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Section: Energy for Buildings

Air quality and energy savings in school and office buildings

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Abstract

The paper focused to the possibility of heat recovery applications in indoor building space. Heat recovery system is designed especially in passive houses, but did not prevent the intended use of the existing building. All objects, whether new or upgraded, especially if you need certification of buildings, should use heat recovery ventilation to improve indoor air quality and improving energy class in buildings. This article is a case study of selected space in school building (classroom) where we will show significant savings by introducing a system recovery. Also the selection of ventilation system and total air ventilation rates defined in Standard STN EN 15 251 present air change rate in which the objective benefit of proper selection of ventilation system and air distribution scheme is lost (erased) in relation to indoor air quality (IAQ) and energy savings. With help of sensory evaluation in research the total minimum ventilation rate was estimated. It was reason how to determine major boundary condition (air quantity = air ventilation rate) for minimizing of responsibility size of air quantity (quantitative component of ventilation) and maximize the impact of the choice of distribution scheme and the distribution element (qualitative component of ventilation) for transfer and distribution of pollutants in research and also for energy savings.

Keywords: Distribution system; ventilation rate; heat recovery; energy.

Nomenclature

φ	relative humidity (%)
OI	odor intensity (-)
n	ventilation rate (1/h)
n_{INF}	ventilation rate (1/h) by infiltration
n_{TOT}	ventilation rate (1/h) by mechanical ventilation
θai	outdoor (exterior) air temperature (°C)
EA	environment acceptability (-)
TC	thermal comfort (-)
Θai	indoor (interior) air temperature (°C)
ppm	parts per million, unit for explaining of CO_2 concentration
CO_2	chemical compound, carbon dioxide
IAQ	Indoor air quality (term abbreviation)

1. Introduction

This paper highlights the importance of environmental protection regarding the reduction of energy consumption while keeping the living standard. The aim of article is to examine the effect of temperature, humidity and CO_2 concentration regarding to the human behaviour in indoor environment with natural ventilation. The next task is to specify buildings intended for an unavoidable installation of ventilation unit equipped also with a recuperation system.

In the past but also in present time, there is a great interest of quality housing, economical operation of buildings and especially the performance and health of the occupants of buildings in the world. Using high-quality healthy (e.g. natural) materials, mechanical ventilation with heat recovery and air distribution system (ventilation system) which is suitably selected and also suitably chosen amount of fresh air, ventilation and ultimately the right choice end distribution element can fulfill these requirements. Research on these aspects in the world dedicated to various studies [8–15].

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2. Research object

To produce the heat-load corresponding to fully occupied classroom [3]. Heat source-simulators were placed in the room. Also carbon dioxide concentrations were 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) [7]. All measurements were carried out under steady state conditions (Table 1).

Table 1. Characteristics of steady state conditions of research

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	C outdoor	
Natural ventilation	16	1	18,5	–	15,5	37,5	360–400	<0,15
Mechanical ventilation A	69,3	16	18,5	27,5 ± 1,5 °C	15,5	37,5	360–400	<0,25

The Figure 1 presented examples of questionnaires for subjective evaluations according to European standard STN EN 15251:2007. These types of questionnaires were used for sensory evaluations. The questionnaires were filled by adapt and unadapt respondents.

