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ANALYSIS OF VENTILATION IN THE SELECTED LECTURE ROOM: CASE STUDY

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The paper documents the determination of the required volumetric air flow of the ventilation unit for the purpose of ventilating the selected lecture room. The contribution briefly characterizes the legislative requirements valid in Slovakia and Poland. Particular attention was paid to the regulations of the Ministry of Health, Ministry of the Environment, Ministry of Transport and Construction of the Slovak Republic and regulations of the Ministry of Education and Sport, Ministry of Infrastructure and European standards. In the paper is documented the experimental measurement performed in the lecture room is also documented. The resulting values of the volumetric air flow required for the ventilation of the lecture room, calculated according to legislative requirements, are compared with the value calculated on the basis of the measured course of the carbon dioxide concentration.

Key words: lecture room, indoor air, temperature, relative humidity, carbon dioxide concentration, volumetric air flow.

Introduction

Children and school youth spend more hours a day in classrooms and, depending on the number of people, are exposed to the effects of worsening indoor air quality. Various studies (Rajagopalan et al., 2022; Burridge et al., 2023; Duarte et al., 2017) that monitor the conditions of the indoor environment point to the need to increase the ventilation rate in classrooms. Current standards and guidelines of ventilation in school classrooms mainly focus on perceived air quality, while the available ventilation in many schools already fail to meet those criteria, leading to poor indoor air quality (Ding et al., 2022). New ways of ventilation are needed in school classrooms, where the design should be shifted from comfort-based to health-based.

Legislative requirements for classrooms ventilation in Slovakia

The legal regulations valid in Slovakia that determine the design intensity of ventilation are:

– Decree of the Ministry of Health of the Slovak Republic No. 210/2016 Coll. which with later modifications the decree of the Ministry of Health of the Slovak Republic No. 259/2008 Coll. on details on requirements for the internal environment of buildings and on minimum requirements for apartments of a lower standard and for accommodation facilities from 30 May 2016 (Decree 210, 2016);

– Decree No. 532/2002 Coll. Decree of the Ministry of the Environment of the Slovak Republic establishing details of general technical requirements for construction and general technical requirements for buildings used by persons with limited mobility and orientation (Degree 532, 2002);

– Decree No. 35/2020 of the Ministry of Transport and Construction of the Slovak Republic dated February 11, 2020, which with later modifications the Decree of the Ministry of Transport, Construction and Regional Development of the Slovak Republic No. 364/2012 Coll., implementing Act No. 555/2005 Coll. on the energy efficiency of buildings and on the amendment of certain laws as amended by Decree No. 324/2016 Coll. (Decree 35, 2020);

– Decree No. 527/2007 Coll. Ministry of Health of the Slovak Republic dated August 16, 2007 on details of requirements for facilities for children and youth (Decree 527, 2007);

– Standard STN EN 16798-1 Energy efficiency of buildings. Ventilation of buildings. Part 1: Input data on the indoor environment of buildings for the design and assessment of the energy performance of buildings – air quality, thermal state of the environment, lighting and acoustics (Standard STN EN 16798-1, 2019).

Legislative requirements for classrooms ventilation in Poland

Pursuant to the Act on the Education System of September 7, 1991 and the Regulation of the Minister of Education and Sport of December 31, 2002 on safety and hygiene in public and private schools and institutions (Posniak, 2010; Regulation 31, 2003), as well as the framework directive 89/391/EEC of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work (Directive 89, 1989), principals of schools and other didactic and educational institutions are obliged to ensure safe and hygienic conditions for staying at school and safe and hygienic conditions for participation in classes organized by the school outside the facilities belonging to these units. This provision is supported by framework statutes of schools or institutions and other general provisions on health and safety at work (Labor Code, 2023; Regulation 75, 2022).

The quality of air in school rooms is largely determined by its parameters: temperature and relative humidity, school air speed and direction, and carbon dioxide concentration. Ensuring proper air parameters, i. e. temperature, humidity, speed and carbon dioxide concentration, as well as appropriate concentration levels of chemical and dust substances as well as microbiological air pollution is one of the elements of health and safety management in school and educational institutions.

