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# Optimization of ventilation system in the open office space

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**Abstract.** The paper presents the results of study into the air parameters in open space offices. As office workers spend about 1/3 of the day in such spaces, it is important to provide them with the right climate comfort, and that is determined, most importantly, by: the temperature and humidity of the air, quality of the air, and the concentration of $CO_2$. Two objects of study were selected - both of them open space facilities, each with a different intensity of use. In the course of study, measurements were taken on the basis of which the distributions of temperature, humidity, and concentrations of $CO_2$ in the entire volume of the space were determined. Also the empirical coefficients of $CO_2$ emission by the office workers were marked out, dependent on the volume of the working area and the number of people using it. The coefficients were developed at optimal working parameters of fans in the ventilation system; the criterion for optimization being heat loss in the office caused by discharge of the used heated air into the atmosphere. The results of the study have also shown that the use of personal ventilation (PV) with an installed recuperator for heat recovery from the used air discharged from the room significantly improves the energy efficiency of an open space office building.

## 1 Introduction

In recent years in Poland there has been a marked increase in investment in global companies which use spacious open space offices for organising their business operations. Such solutions are also becoming commonly used by Polish companies. Open space is a place where the employees' desks are arranged in a large space, without any dividing walls, separate rooms or offices [1]. In this type of space, employees spend about 1/3 of their waking hours, therefore the quality of the air is very important for the working conditions in an open space, especially the composition of the air: the content of oxygen, carbon dioxide, as well as gaseous and particulate pollutants. In highly urbanized regions, where the open space offices are popular, the outside air often exceeds the acceptable concentration of pollutants. However, given the concentration of oxygen and carbon dioxide in the air inside and outside the building, the outside air is still commonly called fresh [2-3].

At the stage of planning of an open space office, it is important to carry out a thorough analysis of the micro-climate that affects people's behaviour in relation to the thermal

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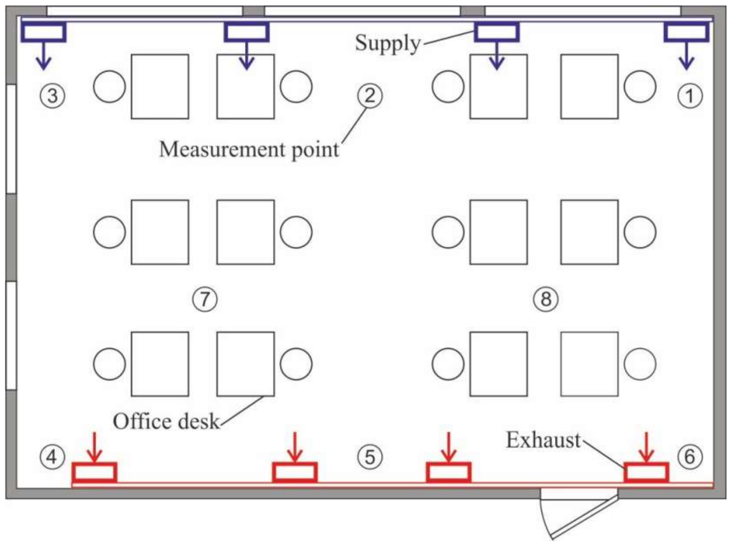
conditions. The climatic conditions and air quality in office buildings affect the health, comfort and productivity of people working in them [4]. According to Polish Standards PN-EN 16798-3:2017-09:2007 "Energy performance of buildings - Ventilation of buildings - Part 3: Ventilation of non-residential buildings - Requirements for the properties of ventilation and air conditioning systems", and PN-83/B-03430/Az3:2000 "Ventilation in habitable buildings of collective and public usefulness. Requirements" the air parameters relevant to the comfort of the indoor climate, are: the temperature of the air, the humidity, the physical and biological quality of the air and the concentration of carbon dioxide ($CO_2$) [5-6]. World Health Organization (WHO) recommends that the concentration of $CO_2$ in the spaces of people's stay should be less than 1000 ppm [7]. The Polish Standard mentioned above specifies also the recommended temperature inside an office space, which during the heating season should be maintained at 20°C, and at 23°C in the summer.

