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AIR DISTRIBUTION, AIR QUALITY AND ENERGY

ROZDZIAŁ POWIETRZA, JAKOŚĆ POWIETRZA I ENERGIA

A b s t r a c t

The ventilation and distribution systems are responsible for providing healthy and comfortable environment for occupants. The non-uniformity pollution related to a distribution system has been investigated with the use of the CO_2 concentration measurement respecting the indoor air quality and energy performance. The objective of this research is to evaluate the performance of natural ventilation systems in school buildings and to carry out the experimental measurements in order to analyse possible methods of the indoor air quality improvement with respect to energy consumption in the school buildings. For the experiment presented in the paper several types of air distribution have been selected within the frame of conventional mixing ventilation system and existing natural ventilation system.

Keywords: *energy capacity index*, *air distribution index*, *ventilation*, *distribution*

S t r e s z c z e n i e

Systemy wentylacji i rozdziału powietrza są bardzo ważne dla utrzymania zdrowych i komfortowych warunków dla użytkowników budynku. W artykule przedstawiono badania nierównomierności rozkładu skażenia związanego z systemem rozdziału powietrza, polegające na pomiarze stężenia CO_2, z uwzględnieniem jakości powietrza i efektywności energetycznej. Celem obecnych badań jest ocena sprawności wentylacji naturalnej w budynkach szkolnych, a także wykonanie pomiarów doświadczalnych, umożliwiających określenie sposobu poprawy jakości powietrza i ograniczenie zużycia energii w szkołach. Do prezentowanego eksperymentu wybrano kilka typów rozdziału powietrza, bazujących na konwencjonalnym systemie wentylacji mieszanej i istniejącym systemie wentylacji naturalnej.

Słowa kluczowe: *indeks energetyczny*, *indeks rozdziału powietrza*, *wentylacja*, *dystrybucja*

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1. Introduction

The ventilation rates and primarily ventilation systems as well as air distributions are the keys factors contributing to the improvement of IAQ in the breathing zone. The field measurement confirmed that the indoor air quality is generally unacceptable at lower ventilation rates due to disrespecting the occupancy density of the spaces. Recent studies on the indoor air quality confirmed the influence of the ventilation rate and distribution system on comfort and hygienic levels in school buildings. The experiments indicate that the increase of the indoor air quality with higher ventilation levels substantially improve the school performance (1–3%) [1]. The ventilation system should ensure not only thermal comfort and an appropriate hygienic level indoor, but also air distribution to the occupancy zone in order to increase the efficiency of pollutants removal, pollutants displacement, pollutants dilution and energy savings.

2. Objectives of the research

The objective of this research is to evaluate the performance of natural ventilation systems in school buildings and to perform the experimental measurements in order to analyse possible methods of the indoor air quality improvement respecting energy in school premises. For the presented experiment several types of air distribution have been selected within the framework of a conventional mixing ventilation system and an existing natural ventilation system.

The distribution systems have been installed in identical classrooms of a naturally ventilated school building. The carbon dioxide concentrations have been analysed under the indoor climate parameters (temperature, relative humidity and air movement).

Three different categories of the indoor environment are specified for the indoor ventilated spaces.

Category I is related to a high standard and is recommended for spaces occupied by persons with poorer state of health or special requirements, e.g. persons who are ill, the disabled, very young children and elderly persons. Category II is related to a normal standard and should be used for new buildings and renovations. Category III is related to an acceptable, moderate standard and may be used for existing buildings. The values exceeding the above categories criteria should only be accepted for a limited part of the year.

Recommended values of the indoor CO_2 concentration for ventilated buildings are estimated as the concentration above the outdoor concentration. The recommended CO_2 concentration is 350 ppm for category I, 500 ppm for category II, 800 ppm for category III and over the 800 ppm for category IV above the background outdoor concentration for energy calculations and demand control [2].

3. Methods

Presented experimental measurements deal with non-uniformity distribution of CO_2 concentration respecting 5 air distribution schemes (1 natural and 4 mixing ventilation) in 24 measuring points. Consequently, the energy demand calculations were done for every distribution system.

21 of the measuring points were located within the occupied zone and 3 of them – outside of it. As an experimental model room a university classroom was used. The model room was used especially for these measuring purposes. The floor area of the model is 62 m^2 and the ceiling height is 3,1 m. The occupancy simulators and furniture arrangements were designed in such a way as to imitate the field measurement conditions (Fig. 1).

