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INDOOR AIR QUALITY – MEASUREMENTS AND CFD SIMULATIONS

IAQ – POMIARY I SYMULACJE CFD

Odpowiedzialność za poprawność językową ponoszą autorzy

A b s t r a c t

This paper presents an experimental building recently completed and currently occupied. The paper contains a brief description of the building, the method and location of the measurement equipments and monitoring of the building‘s operation. Initial results show that the operation of the building meets some of the requirements for passive buildings.

Keywords: measurement, low energy buildings

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

Artykuł porównuje 5 systemów obiegu powietrza i 17 schematów obiegu powietrza. Skonfrontowane zostały wyniki symulacji CFD i doświadczalne pomiary rzeczywiste. Badania określają także efektywność wentylacji indywidualnie dla każdego systemu wentylacji, a także ujawniają niejednorodne zanieczyszczenie w kontekście zmian schematu obiegu powietrza. Wiele różnych poszukiwań odpowiedzi na nurtujące pytania wskazuje na to, że problemy IAQ pojawiają się nie tylko z powodu niewystarczającej wentylacji, ale także w przypadku, gdy umiejscowienie czerpni i wyrzutni nie jest właściwe.

Słowa kluczowe: symulacje CFD, wentylacja mieszana, wentylacja wyporowa, przepływ wentylacyjny, wentylacja osobista, wskaźnik obiegu powietrza, dwutlenek węgla

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1. Introduction

The objective of this research is to evaluate the performance (objective and subjective parameters) of natural and mechanical ventilation systems in school buildings and to perform the REM in order to analyze possible ways for indoor air quality improvement respecting energy efficiency in the schools. Several types of air distribution schemes (17 schemes) were selected for presented experiment within the frame of mechanical ventilation systems (mixing, personal, confluent and displacement) and existing natural ventilation system (infiltration by windows).

The distribution systems were installed in naturally ventilated school building in identical classrooms. The carbon dioxide (CO_2) concentrations were studied under indoor climate parameters (temperature, relative humidity and air movement). Three different categories for evaluating of indoor environment are specified for indoor ventilated spaces. Category I corresponds to a high level of expectation and is recommended for spaces occupied by very sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons. Category II corresponds to normal level of expectation and should be used for new buildings and renovations. Category III corresponds to an acceptable, moderate level of expectation and may be used for existing buildings. Values outside the criteria for the above the categories should only be accepted for a limited part of the year.

Recommended values of indoor CO_2 concentration for ventilated buildings are estimated as concentration above outdoor concentration. 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 background outdoor concentration for energy calculations and demand control [1].

2. Methods and conditions

Presented REM and CFD simulations concern the performance and ventilation efficiency. Ventilation systems are presented by 17 air distribution schemes (1 natural, 10 distribution schemes of mixing ventilation, 1 distribution scheme of confluent ventilation, 4 distribution schemes of displacement ventilation and 1 distribution scheme of personal ventilation).

Distribution schemes are devided to 3 corpuses (for CFD simulations). Corpus A present total ventilation rate 16 l/s (natural ventilation, infiltration – distribution scheme 1), corpus B present total ventilation rate 69,3 l/s (distribution schemes 2, 3A, 4A, 5, 6, 7, 8, 9, 10, 11, 12, 13A, 14A, 15A, 16A and 17A) and corpus C present total ventilation rate 108,8 l/s (distribution schemes 3B, 4B, 13B, 14B, 15B, 16B and 17B).

The REM was realized only for distribution schemes 1, 2, 3A, 4A, 4B and 5 (because of difficult technical conditions for measurements).

The results from CFD and REM were compared (1, 2, 3A, 4A, 4B and 5) and deviation for others CFD without REM (2, 3AB, 4AB, 5, 6, 7, 8, 9, 10, 11, 12, 13AB, 14AB, 15AB, 16AB and 17AB) was determined.