In addition to the amount of fresh air supplied, for the effectiveness of ventilation systems in large open space offices, it is also the fresh air distribution throughout the whole space of the room that is a significant factor. Most of the open space offices have fresh air inlets fitted evenly in the ceiling of the room. This ensures a uniform pattern of air supply to the whole space of the office; however, such air distribution does not always guarantee the fresh air supply to all workstations. This is due to the fact that in many offices, employees are placed in different parts of the room with varying concentration which is not always possible to predict at the stage of design of the ventilation system. The best solution to ensure that the air supply corresponds to the concentration of workers in the office area is personal ventilation (PV) whose purpose is to provide clean and cool air directly to the breathing zone of each employee. PV can, therefore, increase the comfort and efficiency of people working in the office, and reduce the symptoms of the sick building syndrome (SBS) [8].

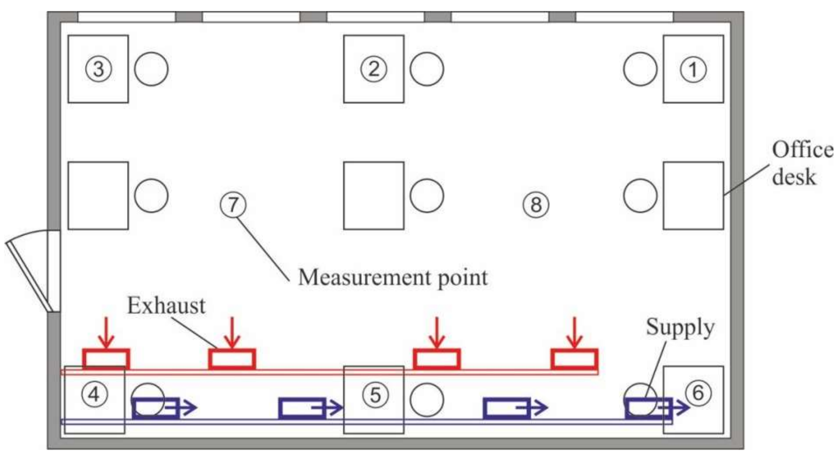
A number of studies have been carried out on the efficiency of ventilation systems in offices, but they were mostly went as far as to determine the required air flow, the distribution of fresh air inside the room, and the temperature of the air [9-12]. However, the concentration of carbon dioxide and other gaseous pollutants, as well as the relative humidity of the air in the office area are no less important for the comfort of work [13-14]. In order to optimize ventilation of an open space, it should also be noted that excessive increase in fresh air input does guarantee the required air quality inside the room, but at the same time it increases heat loss through the ventilation system, which in turn increases the heat demand for the building [15].

## 2 Methods

In order to carry out a detailed analysis of air quality in open space offices and to optimize performance of this type of ventilation systems, two research objects were selected, with different ventilation conditions, and varying work intensity of people using them. Object 1: an office room of an area of 94 $m^2$, used continuously (i.e. 8 hours a day, 5 days a week) by 12 employees working on computers. The object is fitted with intake/exhaust mechanical ventilation, air conditioning system with the feature of automatic control of room temperature called the heating, ventilation, and air conditioning: HVAC [16]. In object 1, workers sometimes open a window during the day, in order to intensify the exchange of air. The diagram of office room 1 is presented in Figure 1(a). Object 2 is an office room of an area of 83.5 $m^2$, where 6 to 10 people work on computers and other office equipment at different hours each working day. The office is fitted with supply/exhaust mechanical ventilation whose operating parameters are coordinated with the temperature set for the air in the room. In the summer months the ventilation system cooperates with the air-conditioning. In this room there is not possible to increase the flow of fresh air in an uncontrolled way by opening windows. The diagram of office room 2 is presented in Figure 1 (b).




(a)




(b)

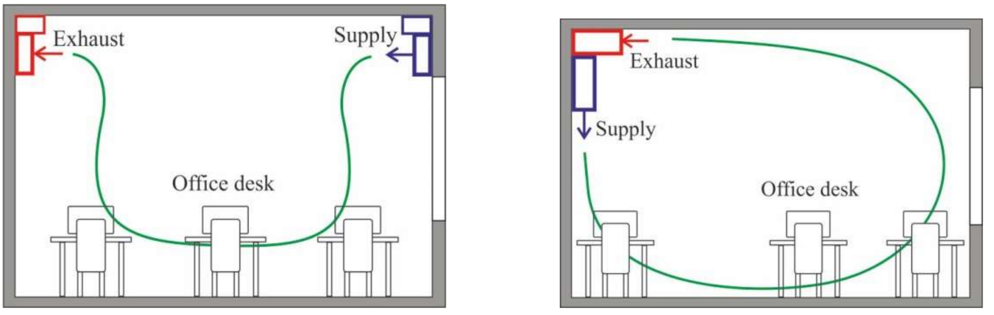
**Fig. 1.** Diagram of open space offices: (a) object 1, (b) object 2.

