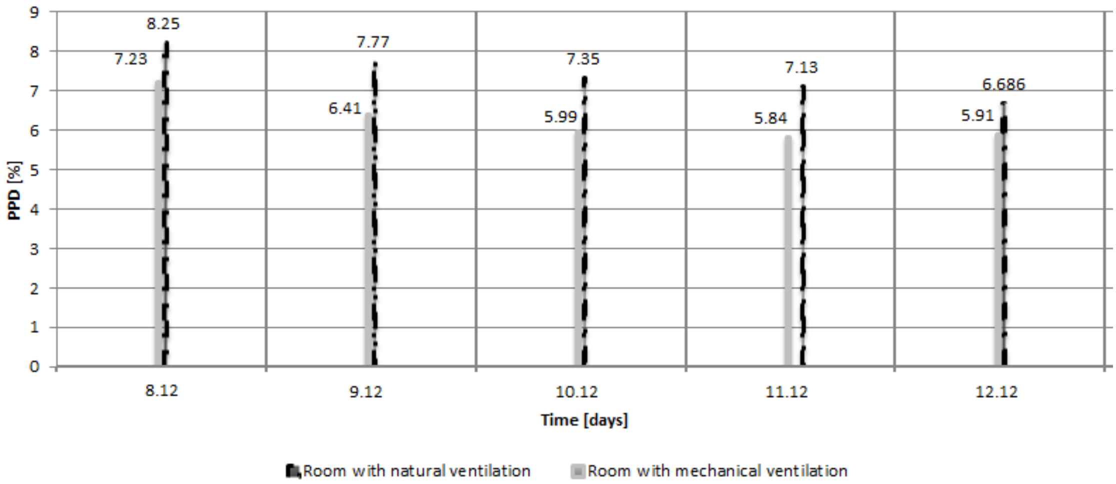

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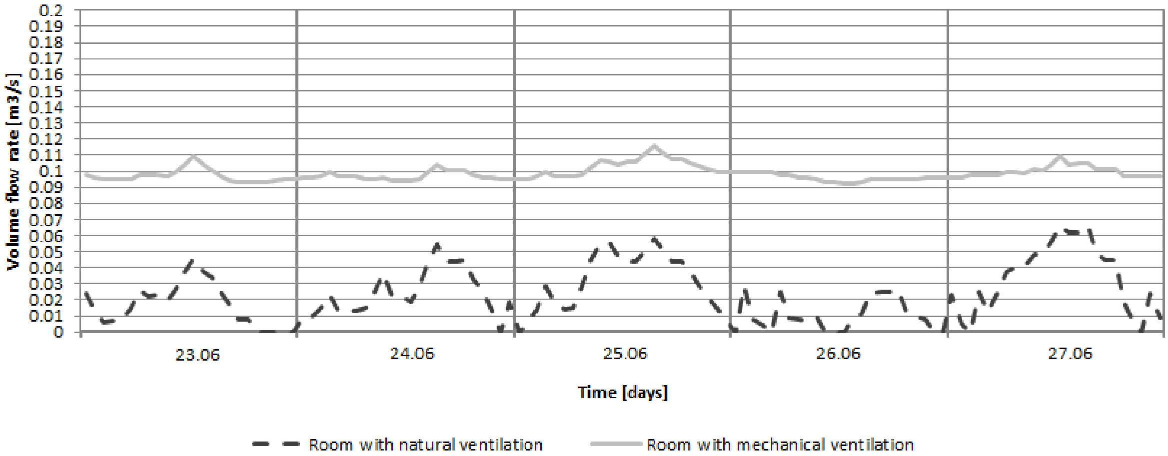
Figure 7: Daily mean values of PPD rate for a) 23rd to 27th of June b) 8th to 12th of December

Results show that values of PMV and PPD rate are within the standard in the model with the room equipped with mechanical ventilation system for both distinctive periods. The number of people dissatisfied with indoor air quality in the room does not exceed 7.23%. For the naturally ventilated room the PPD rate exceeds the optimal value even by 50% in the week of June.