The 21 measuring points were located in occupied zone and 3 points out of this one for REM. As experimental model room for study investigations the university classroom was used. The model room is especially used for these measuring purposes. The floor area of model is 62 m^2 and the ceiling height is 3,1 m. Occupancy simulators and furniture arrangements were designed to fit the field measurement conditions (Fig. 1).

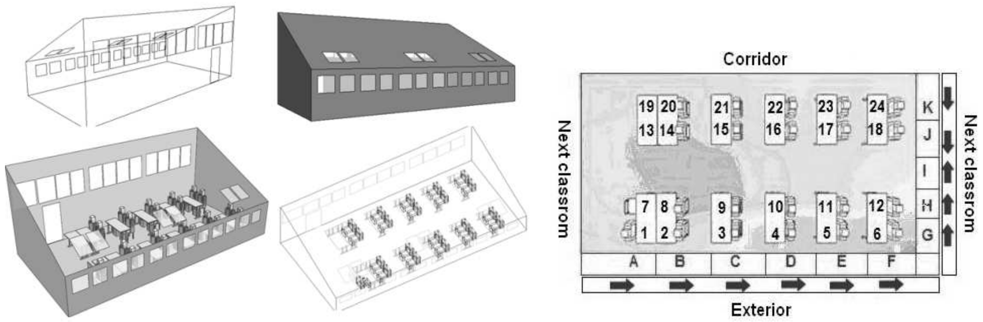


Fig. 1. Experimental model room and measuring points

Rys. 1. Eksperymentalny model pokoju i punkty pomiarowe

To produce the heat-load corresponding to fully occupied classroom, heat source-simulators were placed in the room. Also carbon dioxide concentrations was simulated by 21 CO_2 person-simulators which were placed in the room in breathing zone of sitting person (1,05 m above the floor).

All measurements were carried out under steady state conditions. The parameters of steady state conditions are presented describe in Table 1.

Table 1

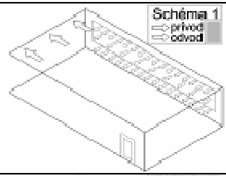
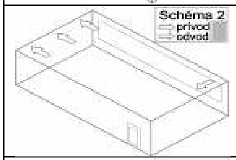
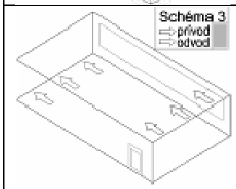
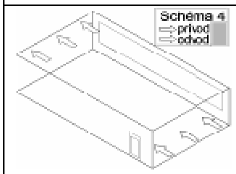
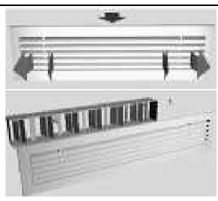
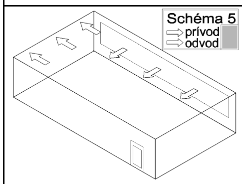
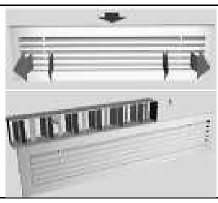
Characteristics of steady state conditions