In both offices the air is exchanged by mechanical intake/exhaust ventilation, i.e. a system with two fans: the supply fan, which draws fresh air from outside and forces it into the room, and the exhaust fan whose task is to remove the used air outside [17]. Average physical and chemical parameters of fresh air supplied to the analysed office space during the tests are presented in Table 1. By use of this type of ventilation system it is possible to adjust the amount of air to the specific needs and requirements of a space. For both research objects, the fresh air is supplied and the used air discharged in the upper zone of the space.

**Table 1.** Average physical and chemical parameters of fresh air supplied to the analysed open space office, measured during the tests.

| Research object | Period of testing | Temperature [°C] | Concentration of $CO_2$ [ppm] | RH [%] | $PM_{2,5}$ [$\mu m \cdot m^{-3}$] |
|---|---|---|---|---|---|
| No.1 | During the heating season | 22 ± 1 | 515 ± 30 | 42 ± 4 | 18 ± 4,5 |
| | Out of the heating season | 20 ± 1 | 460 ± 20 | 39 ± 2 | 11 ± 3,5 |
| No. 2 | During the heating season | 21 ± 1 | 535 ± 25 | 43 ± 3 | 22 ± 4 |
| | Out of the heating season | 20 ± 1 | 485 ± 20 | 41 ± 3 | 13 ± 4 |

The arrangement of the fresh air inlets, the exhaust air outlets, and the exhaust air ducts, as well as the air circulation specified for both objects during testing, are shown in Figure 2.




(a) (b)

**Fig. 2.** Distribution of the ventilation air flows in: (a) object 1, (b) object 2.

As can be seen in the diagrams in Figure 2, for both research objects mixing ventilation systems are used: object 1 - the supply and exhaust on the walls (on opposite sides of the room); object 2 - the supply and exhaust on the ceiling (one side of the room) [18]. In both research objects, just like in the majority of this type of office spaces, the operation of the ventilation system is controlled through setting the required temperature of the inside air [19].

As for carbon dioxide, in open space offices fitted with mechanical ventilation systems, it is not possible to determine the amount of its emission by a single person doing typical office work at the computer. Therefore, for the purpose of this research, an additional enclosed office space was selected: area of 8.5 $m^2$, fitted with the same system of central heating and ventilation as research object 2. The office had one work station equipped with a computer. The room was selected to carry out tests of carbon dioxide emission: by one employee per one metabolic hour [20]. In the room, with the ventilation turned off, one person worked continuously at the computer for four hours. During that time, the average concentration of carbon dioxide in the room was recorded. Trials were carried out with the participation of different persons, so as to determine the average emission of carbon dioxide by a single person during one office hour.

In the tests carried out in the two open space offices from August to December (i.e. both when the rooms are being cooled, and when they were being heated) the measurements of temperature, humidity and the concentrations of $CO_2$ were taken at eight measurement points for each office (measurement points marked in Fig. 1). The measurements were carried out in cycles of five days (working days) from 8:00-16:00, the tested parameters the air were recorded every 5 minutes at all measurement points of both rooms. The concentration of carbon dioxide in the air inside the room was recorded with the reading accuracy of 10 ppm ±5%, temperature and relative humidity of air, respectively, with an accuracy of 0.4°C ± 2.5% and 1% ± 0.1% . The results obtained were used to determine the flow of ventilation air, the distribution of temperature, humidity, and concentrations of $CO_2$ in the entire spaces of both offices, and then an average value was calculated for the entire research object. At the same time, each day, measurements of the temperature, relative humidity, particulate matter ($PM_{2,5}$) and the concentration of carbon dioxide were carried out in the outside air, which was supplied as fresh air via the ventilation system.