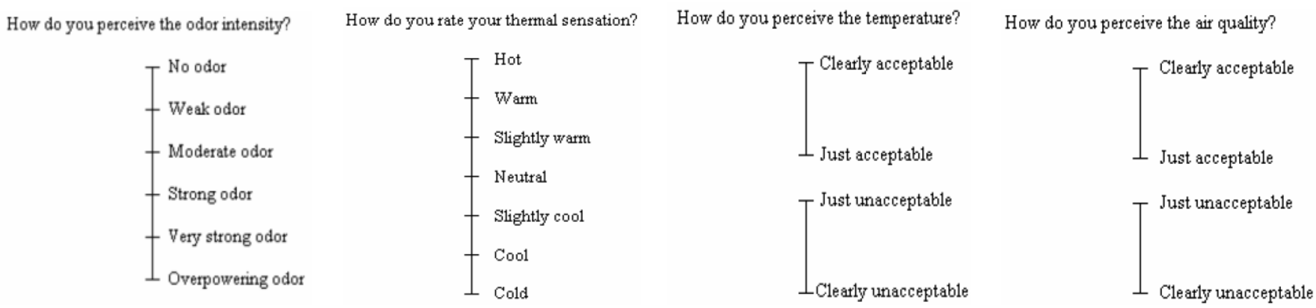

Fig. 1. Questionnaires used for subjective sensory evaluation

3. Objective measurements - indoor air quality

Within the frame of research of energy efficiency of ventilation system, time process (character) of the temperature, humidity and CO_2 concentration were analysed. The aim is to determine optimal methods and techniques of ventilation for variable conditions in within building with occupant using.

The individual parameters were measured in various rooms: in an office-room, in a classroom and in a session-room. The measured values of the CO_2 concentration, the indoor and outdoor air temperature and the indoor air humidity are presented in the Figure 2 [1, 2].

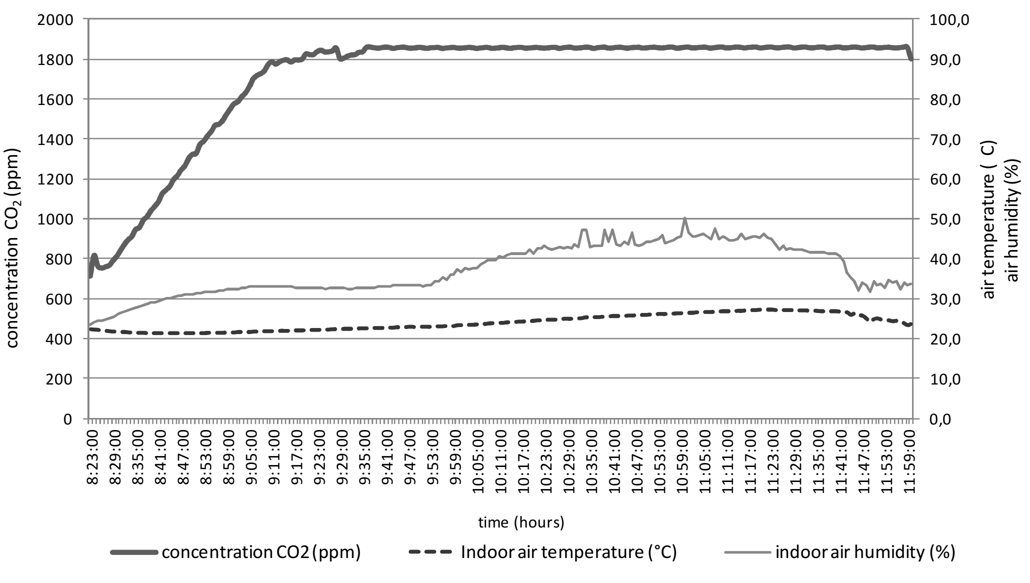

Fig. 2. Temperature behaviour, humidity and concentration CO_2 [1]

4. Subjective sensory evaluation

The sensory evaluations were realized according to European standard STN EN 15251:2007 (Annex H –Methodologies for subjective evaluations). Also the examples of questionnaires for subjective evaluation were passed from this standard [6]. The results of sensory evaluation and the rising and falling trends of odour intensity depending on the air exchange rate at a constant indoor air temperature θai = 26 °C and relative humidity of φ = 35–45% were compared. By considering between of adapted to unadapted respondents the differences in the perceived odour intensity at air ventilation rate n = 0.2[1/h] were detected. Adapted respondents (respondents=occupants which evaluate room) are respondents which evaluate indoor environment in room by the help of questionnaire after 1 hour of room using – respondents were full hour situated in room. Unadapted respondents are respondents which evaluate indoor environment in room by the help of questionnaire immediately after they entered to the room – enter to the room was realized after 1 hour after experiment starts (adapted respondents were still in room during unadapted evaluation).