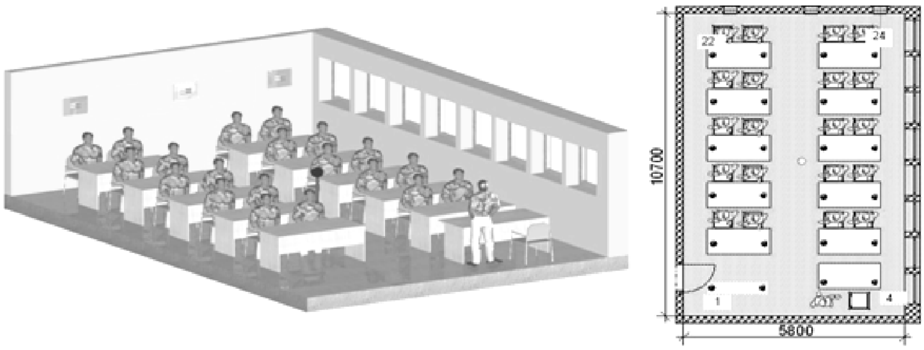

Fig. 1. Experimental model room measuring points
Rys. 1. Punkty pomiarowe w eksperymentalnym modelu pomieszczenia

To produce the heat-load corresponding to a fully occupied classroom, heat source--simulators were placed in the room. At the same time, carbon dioxide concentration was simulated by 21 CO_2 person-simulators which were placed in the room in the breathing zone of a sitting person (1.05 m above the floor).

Table 1

Characteristic of steady state conditions

Ventilation system	Total ventilation rate q_{TOT} [l/s]	Number of distributions	Average surface temperature [°C]	Average supply air temperature [°C]		Average supply air humidity [%]	Average CO_2 concentration [ppm]		Air velocity [m/s]
				Θas	θoa	φas	Co	Ci	
Natural ventilation	17	1	18.5	22.0 ± 2°C	15.5	50	360	378	< 0.15
Mixing ventilation	55	4	18.5	22.0 ± 2°C	15.5	50	360	378	< 0.35

All measurements (except natural ventilation) were done with ventilation rate q_{TOT} = 55 [l/s] which corresponded with 2.6 [l/s · source] and the air supply temperature was kept at constant level 22.0 ± 2°C. An average outdoor air temperature was 15.5°C, which is estimated as an average outdoor air temperature of the period excluding January, February and December in Slovakia. An average initial indoor CO_2 concentration in the model room was 378 ppm and an average outdoor concentration was 360 ppm. All measurements were carried out under steady state conditions (Tab. 1).

The location of air exhaust and air supply jets within the mixing ventilation frame varied accordingly to air distribution schemes. The reference (zero) ventilation as well as the most ineffective distribution system is referred to as case 1 (Fig. 2).

The supply device was designed with the use of the duct located 0.8 m under the ceiling. The air jet was supplied with higher velocity than jet impinging directly on the floor or displacement ventilation. They are also called fast momentum supply devices that cause entrainment of the ambient air into the air jet. The air was supplied by 3 designed supply jets. The exhaust device was realised by 3 exhausted jets at all measurements, only their location under the floor was changed. The experimental model classroom was ventilated perfectly (the indoor CO_2 concentration was close to the outdoor one) before the measurements. The ventilation rates were adjusted to the designed values. The carbon dioxide concentrations for each measuring point (24 measuring points) at the height of 1.05 m at the same time were recorded at the same time after the CO_2 concentrations became quasi stabilised. The devices were tested by measuring CO_2 concentration, air temperature, surface temperature and air velocity at the height of 1.05 m above the floor in the breathing zone.

The air distribution index (ADI) used for the ventilation systems comparison was also applied to analyse the designed distribution systems with regard to IAQ [5]. To assess the ventilation system effectiveness in measurements, the effectiveness for heat removal (ε_T) and contaminant removal (ε_C) are used together with the predicted percentage dissatisfied (PPD) for thermal comfort and percentage dissatisfied (PD) for air quality [6].