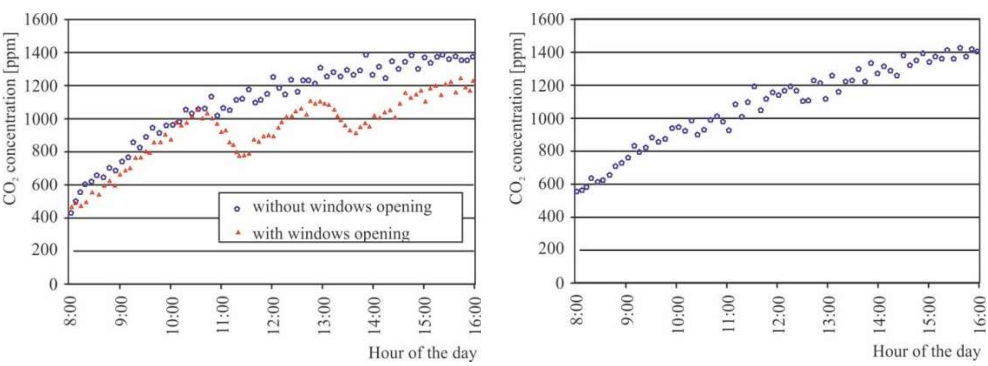
## 3 Results and discussion

The results of the tests carried out by the metabolic method in the additional office room were used to determine the empirical coefficient of $CO_2$ emission by one employee, relative to 1 $m^3$ of the office volume. The recorded emissions of carbon dioxide differed depending on the physical characteristics of office workers involved in that part of the study (gender, height, weight). In view of the above, a decision was made to calculate an average value that was representative of the diverse groups of people (with different physical characteristics) working in the open space type of office. The mean empirical coefficient of $CO_2$ emission by one employee, relative to 1 $m^3$ of the volume of the office is 64 ppm $CO_2$/h. By means of the proposed equation 1, this coefficient allows to specify the essential fresh air stream $\dot{V}$, relative to the number of working people and the volume of the room.

$$\dot{V} = V_o \frac{N \cdot \varepsilon}{C_N - C_F} \tag{1}$$

where: $\dot{V}$ - fresh air stream [$m^3$/h], $V_o$ - volume of the room [$m^3$], $C_N$ - recommend concentration of $CO_2$ (1000) [ppm], $C_F$ - concentration of $CO_2$ in the outside air [ppm], N - the number of employees' [-], ε - empirical coefficient of $CO_2$ emission by one employee [ppm/h]

The tests results were used to draw up charts of variability of carbon dioxide concentrations and the relative humidity of the air. Figure 3 presents the sample charts of variation of carbon dioxide concentration for a single measurement point, for a representative working day.




(a) (b)

**Fig. 3.** Sample charts of variation of $CO_2$ concentration for a single measurement point: (a) object 1, (b) object 2.

After the analysis of the results obtained, the distributions of the air flow inside the two research objects were determined. Also charts of the distributions of carbon dioxide concentration at the measurement points of both offices were drawn up. Sample charts of the concentration of carbon dioxide at the beginning and at the end of the working day, at each measurement point in both research objects are presented in Figure 4.