Materials and Methods

Determination of indoor air parameters used in Slovakia and Poland

Guidelines for designers, owners and users of buildings regarding ventilation and air-conditioning installations that will enable the achievement of internal environment conditions that meet the health and thermal comfort criteria throughout the year, and are characterized by acceptable investment and operating costs, are presented in the PN-EN 13779:2008 which has been replaced by PN-EN 16798-3:2017-09 (Energy performance of buildings – Ventilation for buildings – Part 3: For non-residential buildings – Performance requirements for ventilation and room-conditioning systems (Modules M5-1, M5-4)). The standard covers the following issues: aspects important from the point of view of obtaining and maintaining good energy performance of the installation without negative impact on the quality of the indoor environment; the parameters of the internal environment used and the definition of assumptions for design quantities and plant properties.

The PN-EN 16798-3:2017-09 (2017) standard, which relates to the design and properties of non-residential buildings, is related to the following standards: PN-EN 16798-5-1:2017-07 – Energy performance of buildings – Ventilation for buildings – Part 5-1: Calculation methods for energy requirements of ventilation and air conditioning systems (Modules M5-6, M5-8, M6-5, M6-8, M7-5, M7-8) – Method 1: Distribution and generation, PN-EN 16798-5-2:2017-09 – Energy performance of buildings – Ventilation for buildings – Part 5-2: Calculation methods for energy requirements of ventilation systems (Modules M5-6, M5-8, M6-5, M6-8, M7-5, M7-8) – Method 2: Distribution and generation – in terms of calculating energy for ventilation; PN-EN 16798-7:2017-07 – Energy performance of buildings – Ventilation for buildings – Part 7: Calculation methods for the determination of air flow rates in buildings including infiltration (Modules M5- 5)) – in the scope of calculating air streams and PN-EN 16798-1:2019-06 – Energy performance of buildings – Ventilation for buildings – Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics – Module M1-6) – in terms of criteria for the internal environment.

The effectiveness of ventilation and air-conditioning systems in school buildings is assessed as part of inspections at the final stage of the investment process, during the acceptance of ventilation and air-conditioning systems, and during the use of the buildings. The scope of tests and checks of ventilation and air-conditioning installations is not included in any legal regulation in Poland. This issue is presented in documents that are not binding. These are: PN-EN 12599:2013-04 Ventilation of buildings – Test procedures and measurement methods for acceptance of completed ventilation and air-conditioning systems and PN-78/B-03421 (1978) Ventilation and air conditioning – Calculated parameters for indoor air in the habitats destinated for permanent presence of people.

These documents may be binding in relation to a given investment process when they are referred to in the contract for the installation or in its technical design. Maintaining and controlling the effectiveness of the installation's operation is a continuous process, which consists in ensuring that the level of the installation's operation, obtained as a result of acceptance activities and updating the operating documentation, is maintained.

According to the decree 210/2016, all indoor spaces with long-term and short-term stay of people must be ventilated. Building ventilation should be ensured by natural ventilation or forced ventilation. Ventilation is determined according to the number of people, the activity performed, the heat load and the degree of air pollution in order to meet the requirements for the amount of air for breathing, for the cleanliness of the indoor air, and to prevent people from being bothered by odorous substances. Air exchange by natural ventilation is used in spaces without sources of harmful substances and heat, in which one to two times the intensity of the exchange of untreated air is sufficient and in which the required air exchange can be ensured by location and building solution. The method of ventilation, the position and the size of the openings for air intake and exhaust are determined by calculation. In other cases, air exchange must be ensured by forced, mechanical ventilation (Decree 210/2016).

When exchanging air, the principle of air pressure drop from rooms with a cleaner environment to rooms with a less clean environment must be followed. From this point of view, ventilation is solved as:

a) negative pressure, if the air in the ventilated room containing harmful substances is not supposed to penetrate into neighboring spaces;

b) pressurized, if it is necessary to prevent the penetration of harmful substances from neighboring spaces into the ventilated room;

c) equal pressure, if there is to be no exchange of air between the ventilated room and other spaces.

