Study of the energetic performance of a personalized ventilation system

IUNIA CRUCEANU1, CHADI MAALOUF2, IOLANDA COLDA3, MOHAMMED LACHI2

1 Civil Engineering, UTCB, Bd. Lacul Tei nr. 122 – 124, ROMANIA
2 GRESPI/LTM, University of Reims, Campus du Moulin de la Housse – Reims, FRANCE
3 F.I.I, Technical University of Civil Engineering Bucharest, Blvd Pache Protopopescu, ROMANIA

iunia_cruceanu@yahoo.com; chadi.maalouf@univ-reims.fr

Abstract: The personalized ventilation system aims to improve the quality of the inhaled air, to diminish the risk of transmission of the infectious agents and to improve the thermal comfort of the occupants. The principle of this work is to compare the classical ventilation system and the personalized ventilation system from the energy consumption and the thermal comfort point of view. The analyse was made with a nodal model, using the numerical simulations in the SPARK simulation environment. The object of the simulations was a classroom in Bucharest, Romania. The result showed that personalized ventilation can reduce the energy consumption of about 49% and to provide the desired thermal comfort.

Key-Words: Personalized Ventilation, Classical Ventilation; Energy Consumption; thermal comfort, simulation; SPARK.

1 Introduction

The concept of personalized ventilation was first introduced by Fanger and it is applicable for places where people spend most of their time sitting on a desk. The goal of this type of ventilation is to bring fresh air to the user and in doing so to improve the thermal comfort of the occupants. The system uses supply grilles located close to the breathing area of the user, so that the occupant inhales the air from the unpolluted core of the supply jet (Fig 1). This means that the quality of the inhaled air is increased, the risk of infectious agents diminishes and the efficiency increases. Niu found that over 80% of the inhaled air could be composed of fresh personalized air [1]. The increase of the ventilation efficiency implies reduced outdoor supply air rates and reduced energy consumption [2]. There are two more strategies used to reduce energy consumption: supplying fresh air only when the user is on his desk [3,4,5] and the increase of the interior air temperature due to the fact that the personalized ventilation concept is based on the creation of a microclimate [5,6,7].

The purpose of this study is to analyse the energy consumption of a personalized ventilation system and compare it to a traditional ventilation system in the case of a classroom situated in the city of Bucharest Romania, using the simulation environment SPARK suited to complex problems. We compared both cases for different supply air flow rates and temperatures. Energy performance and thermal comfort conditions are estimated using the heating and cooling energy consumption as well as the cumulated temperature frequency for each case.

Fig 1. Personalized ventilation system

2 Methods

2.1 Description of the classroom

The building is a classroom of 6.4x8.1 (51.84 m²) and 3.5m height. It is located in Bucharest, Romania. Weather file is provided from the ASHRAE data base. The study period is for three
months from April till June. The Western wall is an external wall and the southern façade is made of a double glazing with a shading coefficient of 60%. The other walls are considered as partitions and are in contact with conditioned spaces at 24°C. The floor is composed of an 18 cm concrete slab, 10 cm polystyrene and 7 cm concrete. The ceiling is composed of 10 cm of polystyrene, 18 cm concrete and 2 cm plaster. The west wall is made of 18 cm bricks with an external insulation of 7 cm of polystyrene. The partition walls are made of 15 cm of brick in sandwich between two layers of plaster, 2 cm each.

2.2 Occupancy and internal heat gains
We considered that the room is occupied by 31 persons from 8.00 to 18.00, five days a week. Each hour has a break of 8 minutes during which only 15 occupants remain in the class (months of April and May) and 8 persons in June. The infiltration rate depends on the internal pressure and is considered equal to 0.8 V/h when the ventilation system is off and 0.4 V/h when the system is on. The lighting is on from 8h to 10h for the months of April and May (15 W/m²). The Figure 2 presents the sensible heat load of the room due to lighting and occupants (months of April and May).

Fig 2: Heat load in the classroom due to light and occupancy for the months of April and May.

2.3 Description of the ventilation system
Two ventilation systems are compared:

- A classical ventilation system for which the air flow rate is considered 7 l/s/occupant respecting the Romanian standard. This system is on from 8h till 19h in the evening apart from the weekend. This system is on from 8h till 19h in the evening apart from the weekend.
- A personalized ventilation system for which the air is treated by an air-conditioning unit that regulates the supply air temperature and is adjusting the air flow according to the room’s occupancy. There is no mechanical ventilation and the air is evacuated through room leakage. In both cases, room internal temperature varies freely without any regulation system.

2.3 The simulation software and room model
Simulations are run within the Simulation Problem Analysis and Research Kernel (SPARK), an equation based modelling environment developed by the Simulation Research Group at Lawrence Berkeley National Laboratory [8, 9]. The advantages of this environment are its modularity and its syntax which is suited to parametric studies. Room is modelled using a nodal method which considers the room as a perfectly mixed zone characterized by a pressure, a temperature and a moisture concentration. It involves equations for air and moisture mass balance, heat balance for ambiance and equations describing heat transfer through the walls, additional convection between inside wall surfaces and room balance [10]. The energy balance equation for the air zone can be written as:

\[
(\rho c_p V + I) \frac{\partial T}{\partial \tau} = \Phi_{\text{West}} - \Phi_{\text{East}} + \Phi_{\text{South}} - \Phi_{\text{North}} + \Phi_{\text{Bottom}} - \Phi_{\text{Top}} + \Phi_{\text{Source}}
\]

(1)

where \( I \) is room thermal inertia. This equation involves heat fluxes through the envelope (from walls and openings) and internal heat sources.