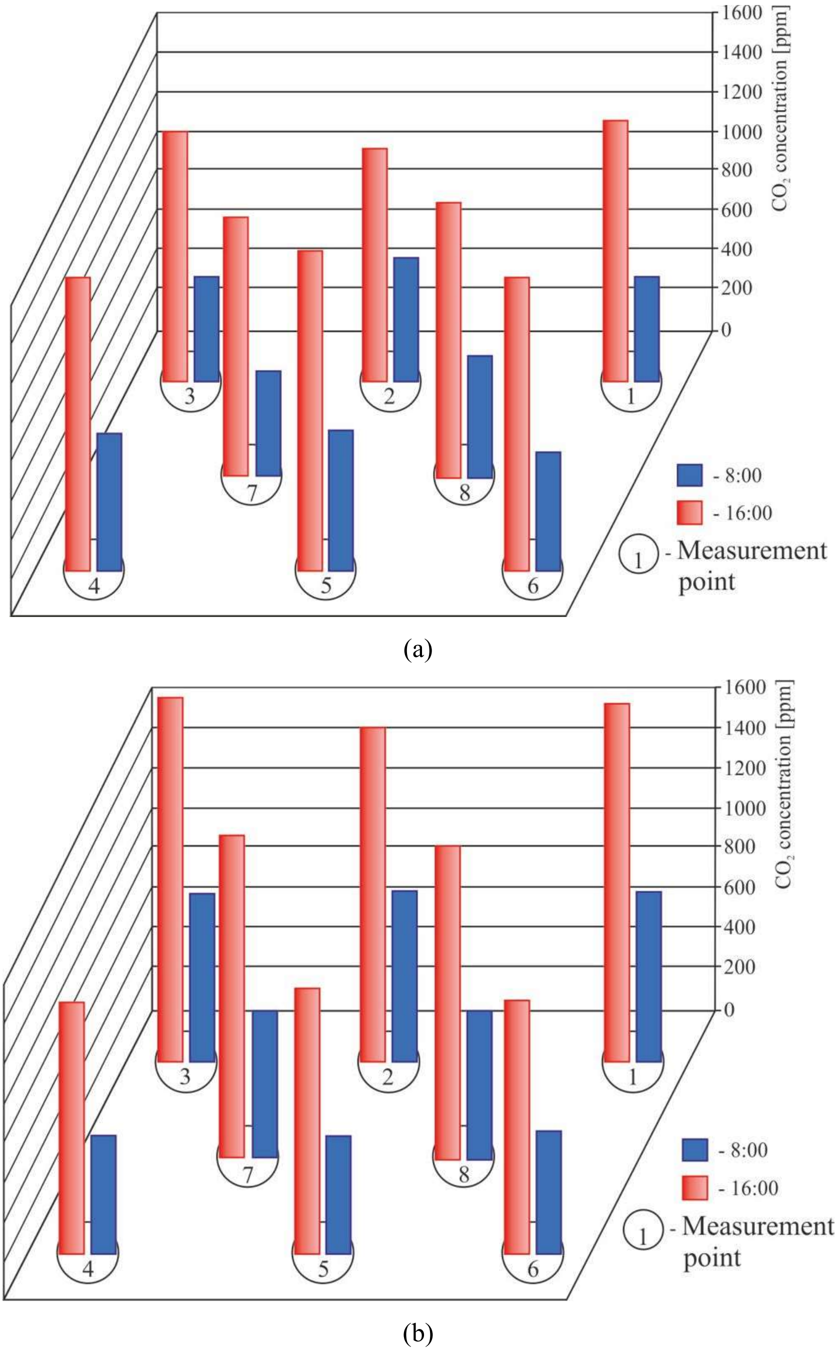



**Fig. 4.** Sample charts of the concentration of $CO_2$ at the beginning and at the end of the working day: (a) object 1, (b) object 2.

Following the studies, it has been concluded that by use of personalized ventilation it is possible to reduce the essential ventilation air flow in the open space offices. One of the features of this type of ventilation is high efficacy of supplying of the fresh air directly to the work station, which allows to reduce energy consumption while ensuring the required quality standards of the air in an office space. On the basis of the simulations carried out, a conclusion was drawn that due to the use of PV ventilation in the buildings analysed it would be possible to reduce the required fresh air flow by about 12%.

The results of the measurements of relative humidity of the air inside both research objects have shown very small changes of this parameter during office hours; it ranged between 21 and 28% throughout the day, which was much lower than the recommended 50-55% humidity for rooms used by people in a continuous way.

In the case of open space offices, where the number of people staying in the room varies significantly throughout a working day, it is possible to improve the quality of the air in the room while increasing the energy efficiency of the ventilation system by adjusting the flow of air supplied into the office room based on the sensor readings of carbon dioxide.

In both open space offices the temperature of the air inside the room was the parameter that did not change in fact. That was due to the fact that the automatic control of the system of ventilation and heating of the room has the temperature of the room air as a parameter set for controlling both systems. As confirmed in the course of the ongoing research, the average air temperature in the research objects differed from the set point in the controlling system by ± 2°C. In both open-space offices, the temperature of the used air was 4 to 5°C higher than the temperature of the fresh air. The used air in both objects is removed directly outside, which generates significant heat loss during the heating season. The value of the heat loss Q in the spaces via a ventilation system can be determined by equation 2.

$$Q = \dot{V} \cdot \rho \cdot c_p (T_U - T_F) \cdot 3600^{-1} \tag{2}$$

where: Q - heat loss [W], $\dot{V}$- fresh air stream [m³/h], ρ - air density [kg/m³], $c_p$ - specific heat capacity of the air [J/(kgK)], $T_U$ - used air temperature [K], $T_F$ - fresh air temperature [K]

As equation 2 shows, in order to reduce the heat loss in a room via the ventilation system, it is necessary to reduce the ventilation air flow or increase the temperature of the fresh air. There are limitations to the reduction of the air flow because of the involved risk of lowering the air quality below the parameters required by standards. In the case of supplying the fresh air directly from the outside of the building it is not possible to change its temperature. To reduce the loss of heat it is necessary to fit the ventilation system with an air exchanger recovering heat from the used air (recuperator). Then the temperature differential ($T_U$ - $T_F$), may be reduced, even by 65%. The heat demand for heating the fresh air is significantly reduced, and the energy efficiency of the HVAC system is improved.

Sample balances of the intake and exhaust air parameters of office building no. 1 with ventilation in different conditions are shown in Table 2.

The empirical coefficient of $CO_2$ emission by one office worker allows to optimize the parameters of performance of fans in the ventilation system, given the criterion for optimization of keeping the recommended concentration of carbon dioxide in the room (below 1000 ppm) while reducing heat loss in the offices caused by the discharge of the heated used air into the atmosphere. Figure 5 shows a sample chart of optimization of operation parameters of the ventilation system for research object 1.

**Table 2.** Sample balances of parameters of the air inside office building No. 1.

| Air parameters | Out of the heating season | Out of the heating season: (employees opening windows for air exchange) | In the heating season |
|---|---|---|---|
| $\dot{V}$[m$^3$·h$^{-1}$] | 164,0 | 176,0 | 152,5 |
| $T_F$ [ºC] | 20,5 | 20,0 | 22,0 |
| $T_U$ [ºC] | 24,0 | 24,8 | 24,5 |
| $CO_{2F}$ [ppm] | 455,0 | 453,0 | 521,0 |
| $CO_{2U}$ [ppm] | 586,0 | 592,0 | 724,0 |
| $RH_F$ [%] | 37,0 | 38,5 | 41,5 |
| $RH_U$ [%] | 28,5 | 27,0 | 32,6 |

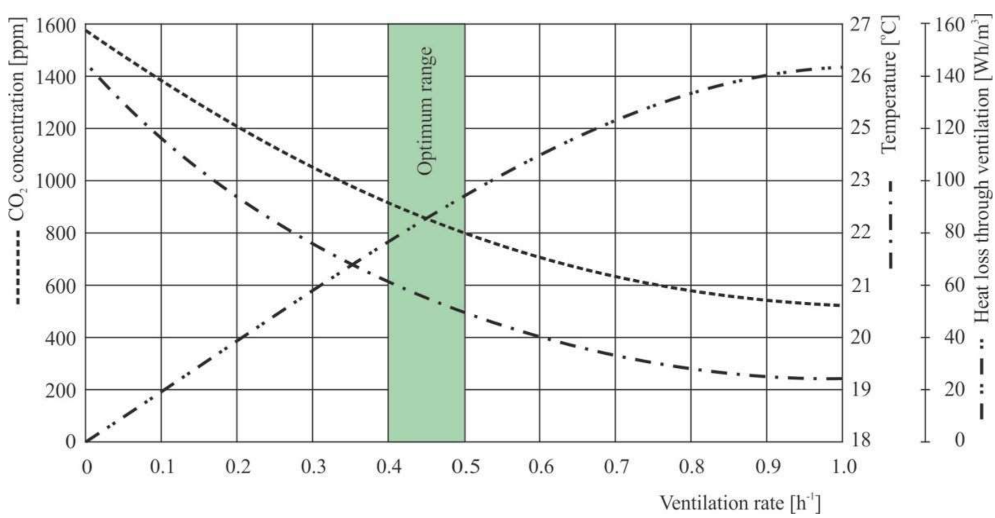



**Fig. 5.** Sample chart of optimization of operation parameters of the ventilation system (for object 1).

The study has lead to a conceptual design of an upgrade of the ventilation system in both research objects by use of a recuperator and a personalized fresh air supply to each workstation. Through the simulations it was determined that such an upgrade in the ventilation system will allow to reduce energy consumption for heating and ventilation of the analysed open space offices by about 54%, while maintaining the required air quality.

## 4 Conclusions

The relative air humidity recorded in the research objects throughout the testing period reached the level ranging from 21 to 28%. These values are distinctly smaller than the recommended ones for office spaces, and that affects negatively the comfort of people using both open space offices.

Coordination of control of room ventilation system with the concentration of carbon dioxide allows to reduce ventilation air flow, which can be determined using equation 1. Thanks to the precisely determined air flow, calculated for the needs of people working in the given office, it is possible to optimize the performance parameters of the ventilation system, and thus reduce heat loss in that space.

Results of the conducted studies and simulations have shown that the application of personalized ventilation (PV) in open space offices and the use a recuperator for heat recovery can significantly reduce energy consumption (approximately by 54%), compared to heating and ventilation systems currently used in the analysed objects, while ensuring the required standards of the quality of the air for an office space.

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