The quality of the supplied air and exhaust air is considered satisfactory if its composition does not endanger the health and at the same time does not worsen the living conditions of people in the premises of the building or in the vicinity of the building. The flow of ventilation air in the ventilated space must guarantee good ventilation of people's residences, reducing the concentration of harmful substances to values lower than the limit values of factors harmful to health. In spaces without the possibility of natural ventilation, in the event of a malfunction, at least a reduced air exchange is provided for the time necessary to eliminate the malfunction. This requirement must already be ensured in the project documentation. In indoor spaces with a long-term stay of people, forced ventilation must be solved in such a way that the air flow does not disturb the permissible conditions of the thermal and humid microclimate.

In the technical conditions to be met by buildings and their location in Poland, the PN-78/B-03421 standard was invoked. For people in the lecture room in a sitting position, the total energy loss is assumed to be 120W, for people standing 140W, and for people in motion 240W.

In lecture room where the main source of pollution is people, the intensity of ventilation (in particular per person and in particular per m^2) can be derived using outputs from carbon dioxide (CO_2) concentration measurements. Measurements must be carried out in the areas most used for people's stay.

The required volumetric air flow during ventilation can be determined on the basis of the balance equation (Persily, 1997; Persily, 2006) for the concentration of CO_2 taking into account the concentration of CO_2 in the outside air. The recommended increase in the concentration of CO_2 with respect to the concentration of CO_2 in the outside air for lecture rooms is a maximum of 1,000 ppm in the room. The stated

CO_2 value can be used when designing demand-controlled ventilation. Indoor air quality can be ensured by controlled mechanical ventilation, which is regulated on the basis of the current CO_2 concentration – the so-called demand-controlled ventilation.

Table 1

Activity in lecture room

Activity class	Total energy expenditure		Activity. Examples of activities
	q_M [W/m^2]	M [met]	
Slovak decree 210/2016	66–80	1.13–1.38	Sitting activity with minimal physical activity (activity in classrooms)
Poland PN-EN 13779:2008	70	1.2	Working in a sitting position (office, school)

Note: The given examples of activity are for orientation only. To reliably classify the work, an objective measurement of the energy expenditure or a detailed analysis of the performed activity is carried out [1].

At higher temperatures, the total heat produced does not change, but the sensible heat values decrease (for 26 C by about – 20 %) 1 met = 58 W/m^2.

The method of calculating the volume flow of air is achieved by the method of indoor air quality, where we first calculate the volume flow of air needed for lecture room ventilation:

$$q_V = q_m / (C_{IDA} - C_{SUP}), \quad (1)$$

where: q_V is volumetric air flow required for room ventilation (m^3/s), q_m – mass flow of CO_2 in the lecture room from the pollutant source (mg/s), C_{IDA} – concentration of CO_2 in the air in the lecture room (mg/m^3) and C_{SUP} – concentration of CO_2 in the supplied air (mg/m^3).

Results and discussions

In order to determine the indoor air parameters, an experimental measurement was carried out in a selected lecture room with a seating capacity of 222 people. The ventilation of the room is currently ensured by means of an air-handling device that supplies fresh air through pipes located along the side walls under the ceiling. Air drainage is ensured by slits located between individual seating levels. There is a skylight above the room that illuminates the lecture room.

The dimensions of the lecture room are: width 11.55 m, length 17.75 m and height from 3.2 m to 4.7 m. The internal volume of the room is approx. 820 m^3. The floor area of the lecture room is 205 m^2.