The odour intensity was determined at 20% lower by adapted respondents as unadapted respondents. However with ventilation rate increasing to value n = 2.0[1/h] then the percentage difference was negligible and distinction approaching to zero. The impact of increased air ventilation rate to odour intensity was significantly expressed for air ventilation rate value n = 1.0[1/h]. The related results are presented in Figure 3. The impact of air ventilation rate to odour intensity at increased indoor air temperature θai = 29 °C was evaluated in the second measurements phase. The results are presented in Figure 4. When the indoor air temperature was increased then odour intensity percentage value increased at value 35% at unadapted respondents in compared to (against) adapted respondents. From results of Figures 3, 4 is assumed that the higher air ventilation rates above the value n = 2.0[1/h] cause that the distinction between unadapted and adapted respondents will be erasured.

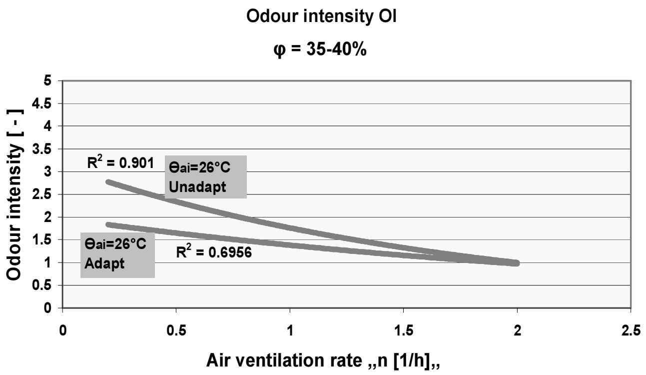

Fig. 3. The influence of air ventilation rate to odour intensity for adapted and unadapted respondents (θai = 26 °C, φ = 35–45%)

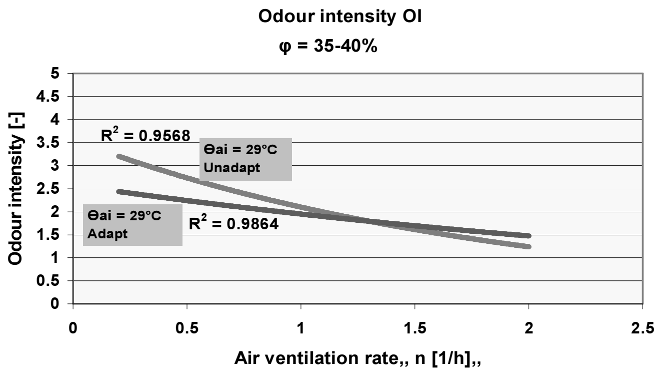

Fig. 4. The influence of air ventilation rate to odour intensity for adapted and unadapted respondents (θai = 29 °C, φ = 35–45%)

The odour intensity is closely associated with environment acceptability (perceived air quality) [3, 4]. The environment acceptability was evaluated at indoor air temperature θai = 26°C and θai = 29 °C at constant relative humidity and air ventilation rate by same respondents group with assistance of environment acceptability scale (Figure 5). The sensory research was evaluated realized by European standard STN EN 15251:2007 (Annex H – Methodologies for subjective evaluations) [6].

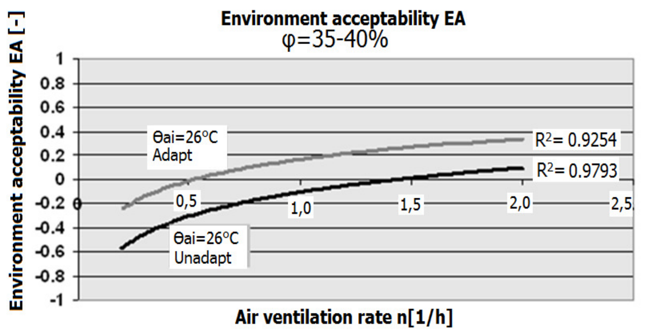

Fig. 5. The influence of air ventilation rate to environment acceptability for adapted and unadapted respondents (θai = 26 °C, φ = 35–45%)