Concerning radiation heat exchange between room walls it was computed using the mean radiant temperature method in which the radiative flow between a wall and all the other walls of the room is written as:

\[
\Phi_{\text{rad,LW}}^\text{int} = h_r S(T - T_m)
\]

(2)

The value of \( h_r \) is expressed by:

\[
h_r = 4\varepsilon\sigma_0 T_m^3
\]

(3)

Where \( T_m \) is the mean radiant temperature of the walls and is given by:

\[
T_m = \frac{\sum S_j T_j}{\sum S_j}
\]

(4)
2.4 Simulated cases

We compared the two ventilation systems from both energy consumption and thermal comfort sides. For the conventional ventilation system (VC), the inlet air flow rate was calculated according to the Romanian Standard. Two values are considered of 840 m$^3$/h and 995 m$^3$/h. The supply temperature may vary in the range of 18°C (minimal) and a maximal value that could be 18, 20, 22 and 24°C. We have analyzed a total of 8 cases.

For the personalized ventilation system (VP) several supply air flow rates are simulated - 2.5 l/s; 4 l/s; 5.5 l/s; 6.5 l/s; 7 l/s; 8 l/s and 10 l/s for occupant. Due to the fact that the system supplies the air to the breathing zone of the occupant, some restrictions must be imposed regarding the supply air temperature. The temperature will vary between minimum of 20°C and an imposed maximum of 22, 24 or 26°C (the fresh air will be heated or chilled). We’ve studied a total of 21 cases.

For each case, 3 parameters were taken into consideration:

- The energy consumption HC needed to heat up the fresh air to reach its imposed minimum temperature.
- The energy consumption CC needed to cool external air to its requested maximal temperature.
- The cumulated frequency that characterizes the interior comfort and is defined by the following relation:

$$ FC = \sum_{t} \left[ T_i(t) - T_{ref} \right] \delta(T_i) $$

(1)

$T_{ref}$ is the reference temperature taken to be 28°C for the classic ventilation and 30°C for the personalized ventilation. $\delta(T_i)$ is the symbol of Kronecker and is equal to 1 if $T_i$ is superior to $T_{ref}$, otherwise it is equal to 0. This frequency accounts for the degrees-hours of thermal discomfort. The smaller it is, the greater thermal comfort is expected. The simulations are carried for April, May and June however, in order to initialize the calculations and to avoid the influence of the initial conditions, only the results of May and June are taken into consideration.

3 Results

Figure 3 shows the cooling energy consumption (CC) for both cases, personalized and classic ventilation, as a function of air flow rate and for different maximal air supply temperatures. As we can see in both cases, energy consumption increases with air flow rate and decreases with the growth of maximal air supply temperature. For the classic ventilation system and an air flow of 25 m$^3$/h/person, the energy consumption varies from 182.9 kWh to 755.8 kWh when the temperature is lowered from 24 to 18°C. Increasing the air flow from 25 to 30 m$^3$/h/person brings an 18% increase in the energy consumption. For the case of the personalized ventilation and the same air flow rates, the consumption varies between 80.3 kWh and 262.7 kWh for a maximum temperature of 26 to 22°C. Due to the fact that the air, in this case, is introduced at distance between 30 to 50 cm from the user, an inlet temperature of 18°C cannot be used. With a growth of 2°C, cooling energy consumption decrease about 50%.

Figure 4, presents the heating energy consumption variation (HC) for both the classical and personalized ventilation systems. We notice that this consumption increases with supply air flow rate.

![Fig3: The energy consumption needed to cool the inlet air as a function of air flow rate and maximum supply temperature for both PV (left) and CV (right) cases.](image)
Figure 5 shows the variation of the cumulated frequency for both cases and for different air flow rates and maximum air supply temperatures. Higher air flow rates or lower supply air temperatures lead to a decrease of the cumulated frequency indicating that the internal temperature is lowered and the thermal comfort is improved.

For the classical ventilation case, the FC value is very high and it has satisfying values only for an inlet temperature of 18°C (both air flow rates) or a 20°C and for air flows larger than 6 l/s/person. In the case of personalized ventilation the smaller values are for a maximal temperature of 22°C and for air flows larger than 6 l/s/person.

Fig. 6 shows the variation of the interior temperature during the hottest week of June in the case of classical ventilation with different air flows. For 24°C the interior temperature is higher than 28°C for the whole week and even reaches 32.2°C. The cumulated frequency is, in this case, 315 (°hours). When the inlet temperature is 18°C, the maximum interior temperature is 29.4°C and the frequency 27.5 (°hours). The energy consumption for cooling varies from 183 kWh to 755.8 kWh. To these values, 88.8 kWh (HC) must be added to take into account the energy needed for the air when its temperature is below 18°C.

When comparing energy consumption for the same air flow and the same maximal supply temperature for both systems, we notice that cooling energy is very higher for the classical case than the personalized ventilation case and that heating energy is lower for the classical case. The difference comes from the fact that in the personalized ventilation system the minimum supply air temperature is 20°C while for the traditional system it is 18°C. These results confirm Schiavon results [11] that personalized ventilation is suited to hot climates and not to cold climates where heating energy consumption is higher than the classical ventilation system case.

In our case, as the system is used for cooling, total energy consumption is reduced from 844.6 kWh to 430 kWh when using personalized ventilation system with a supply temperature of 22°C and an air flow rate of 7 l/s/person, with about 49% of reduction.
4 Conclusions and perspectives
In this paper, energy consumption of two ventilation systems was analyzed and compared: classical ventilation system and a personalized ventilation system. The system is used to cool a classroom in Bucharest, Romania. Both systems were modelled using the simulation environment SPARK. Simulations are used to evaluate energy consumption and thermal comfort conditions. Our results suggest that when compared to classical ventilation system, personalized ventilation can provide comfortable conditions and reduce energy consumption of about 49%. These results should be taken carefully as more analysis is to be done for the personalized system in order to analyze air flow around occupants.

References: