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THE EFFECTIVENESS OF VARIOUS TYPES OF VENTILATION ON AIR QUALITY IN MULTI-FAMILY BUILDINGS

SKUTECZNOŚĆ RÓŻNYCH TYPÓW WENTYLACJI NA JAKOŚĆ POWIETRZA W BUDYNKACH WIELORODZINNYCH

Abstract: Currently, regulations and norms require control of building ventilation only in terms of air velocity, which unfortunately does not always guarantee the ideal air quality required for health reasons. The study investigates the effectiveness of various types of ventilation in multi-family residential buildings (buildings occupied by more than one family) with particular emphasis on natural ventilation, which is the most common solution in residential buildings in Poland. The effectiveness of ventilation systems and their influence on basic properties of air quality, *ie* carbon dioxide concentration, relative humidity and temperature were examined, as well as the possibilities of changing the work done by ventilation systems in multi-family residences to adjust factors pertaining to air quality. The results obtained from the research show that, in the case of multi-family residential buildings, natural ventilation does not function effectively and should be replaced by mechanical ventilation – preferably intake and exhaust ventilation with heat recovery.

Keywords: ventilation system, multi-family buildings, air quality, carbon dioxide concentration, air humidity

Introduction

The quality of indoor air in which people live depends on the type of rooms and the way they are used. In residential buildings, pollution that decreases air quality results mainly from human life functions. Carbon dioxide contamination is caused by the process of breathing (people exhale carbon dioxide) but also during the combustion process in gas stoves, gas water heaters or biomass fireplaces. An important factor influencing indoor air quality is water vapor produced in bathrooms and kitchens and emitted from the surface of the skin and the exhaled air [1–3].

In most residential buildings, the aforementioned air quality deteriorating factors cannot be completely eliminated. Therefore, after a few hours of occupancy in a closed

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room, the recommended by the European division of World Health Organization – WHO CO_2 concentration limit of 1000 ppm can be exceeded [4–6]. A person spends at least 1/3 of his life inside the house or flat, therefore, the only way to ensure adequate air quality in residential spaces is to replace the air with a well-functioning ventilation system that channels exhaust air and introduces fresh air from the building's environment to the living space.

In Poland, the parameters of indoor air quality in residential buildings are specified in the Polish PN-B-03430:1983/Az3:2000 Standard: Ventilation in public housing and public buildings – Requirements [7]. According to the aforementioned standard, air parameters affecting the comfort of indoor climate are: air temperature, air humidity, physical and biological quality of air and CO_2 concentration. According to [7] the apartment ventilation system should provide at least:

a) supply of outdoor air to living rooms and kitchens with outside windows;

b) removal of exhausted air from the kitchen, bathroom, separate toilet, and auxiliary room with no window (closet, dressing room) [7].

In order to be able to compare the efficiency of various ventilation systems for residential spaces, it is necessary to determine measurable flow parameters such as local velocity and temperature of air distribution, pollution concentration distributions, etc., characterizing the essential features of air distribution and its target effects and performance [8]. Taking into account the above, it was decided to conduct research to determine the efficiency of various ventilation systems for multi-family residential buildings, with particular regard to natural ventilation. The selection of research facilities equipped with natural ventilation systems results from the fact that this ventilation system is the most common solution in multi-family residential buildings in Poland.

Materials and methods

Two research facilities were selected to compare the efficiency of natural ventilation systems in different multi-family buildings. Object 1 is a residential area of 56 m^2, located on the 3^{rd} storey in a 11-storey multi-family building, built in the technology of a large plate. Object 2 is a residential building of 60.0 m^2, located on the 3^{rd} storey in a 4-storey building, built in the traditional technology. There are two people living in both houses, which, taking similar area of objects into account, will allow to compare the results of the research. The layouts of both objects are shown in Fig. 1.

The studied objects are equipped with a ductile natural ventilation system. In buildings up to 25 m (7 storeys) above ground level, gravity or mechanical ventilation can be used. For buildings above 25 m, only mechanical ventilation should be used. The dwelling chosen as object 1, despite being higher than 25 m, has not been equipped with mechanical ventilation. This is due to the fact that it was built in the 1970s when the standards that were in force at that time allowed natural ventilation for such high buildings.