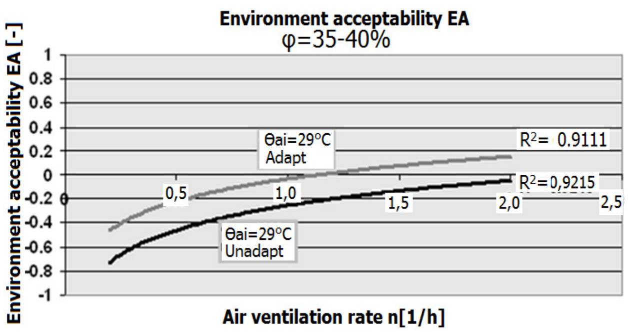

Fig. 6. The influence of air ventilation rate to environment acceptability for adapted and unadapted respondents (θai = 29 °C, φ = 35–45%)

The average evaluated indoor environment acceptability must be bigger than value 0 and then the environment will be acceptable. The environment was evaluated as acceptable at air ventilation rate n = 0,6[1/h] for adapted respondents. For unadapted respondents it was necessary to achieved air ventilation rate n = 1.3[1/h] for environment acceptability. The environmental acceptability increasing trend was expressed of low air ventilation rates and this increased trend to air ventilation rate n = 2.0[1/h] for both groups of respondents was maintained. By temperature increasing about 3 °C to value θai = 29 °C was caused that the comfort becomes more acceptable until air ventilation rate n = 1.0[1/h] in compare with to the evaluations which were carried out at temperature θai = 26 °C at adapted respondents (Figure 6). The comfort was considered as acceptable until for air ventilation rate n = 2.0[1/h] at unadapted respondents. Also influence of indoor air temperature increasing was expressed and therefore environment acceptability was decreased.

According presented results, the odour intensity and environment acceptability are significantly influenced nor only by air ventilation rate but also by indoor air temperature. The temperature increase has negative influence and air ventilation rate has positive influence to odour intensity and environment acceptability. In this context it is very important to considered also thermal comfort which is influenced by air ventilation rate, ventilation system (air distribution scheme), thermal resistance of clothing and human activities [5].

The thermal comfort ensuring is important factor for the human body, health, productivity and occupant performance [3]. Under the optimum conditions of air temperature, air humidity and air ventilation rate (θai = 26 °C, φ = 35–45%, n = 0,2[1/h]) is the percentage difference between the two groups of respondents equal to value 30%. The close attention is asked for the difference of thermal comfort for adapted respondents, which is at about 50% better than unadapted respondents at ventilation rate n = 2.0[1/h]. Despite the large difference, the thermal discomfort (thermal stress) was not perceived. The results are presented in Figure 7. For Adapted and unadapted respondents at air ventilation rate n = 0,2[1/h] and air temperature 29 °C the thermal discomfort was perceived. By ventilation rate increasing to value n = 2.0[1/h] the thermal comfort was achieved for adapted respondents however for unadapted respondents thermal discomfort was still perceived. The percentage difference presents 79.4% (Figure 8).

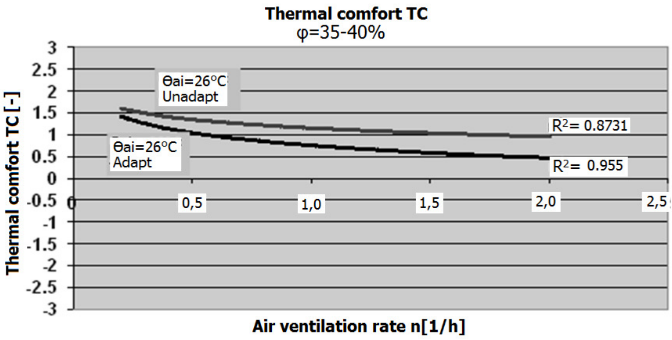

Fig. 7. The influence of air ventilation rate to thermal comfort (θai = 26 °C, φ = 35–45%)

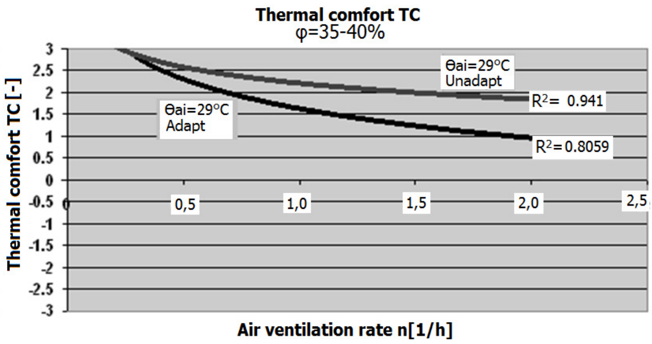

Fig. 8. The influence of air ventilation rate to thermal comfort (θai = 29 °C, φ = 35–45%)

Total air ventilation rates were determined from results on the basis of sensory analysis of odour intensity, environment acceptability, thermal comfort evaluation and experimental measurements at air temperature θai = 26 °C (Figure 9, 10, 11).

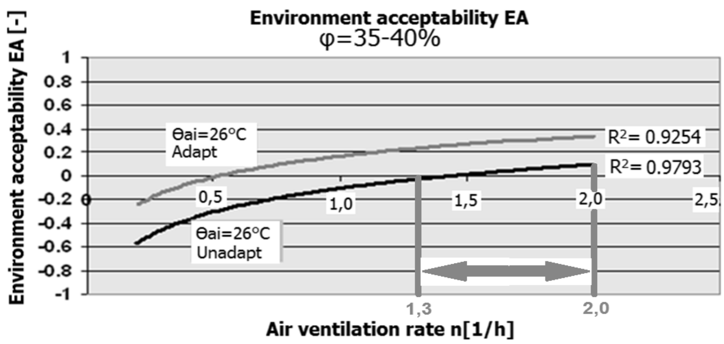

Fig. 9. Total ventilation rates–determination of applicable range (EA = 1.3–2.0), Air Conditions – (θai = 26 °C, φ = 35–45%)

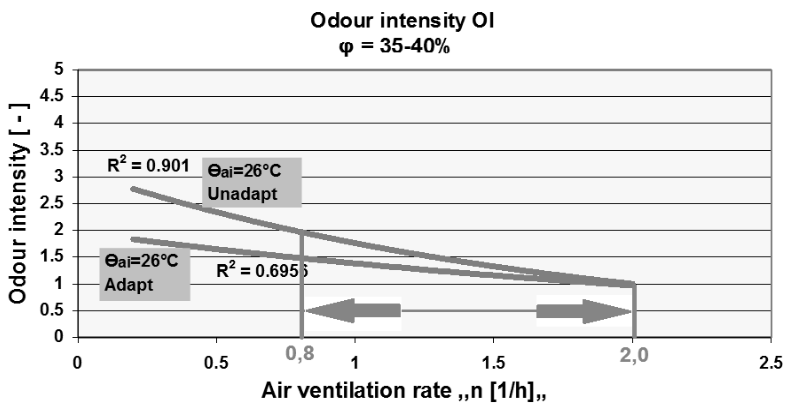

Fig. 10. Total ventilation rates–determination of applicable range (OI = 0.8–2.0), Air Conditions – (θai = 26 °C, φ = 35–45%)

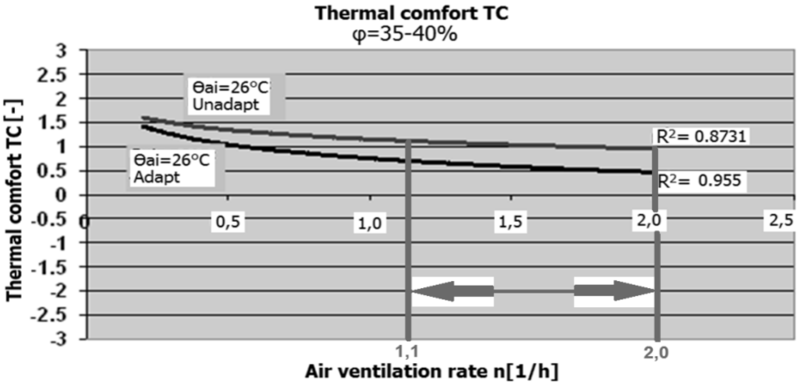

Fig. 11. Total ventilation rates–determination of applicable range (TC = 1,1–2,0), Air Conditions – (θai = 26 °C, φ = 35–45%)