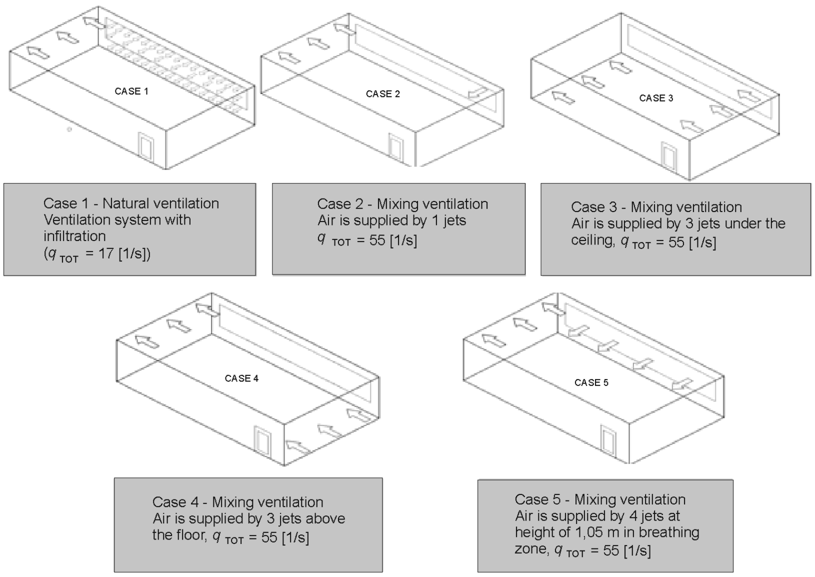

Fig. 2. Ventilation and distribution schemes
Rys. 2. Schemat wentylacji i rozdziału powietrza

4. The air distribution indices

The heat removal effectiveness (ε_T) and contaminant removal effectiveness (ε_C) are defined (1, 2). The effectiveness ranges for ε_C is evident from Tab. 2.

Table 2

The ε_C value range

Effectiveness ε_C	Consequences
$0 < \varepsilon_C < 1.0$	Cumulating
$\varepsilon_C = 1.0$	Total mixing
$1.0 < \varepsilon_C < \infty$	Dilution

$$\varepsilon_C = \frac{C_E - C_s}{C_m - C_s} \; [-] \tag{1}$$

$$\varepsilon_\theta = \frac{\theta_E - \theta_S}{\theta_m - \theta_S} \; [-] \tag{2}$$

where

θ_E – air exhaust temperature,
θ_S – air supply temperature,
θ_m – mean air temperature in occupancy zone,
C_E – exhaust air CO_2 concentration,
C_S – supply air CO_2 concentration,
C_m – mean CO_2 concentration in occupancy zone.

PD and PPD values represent predicted percentage of large panel dissatisfied with thermal comfort and it is defined as a function of predicted mean vote (PMV) (3, 4). Air distribution index is influenced by comfort number (NT) and air quality number (NC) (5, 6, 7).

$$\mathrm{PPD} = 100 - 96 \cdot e^{-(0.03353 \cdot \mathrm{PMV}^4 + 0.2179 \cdot \mathrm{PMV}^2)} \quad [\%] \tag{3}$$

$$\mathrm{PD} = 396 \cdot e^{-1.83 . q t_{\mathrm{TOT}} 0.25} \quad [\%] \tag{4}$$

where:
q_{TOT} – total ventilate rate per source [l/s · source]

$$N_T = \frac{\varepsilon_T}{\mathrm{PPD}} \tag{5}$$

$$N_C = \frac{\varepsilon_C}{\mathrm{PD}} \tag{6}$$

$$\mathrm{ADI} = \sqrt{(N_T \cdot N_C)} \quad [-] \tag{7}$$

5. Indoor air quality

The indoor air quality depends on many parameters and sources, e.g. a number of people, emissions from activities, emissions from furnishing, flooring materials, etc. With respect to ventilation, one should be particularly concerned with humidity, as it is related to most of the adverse health effects and building disorder. Several of these sources cannot be influenced or controlled by the designer.

Required design ventilation rates shall be specified as an air change per hour for each room, and/or an outside air supply and/or required exhaust rates, or given as an overall required air-change rate. Most national regulations and codes give precise indications on detailed air-flows per room and shall be followed. The required rates shall be used for designing mechanical-, natural- and exhaust ventilation systems.

The presented experimental research deals with the non-uniformity distribution of CO_2 concentration in an experimental model room. It also concentrates on a different indoor air quality as detected for uniform pollution production in individual cases.

The air distribution assessment refers to the air distribution index presented in Tab. 3. All required input data were obtained by measurements. The higher ADI, the better and more effective air distribution can be achieved. The highest air distribution index was calculated for the distribution represented by case 5 respecting the designed ventilation rate for category II and for distribution represented by case 2 respecting the designed ventilation rate for category I. However ADI = 5.07 (case 2) and ADI = 4.11 (case 4) only in a small zone of the model room were achieved. The air distribution represented by case 4 mostly (91%) met the category II.