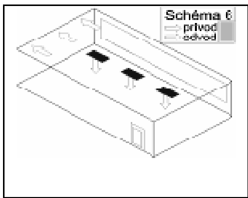
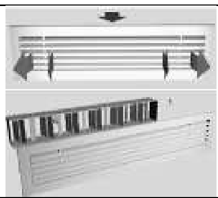
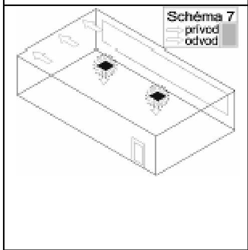
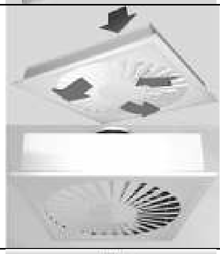
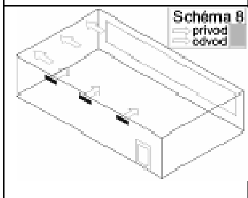
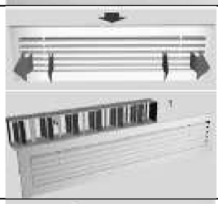
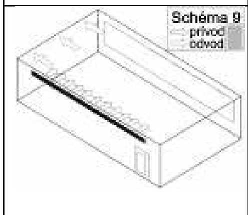
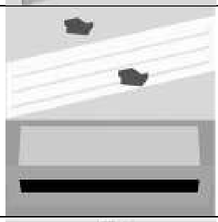
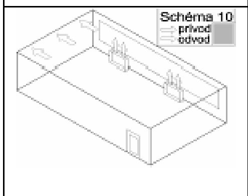
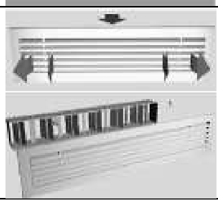
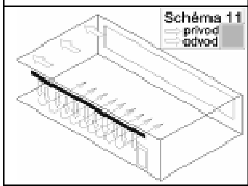
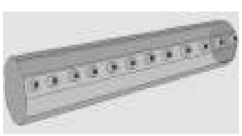
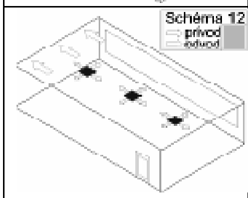
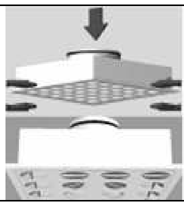
Ventilation system	Total ventilation rate q_{TOT} [l/s]	Number of distributions	Average surface temperature [°C]	Average supply air temperature [°C]		Average supply air humidity [%]	Average CO_2 concentration [ppm]		Air velocity [m/s]
				Θas	θoa	φas	Co	Ci	
Natural ventilation	16	1	18,5	22,0 ± 2°C	15,5	50	360–400	378	< 0,15
Mechanical ventilation A (CFD+REM)	69,3	16	18,5	22,0 ± 2°C	15,5	50	360–400	378	< 0,25
Mechanical ventilation B (CFD)	108,8	7	18,5	22,0 ± 2°C	15,5	50	360–400	378	< 0,25

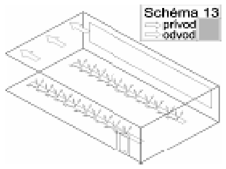
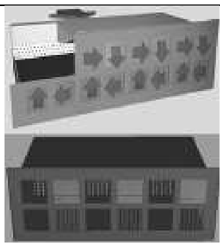
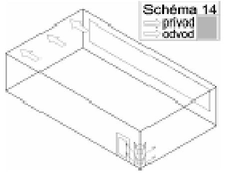
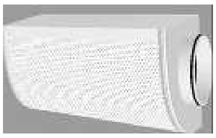
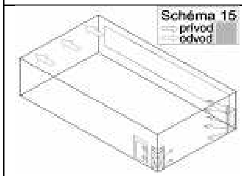
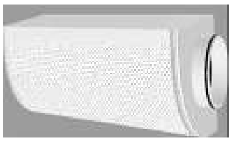
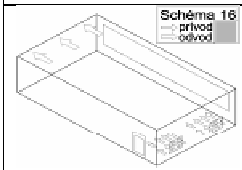
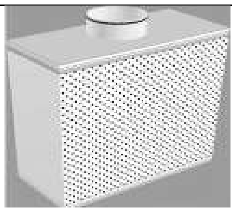
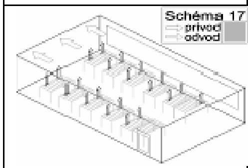
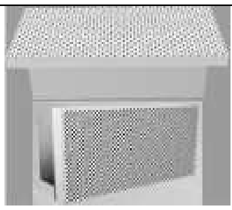
Individual distribution schemes in Table 2 present illustration sketch of distribution scheme, figure of distribution element, the methods of research and detailed ventilation characterization. The ventilation is characterized by position of air supply input and air exhaust output but also by ventilation rates.