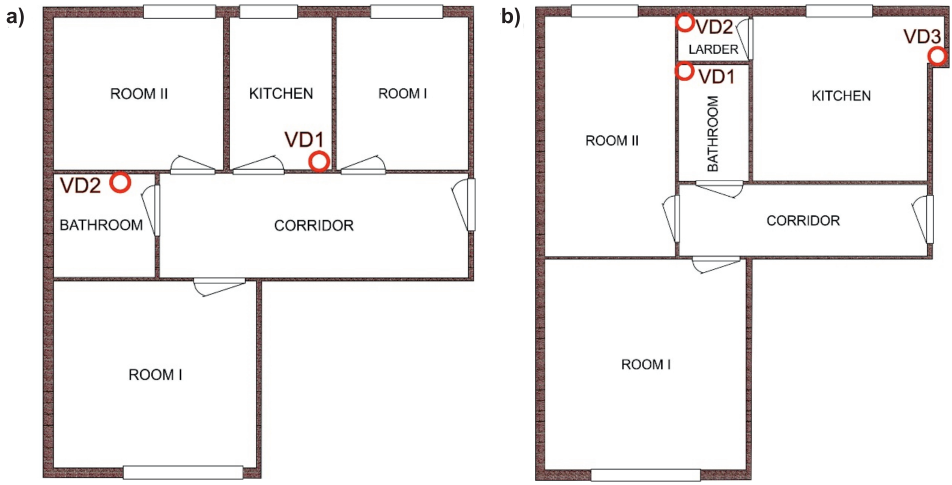

Fig. 1. Floor plans of facilities: a) apartment 1, b) apartment 2. VD – ventilation ducts

The scope of the research included:

– studying the performance of the gravitational ventilation system of the objects during the heating season, as well as after the heating season, by measuring the air flow for the whole object's area;

– investigation of the effect of changes in the air flow rate on the concentration of carbon dioxide and relative humidity in the object.

In buildings equipped with a natural ventilation system, exhaust air is discharged from kitchens, bathrooms, toilets, and auxiliary rooms with no windows through the exhaust holes located in the upper part of a wall and connected to the vertical gravity ventilation ducts. Object 1 contains two ventilation ducts. Channel inlets are located in the bathroom and the kitchen (location of inlets in individual rooms is shown in Figure 1a). In contrast, there are 3 channels of gravity ventilation in Object 2. Ventilation inlets are located in the bathroom, the pantry and the kitchen (Fig. 1b).

The ventilation air flow in the analyzed objects was determined by summing ventilation air flows for inlets to all ventilation ducts in the given objects. The air flows in the individual ventilation ducts were calculated on the basis of the air velocity in the individual inlets of the ventilation ducts. A Kestrel 2000 anemometer with a resolution of 0.1 m/s and accuracy of ± 3% was used for speed measurement. At the same time, measurements of indoor air temperature (T_w) and outdoor temperature (T_z) were performed. The relative humidity of indoor air was also recorded (±), as well as atmospheric pressure (p). These measurements were made using the Commeter C4130 hytherograph, which measures temperature to the nearest 0.4°C, relative humidity to the nearest ± 2.5% and atmospheric pressure to the nearest ± 2 hPa. The main parameter determining the efficiency of the ventilation system, for the purpose of the research, was the concentration of carbon dioxide, recorded in all the rooms of analyzed objects. It is a widely used method for analysis of ventilation systems, adopted by many researchers

[9–13]. Measuring of carbon dioxide concentration was made at three measuring points in each room using AZ 77535 multifunctional carbon dioxide gauge with accuracy of 30 ppm ± 5% of reading. On the basis of obtained results,, the approximate carbon dioxide concentration for the whole area of objects was calculated.

The study of the ventilation system and air parameters in analyzed objects was conducted between September 2015 and May 2017, *ie* during and after the heating season.

All indoor air quality tests were performed at different heights and at different locations in individual rooms and then average values were determined. The same test procedure was used for both objects. Measurements were carried out in five-day cycles, continuously recording carbon dioxide concentrations, while remaining air parameters were measured every 15 minutes 24 hours a day. The study was conducted only on working days when the daily cycle of residents' activities was almost identical. This approach allowed to compare the results obtained at different times of the year and with different weather conditions.

Results and discussion

For both research facilities located at various points in Opole, outdoor air parameters were recorded. The analysis of the obtained results showed that the background of CO_2 in the outdoor air reaches an average value of 540 ppm. When it comes to temperature, its average monthly values correspond to the values given in the Polish climate database compiled by IMGW for the meteorological station of Opole [17].

The examples of variation of carbon dioxide concentration in the examined objects during the heating season and summer season are shown in Fig. 2.

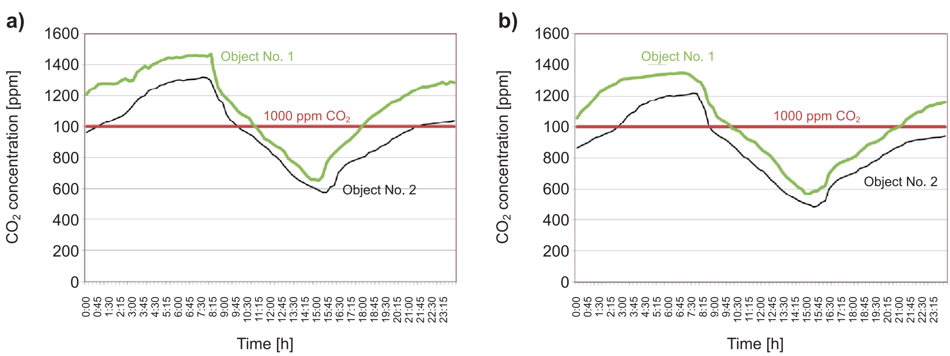

Fig. 2. Selected CO_2 concentration variation during: a) the heating season, b) summer season

The examples of variation of the ventilation flow in examined objects are shown in Fig. 3.