The evaluation of total air ventilation rate in related to odour intensity, environment acceptability and thermal comfort is presented in Figure 9–11. The applicable range of values of air ventilation rate, where odour intensity (OI) presents executed criterion „OI < 2„ are presented in the range of 0.8 to 2.0[1/h]. The applicable values of air ventilation rate, where environment acceptability (EA) presents executed criterion „EA> 0„ are presented in the range 1.3 to 2.0[1/h]. The applicable values of air ventilation rate, where thermal comfort (TC) presents executed criterion „<0; 1>„ are presented in the range 1.1 to 2.0[1/h].

The total air ventilation rate by mechanical ventilation in the range (<1.3; 2.0>) by mathematics intersection of 3 sets of numbers [(<0.8;2.0>)Λ(<1.3;2.0>)Λ(<1.1;2.0>)] was estimated. The first idea was application the lowest possible air ventilation rate like value input for next real experimental measurements and also like value input to CFD simulations. Based on this assumption the air ventilation rate was established to value $n_{TOT} = 1.3$[1/h].

5. Conclusions

The air ventilation rates defined in Standard STN EN 15 251:2007 [6, 7] present air change rate in which the objective benefit of proper selection of ventilation system and air distribution scheme is lost (erased) in relation to IAQ. The total ventilation rate „n_{TOT}„ was determinated by sensory evaluation application. It was reason how to determine major boundary condition (air quantity = air ventilation rate) for minimizing of responsibility size of air quantity (quantitative component of ventilation) and maximize the impact of the choice of distribution scheme and the distribution element (qualitative component of ventilation) for transfer and distribution of pollutants in research.

The total air ventilation rate for next experimental measurements was established as the intersection of three air ventilation rates according to research (Figs 9–11). This air ventilation rate was necessary to supply to occupant to experimental classroom and also as input value to CFD simulations (CFD - next research work results in future). The total air ventilation rate $n_{TOT} = 1.3$[1/h] presents air ventilation rate taking into account the impact of air infiltration $n_{INF} = 0.3$[1/h].

The perceived quality and sensory evaluation are considered acceptable for air ventilation rates which ensure that the requirements above will be executed. In the light of these facts holds, that odour intensity was less than 2 (OI<2) at air ventilation rates in range of 0.8 to 2.0[1/h]; environmental acceptability was bigger than 0 (EA>0) at air ventilation rates in range of 1.3 to 2.0[1/h] and thermal comfort is suitable from 0 to 1 (TC (<0; 1>)) at air ventilation rates in range of 1,1 to 2.0[1/h].

The measurements were realized only to air ventilation rate n = 2.0[1/h] for determination of minimize required air ventilation rate. From the results is evident that these criterias are executed at higher air ventilation rate than n = 2.0[1/h]. The results are presented in Figures 3–11. This assumption is-but irrelevant for measurement purposes of this research.

The total minimum air ventilation rate is determined by $n_{TOT} = 1.3$[1/h]. In that $n_{TOT} = n_{INF} + n_{MECH}$ and then $q_{TOT} = q_{INF} + q_{MECH}$, the total air ventilation rate is $q_{TOT} = 69.3$[litre/s] or (250 m^3/h).

Within the frame of older research of air infiltration quantification the value of air infiltration was determinated for an experimental classroom at value level $n_{INF} = 0.3$[1/h] respectively $q_{INF} = 16$[litre/s] [8, 9, 10]. It is average air infiltration value for Schools Buildings with new windows. It was necessary to ensured increased air ventilation rate $n_{MECH} = 1.0$[1/h] respectively $q_{MECH} = 53.3$[litre/s] by mechanical ventilation system.

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