Table 2

Distribution schemes – characterization and describe

Distribution scheme	Distribution element	Method	Ventilation characterization	
	Infiltration by windows SUPPLY EXHAUST	REM CDF- IESVE	1	Natural ventilation q_{TOT} = 16 [l/s]
	1 input by circle duct SUPPLY EXHAUST	REM CDF- IESVE	2	Mixing ventilation, supply by 1 inlet in duct, q_{TOT} = 69,3 [l/s]
		REM CDF- IESVE	3A	Mixing ventilation, supply by 3 inlets in duct under ceiling, angle lamella –45°, q_{TOT} = 69,3 [l/s]
			3B	Mixing ventilation, supply by 3 inlets in duct under ceiling, angle lamella –45°, q_{TOT} = 108,8 [l/s], category III (STN EN 15 251)
		REM CDF- IESVE	4A	Mixing ventilation, supply by 3 inlets in duct above floor, angle lamella +45°, q_{TOT} = 69,3 [l/s]
			4B	Mixing ventilation, supply by 3 inlets in duct above floor, angle lamella +45°, q_{TOT} = 108,8 [l/s], category III (STN EN 15 251)
		REM CDF- IESVE	5	Mixing ventilation, horizontal convection, 3 inlets under windows, q_{TOT} = 69,3 [l/s]

		REM CDF-IESVE	6	Mixing ventilation, vertical convection, 3 inlets under ceiling, q_{TOT} = 69,3 [l/s]
		REM CDF-IESVE	7	Mixing ventilation, vertical convection, 2 whirling inlets under ceiling, q_{TOT} = 69,3 [l/s]
		REM CDF-IESVE	8	Mixing ventilation, horizontal convection under ceiling, angle lamella 0°, 3 inputs on side wall, q_{TOT} = 69,3 [l/s]
		REM CDF-IESVE	9	Mixing ventilation, horizontal convection under ceiling, angle lamella 0°, 1 input on side wall, q_{TOT} = 69,3 [l/s]
		REM CDF-IESVE	10	Mixing ventilation, air convection to windows, 2 fancoil unit inputs under windows, q_{TOT} = 69,3 [l/s]
		REM CDF-IESVE	11	Confluen ventilation, air convection with angle –30° to wall, 1 confluent input on wall above students, q_{TOT} = 69,3 [l/s]
		REM CDF-IESVE	12	Mixing ventilation, vertical air convection, 3 multi-diffusor inputs (perforated) under ceiling, q_{TOT} = 69,3 [l/s]

		REM CDF-IESVE	13 A	Displacement ventilation, vertical air convection from floor, 2 line floor diffuser inputs, q_{TOT} = 69,3 [l/s]
			13 B	Displacement ventilation, vertical air convection from floor, 2 line floor diffuser inputs, q_{TOT} = 108,8 [l/s], category III (STN EN 15 251)
		REM CDF-IESVE	14 A	Displacement ventilation, 1 corner diffuser input in wall, q_{TOT} = 69,3 [l/s]
			14 B	Displacement ventilation, 1 corner diffuser input in wall, q_{TOT} = 108,8 [l/s], category III (STN EN 15 251)
		REM CDF-IESVE	15 A	Displacement ventilation, 2 corner diffuser inputs in wall, q_{TOT} = 69,3 [l/s]
			15 B	Displacement ventilation, 2 corner diffuser inputs in wall, q_{TOT} = 108,8 [l/s], category III (STN EN 15 251)
		REM CDF-IESVE	16 A	Displacement ventilation, 2 straight diffuser inputs in wall, q_{TOT} = 69,3 [l/s]
			16 B	Displacement ventilation, 2 straight diffuser inputs in wall, q_{TOT} = 108,8 [l/s], category III (STN EN 15 251)
		REM CDF-IESVE	17 A	Personal ventilation, vertical air convection, 21 perforated inputs integrated in desk, q_{TOT} = 69,3 [l/s]
			17 B	Personal ventilation, vertical air convection, 21 perforated inputs integrated in desk, q_{TOT} = 108,8 [l/s], category III (STN EN 15 251)
REM – real experimental measurements				
IESVE – dynamic simulation software CFD				

3. Results and discussion

The field measurements in-situ (tracer gas technique by CO_2) and CFD simulations in IESVE 6.0.0 for 5 different ventilation systems confirmed that the indoor air quality in the schools is generally unacceptable (out of category I, II and III) at lower ventilation rates for

NV because of not respecting the occupancy density. Some distribution schemes of MV, DV and PV represent category I, II - acceptable.