Figure 8 presents volume flow rate of the internal air in area of work spot for two selected weeks for both models of ventilated office room.



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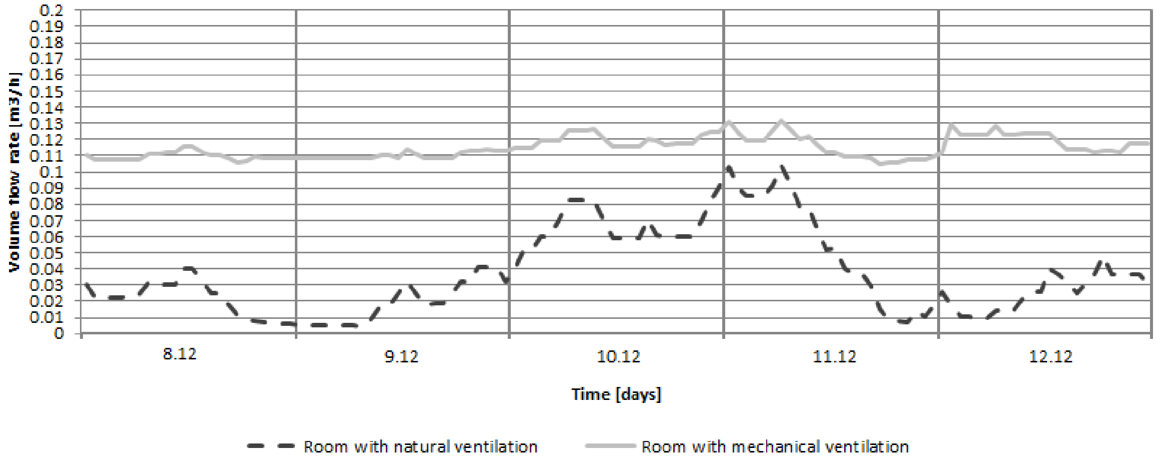

b)

Figure : Volume flow rate in Zone A for a) 23rd to 27th of June b) 8th to 12th of December

Graphs show that volume flow rate is higher during the winter week. For room with natural ventilation values of the volume flow rate in occupied zone are lower than for room equipped with mechanical ventilation system. Differences vary from $0.002m^3/s$ in December to $0.009m^3/s$ in June. It is easy to observe that the volume flow rate of the air supplied form the mechanical ventilation unit is maintained constant level while volume flow rate of the air in natural ventilated room is variable and its values equal from 0.000 to $0.009m^3/s$. The unstable character of air flow for natural ventilation system effects from changeable wind speed and direction as well as indoor and outdoor temperature differences for analysed period.

5 CONCLUSIONS

Conducted simulations showed that PV panels as a source of renewable energy acquired from solar radiation characterise with a very high efficiency. Installation of PV panels in the building has the potential to supply it with enough power to power one or more electrical device. The amount of energy supplied from the panel of a surface area about $3m^2$ greatly exceeds the capacity of an average battery. Installing the appropriate number of panels gives the possibility of obtaining energy amounting to several hundred thousand Watts per hour during the calendar year. A proper project of PV system equipped with a battery of high efficiency and capacity allows to power high number of electrical devices in building that are used in everyday life. One of these appliance can be a mechanical ventilation unit supplying building in the proper amount of high quality air. This is especially useful for office buildings which are workplaces for many people. Employee satisfaction with thermal conditions and indoor air quality increases his work efficiency and reduces the likelihood of diseases. The results of the calculations confirm that the mechanical ventilation system works much better than the natural ventilation system, even it is supply from renewable energy source. It provides significantly better thermal comfort and indoor air quality thanks to higher volume of the air stream supplied during the entire calendar year. Nowadays, in order to gain a high comfort conditions currently existing and new buildings are being equipped with more and more mechanical ventilation devices. Buildings supplied with such an installation have a great opportunity to obtain the status of a zero-energy building with high indoor air quality.

6 ACKNOWLEDGEMENTS

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