Table 3

Air distribution related to IAQ (CO_2 concentration)

Case	Cat.	q_{TOT} [l/s·source]	PD	Cm	ε_c	N_c	PMV	PPD	ε_t	N_t	ADI
			[%]	[ppm]	[–]	[–]		[%]	[–]	[–]	[–]
	I	0.81	69.6	–	–	–					–
Case 1	II	0.81	69.6	–	–	-	1.80	67.02	2.00	2.98	–
	III	0.81	69.6	1585	1.22	1.75					2.28
	I	2.62	38.5	640	2.46	6.40					5.07
Case 2	II	2.62	38.5	1059	0.99	2.56	1.45	48.19	1.93	4.01	3.21
	III	2.62	38.5	931	1.21	3.14					3.55
	I	2.62	38.5	–	–	–					–
Case 3	II	2.62	38.5	–	–	–	1.60	56.35	1.33	2.37	–
	III	2.62	38.5	1005	1.30	3.37					2.82
	I	2.62	38.5	710	1.56	4.05					4.11
Case 4	II	2.62	38.5	735	1.46	3.78	1.20	35.25	1.47	4.16	3.97
	III	2.62	38.5	862	1.09	2.83					3.43
	I	2.62	38.5	–	–	–					–
Case 5	II	2.62	38.5	834	1.41	3.67	0.88	21.35	1.67	7.81	5.35
	III	2.62	38.5	904	1.23	3.19					4.99

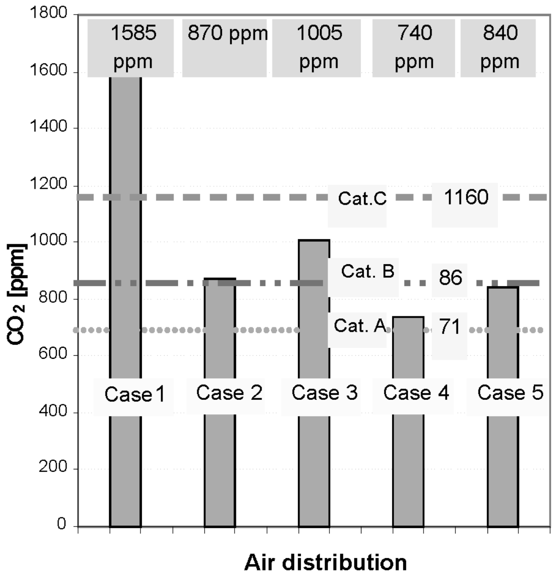

Fig. 3. Air distribution related to IAQ (CO_2 concentration)
Rys. 3. Dystrybucja powietrza w zależności od IAQ (stężenie CO_2)

The mean indoor CO_2 concentrations for individual cases are presented in Fig. 3. The highest concentrations were measured for case 1 – no ventilation (only infiltration). The lowest CO_2 concentrations were detected for mixing ventilation in case 4. No concentrations exceeded category I, and 3 cases exceeded only category II (case 2, 4, 5).

6. Energy consumption

Ventilation systems consume energy, primarily because the ventilation air is thermally conditioned, i.e., heated, cooled, and dehumidified or humidified. In mechanically ventilated buildings, the operation of ventilation fans also consumes energy. This paper presents specific thermal loss for 5 distributions schemes. The specific thermal losses were calculated of eq. 8

$$Hv = 0,264 \cdot n \cdot Vb \quad \text{[W/K]} \tag{8}$$

where:

n – air change level per hour,
Vb – building volume.

Table 4 present results of specific thermal losses and energy capacity index (ECI). The lower energy capacity index ECI, the better and more effective energy consumption in rate to air distribution index ADI (criterion for indoor air quality).

Table 4

Results of specific thermal losses and ECI

Ventilation system	Total ventilation rate q_{TOT} [l/s]	Total ventilation rate q_{TOT} [m^3/h]	*n* [1/hod]	*Hv* [W/K]	Pre $\Delta\Theta$ = 15 [K/W]	Category	ADI [–]	ECI ($\Delta\Theta$/ADI) [–]
Case 1	17	61,2	0.32	16.22	243.3	A	–	–
						B	–	–
						C	2.28	106.7
Case 2	55	198	1.03	52.21	783.15	A	5.07	154.4
						B	3.21	243.9
						C	3.55	220.6
Case 3	55	198	1.03	52.21	783.15	A	–	–
						B	–	–
						C	2.82	277.7
Case 4	55	198	1.03	52.21	783.15	A	4.11	190.5
						B	3.97	197.3
						C	3.43	228.3
Case 5	55	198	1.03	52.21	783.15	A	–	–
						B	5.35	146.4
						C	4.99	156.9

7. Conclusion

The presented research focuses on the comparison of 5 air distribution systems, which aims at selection of the most suitable distribution of mixing ventilation for a studied model room. The best ventilation strategy in relation to the predicted ADI value seems to be the mixing ventilation with air distribution represented by case 5. However, with respect to the predicted CO_2 concentration, the mixing ventilation presented in case 4 seems to be the most effective.

The paper also deals with the comparison of 5 air distribution systems with the aim to find out the most suitable distribution for a studied model room respecting an energy criterion. The most efficient energy consumption was stated in case 1 (value ECI = 106.7), yet in relation to predicted ADI = 5.35 the value seems to be better for case 5 (category II) with value ECI = 146.4.

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