The simulations results showed that the main problem is also space geometry characterization not only distribution systems. The simulation Scheme 1 is presented as the worst distribution scheme respecting IAQ and Scheme 15B, 17B as the best distribution scheme respecting IAQ. The results are presented on Figure 2.

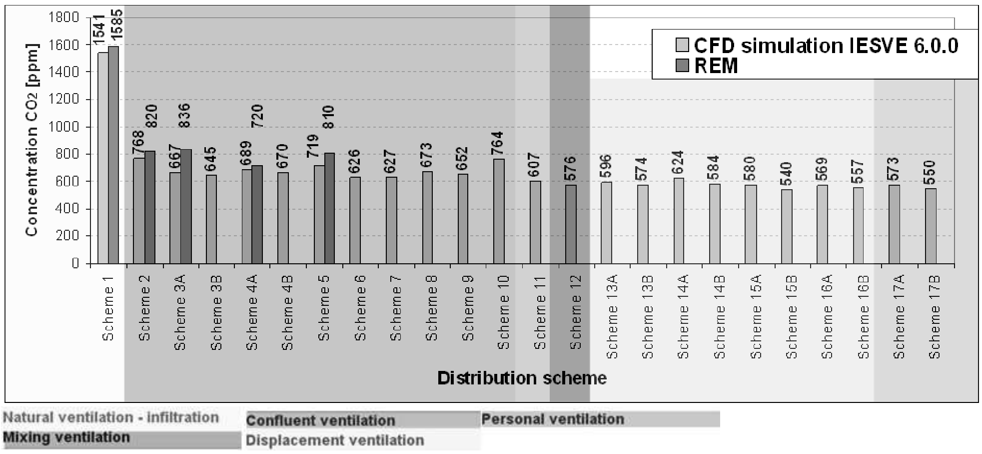


Fig. 2. Carbon dioxide (CO_2) concentrations for individual distribution schemes (time 3600 s, CFD simulation IESVE 6.0.0 and REM)

Rys. 2. Koncentracja dwutlenku węgla (CO_2) dla indywidualnych planów dystrybucyjnych

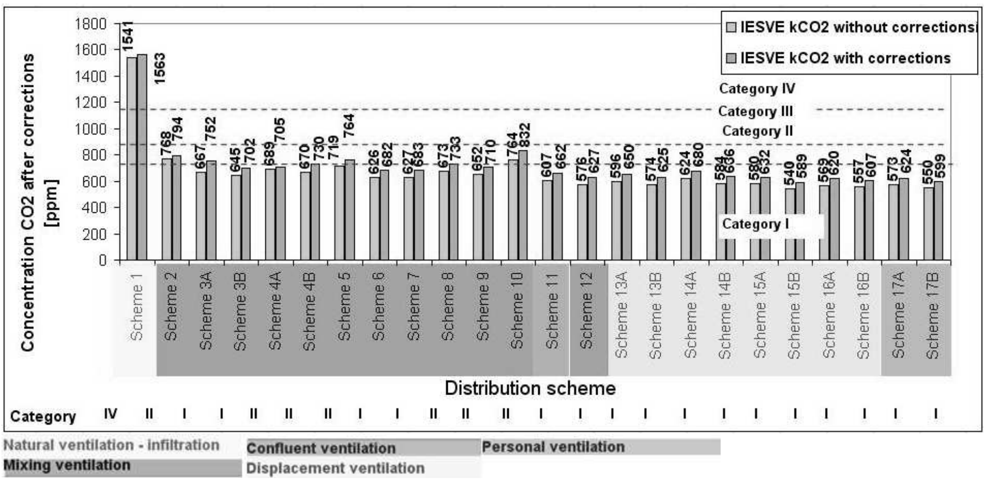


Fig. 3. Carbon dioxide (CO_2) concentrations for individual distribution schemes after corrections by real experimental measurements REM (time 3600 s, CFD simulation IESVE 6.0.0 and REM)