The analysis of the data presented in Fig. 3 shows that in both analyzed objects natural ventilation systems do not meet the requirements of the Polish PN-B-03430:1983/Az3:2000 Standard [7] for the required air exchange rate. It should also be noted that, after the

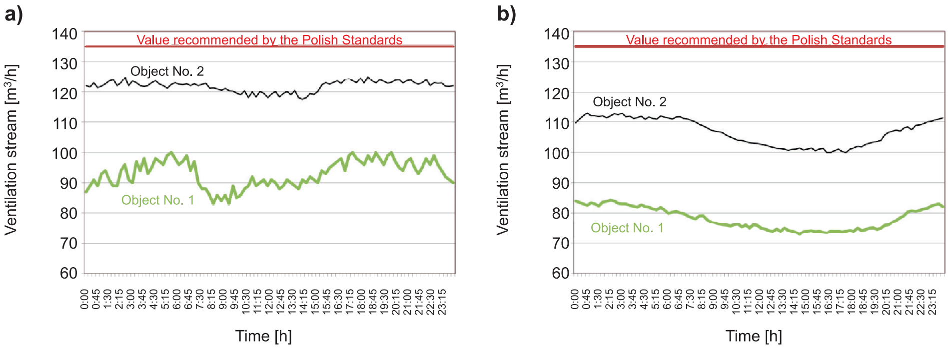

Fig. 3. Selected ventilation stream variation during: a) the heating season, b) summer season

heating season, in the case of both surveyed objects, the ventilation air flow is clearly reduced. During the heating season, both objects were periodically ventilated by opening the windows, but due to the reduction of the air flow, no significant reduction in carbon dioxide concentrations was observed in the surveyed objects (Fig. 2).

The examples of relative atmospheric humidity in the examined objects are shown in Fig. 4.

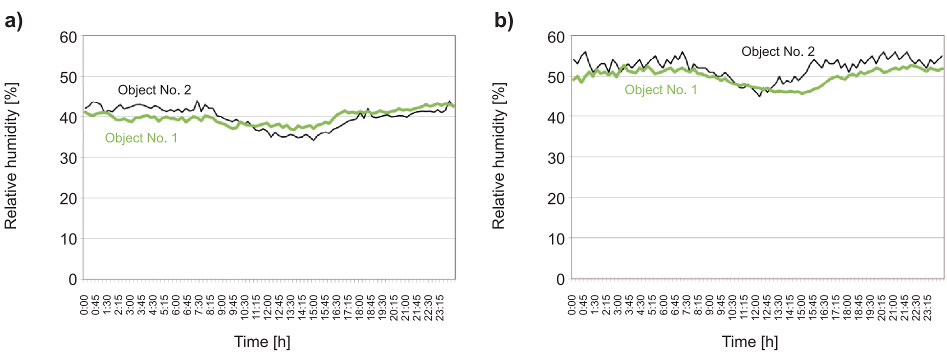

Fig. 4. Selected relative humidity variation: a) during the heating season, b) summer season

The measurements of carbon dioxide concentrations during night hours (22:00–6:00) were also conducted in the room where the occupants slept. The values of carbon dioxide concentration depending on the way of the room ventilation in a given objects are presented in Table 1.

On the basis of the obtained research results it was estimated that a person staying in the analysed object is the source of an average of 11.5 dm^3 of carbon dioxide per hour. This value is variable and highly dependent on the type of physical activity (there were clear differences between hours of sleep and hours of greater physical activity of the occupants). The value of the average CO_2 emission for a single occupant of the object allowed to determine the optimal multiplicity of air exchange in the object performed by the ventilation system.

Table 1

Maximum carbon dioxide concentration in the rooms in which the occupants slept, with different methods of ventilating the room

Way of the room ventilation	Maximum carbon dioxide concentration [ppm]	
	Object 1	Object 2
Closed window and door (during the heating season)	4750	4460
Open door (during the heating season)	1540	1320
Closed door and micro ventilation through the window (summer season)	1670	1250
Open door and micro ventilation through the window (summer season)	1000	920

The tests of indoor air parameters in both research objects showed that despite the natural ventilation system used in accordance with the requirements of Polish PN-03430:1983/Az3:2000 Standard, after 3 hours of continuous occupancy, the concentration of carbon dioxide exceeded the recommended value of the European division of World Health Organization (WHO), which is 1000 ppm [4, 5]. On the other hand, the relative humidity value of the air, even though the number of occupants in the object increased, did not reach the recommended value, *ie* 50–60%.

Less effective operation of the natural ventilation system has been observed in the object 1. In the case of an 11-storey building, natural ventilation does not provide air exchange required by the Polish Standard for individual premises. For both research facilities, the efficiency of the natural ventilation system has been much lower after the heating season, but this can be significantly improved by regular ventilation of the premises. When outdoor air temperatures exceed 20^{o}C, additional intensive ventilation will not cause thermal discomfort to residents.

Based on the carbon dioxide emission factor determined during the test and the optimal multiplicity of air exchange in the object of 0.5 h^{-1}, the performance, fan-working period and cross-sections of wall ventilators can be chosen in such a way as to ensure optimal air exchange to obtain indoor climate recommended by the Polish Standard [6].

When planning a thermal efficiency improvement of a tall multi-family building such as the object 1, it is worth considering changing the existing natural ventilation system to individual ventilation of the flats with heat recovery system by means of recuperators. The wall recuperator is a heat exchanger with fresh air flow through the building's wall separately for each room (Fig. 5). In the wall recuperator, the used warmed up air is thrown out of the room and heats up the ceramic element. Then the device changes the direction of air flow and fresh air is drawn from the building's surroundings into the room and heated by the heat stored in the ceramic element. The use of this type of wall recuperators in all the rooms allows to recover up to 85% of the heat from the air evacuated from the dwelling to the environment compared to the current ventilation system of the objects under test. The use of a wall recuperator in a room where the occupants sleep will keep the optimal concentration of carbon dioxide

Fig. 5. Scheme of the heat recovery inside wall [18]

while ensuring thermal comfort and reducing heat loss from the building. Installation of the centralized mechanical ventilation with heat recovery in such a large facility is technically very difficult to implement, however, by installing separate ventilation systems for every flat, equipped with wall recuperators, the modernization of the ventilation system can be done without major renovations of the entire building.

Conclusions

The results of the studies show that the natural ventilation systems of multi-family buildings do not fulfill their role. The lack of opportunity to regulate ventilation air flow, limited fresh air flow (during the heating season, resulting from the tight closing of the premises to minimize heat loss), and the use of gas cookers reduces the supply of oxygen to the living space. This results in a rapid increase of carbon dioxide concentration in the air and adversely affects the microclimate of the premises and the well-being of the residents.

Based on the results of the study, it was calculated that each person staying in the analyzed object is the source of carbon dioxide emission of 11.5 dm^3 per hour. Established during the tests the optimal multiplicity of air exchange in the object is 0.5 h^{-1}.

The installation of additional wall ventilators allows for an increase in the supply of fresh air to the premises, but significantly reduces the thermal comfort of the rooms and causes significant heat loss. For the analyzed objects, the most advantageous solution is to change the existing natural ventilation system to individual ventilation system with heat recovery by means of wall recuperators. The results of the research also indicate the need to make changes in construction legislation, forcing the owners of existing multi-family buildings to change natural ventilation systems to mechanical ventilation systems, preferably with heat recovery means.

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SKUTECZNOŚĆ RÓŻNYCH TYPÓW WENTYLACJI NA JAKOŚĆ POWIETRZA W BUDYNKACH WIELORODZINNYCH

Samodzielna Katedra Inżynierii Procesowej
Uniwersytet Opolski

Abstrakt: Przepisy prawne oraz normy obligują do kontroli systemów wentylacji budynków jedynie pod względem prędkości strumienia powietrza, co niestety nie zawsze gwarantuje zalecaną ze względów zdrowotnych jakość powietrza. W pracy podjęto badania skuteczności różnych typów wentylacji wielorodzinnych budynków mieszkalnych ze szczególnym uwzględnieniem wentylacji naturalnej, stanowiącej najczęściej spotykane rozwiązanie w budynkach mieszkalnych w Polsce. Badano wpływ skuteczności wentylacji na podstawowe parametry charakteryzujące jakość powietrza, tj. stężenie ditlenku węgla, wilgotność względną oraz temperaturą. Badano również możliwość regulacji pracy systemu wentylacji budynków wielorodzinnych w zależności od zmieniających się parametrów jakości powietrza. Wyniki przeprowadzonych badań wykazały, iż w przypadku wielorodzinnych budynków mieszkalnych systemy wentylacji naturalnej nie spełniają swojej funkcji i powinny zostać zastąpione przez systemy wentylacji mechanicznej (najlepiej nawiewno-wywiewne z odzyskiem ciepła).

Słowa kluczowe: system wentylacji, budynki wielorodzinne, jakość powietrza, stężenie ditlenku węgla, wilgotność powietrza