Rys. 3. Koncentracja dwutlenku węgla (CO_2) dla indywidualnych planów dystrybucyjnych po zmianie przez realne eksperymentalne pomiary REM

The Figure 3 compares carbon dioxide concentration (CO_2) for individual distribution schemes with respecting to corrections. For distribution schemes of 6 up to 17B (also of 1 up to 5) mean deviations were calculated. The mean deviations were calculated from real experimental measurements (REM) from schemes of 1 up to 5 as a mean average value.

The values of air distribution index (ADI) are presented on Figure 4. The index ADI connects both subjective and objective parameters (thermal comfort, carbon dioxide concentration, comfort number, PPD, PMV) of indoor air quality. Expectations from confluent ventilation (Scheme 11) respecting CO2 concentration and subjective parameters were repleted.

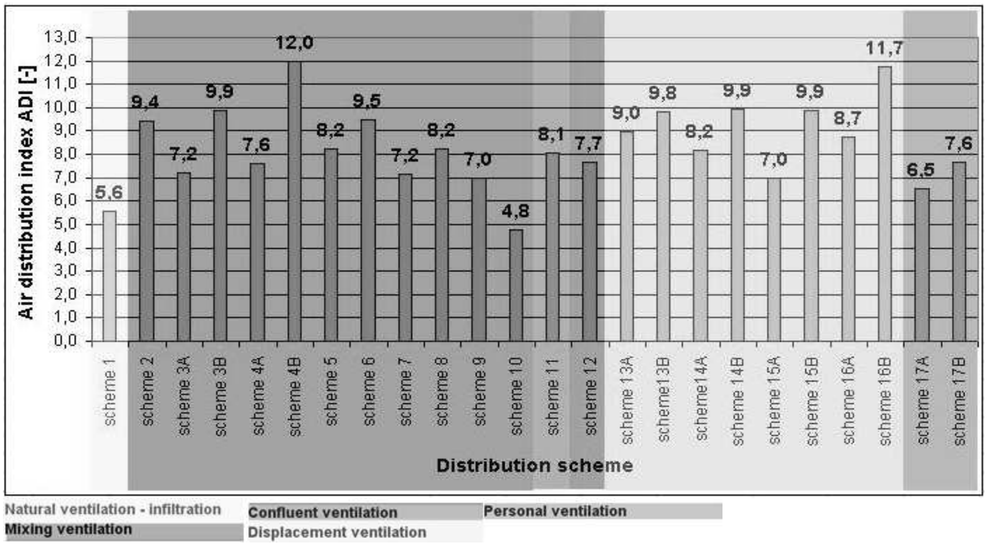


Fig. 4. Values of air distribution index from CFD simulations

Rys. 4. Wartości wskaźnika dystrybucji powietrza z symulacji CFD

This paper shows some promising ways to go for that goal and the successful optimization of ventilation design using simulations. The paper compared air distribution schemes with aim to find out the most suitable distribution of ventilation systems for studied experimental model room.

The best ventilation strategy in relation to CO_2 concentration and subjective parameters seems to be displacement distribution schemes and personal ventilation schemes. Also mixing ventilation schemes (scheme 2 and 5, 6) show good results, but scheme 2 allocate discomfort in relation to air velocity.

Distribution schemes 3B, 4B, 13B, 14B, 15B and 16B show very good results but in relation to increased ventilation rate (corpus B).

References

[1] STN EN 15251:2007 Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.

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