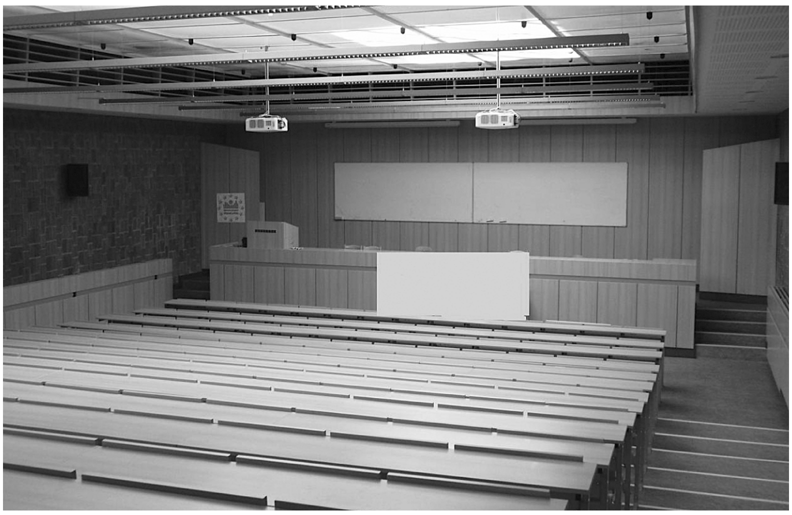

Fig. 1. The lecture room – a look at the teacher's desk

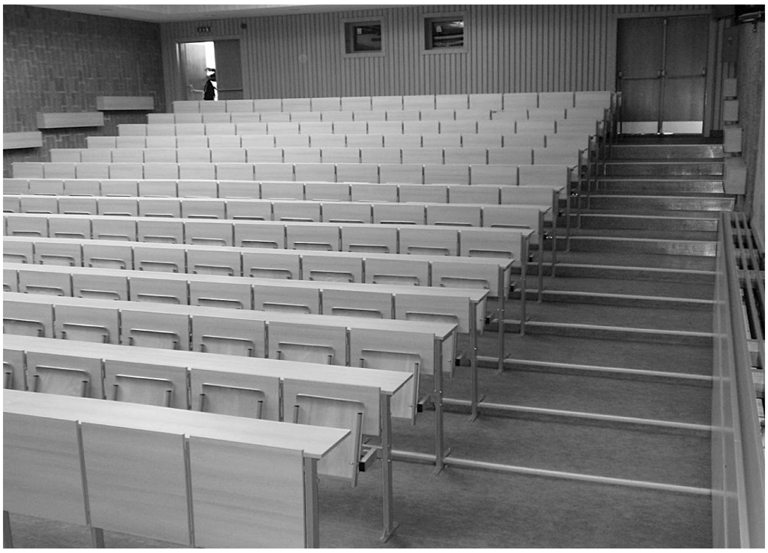

Fig. 2. The lecture room – a look at the audience

Before starting the measurement of indoor air parameters, the lecture room was ventilated by mechanical ventilation and the lecture room was closed. At the beginning of the lesson, the door through which students entered the room was opened. During the first lecture, the air conditioning equipment was out of order. There were a total of 75 people in the room. All windows and doors were closed.

Table 2

The measured indoor air parameters

Class	Time	Indoor air temperature (°C)		Relative humidity (%)		CO_2 concentration (ppm)	
		At the beginning of the lesson	At the end of the lesson	At the beginning of the lesson	At the end of the lesson	At the beginning of the lesson	At the end of the lesson
1	7:15– 9:45	22.6	27.2	39.8	36.1	510	1.367
2	10:00–11:15	25.3	23.8	30.3	30.4	894	635

At the time of the experimental measurement, the outside temperature was measured at 9 °C and the relative humidity was about 70 %. The internal air temperature in the lecture room at the beginning of the students' stay was 22.6 °C. During the stay of the students, it increased to 27.2 °C. The initial value of the CO_2 concentration was 510 ppm. During the lecture, the CO_2 concentration increased to a value of 1.367 ppm.

Before the start of the next lecture, the air conditioning system was started. Mechanical ventilation ensured a significant decreased in CO_2 concentration to a value of 635 ppm. The temperature steadied and stabilized at around 23.8 °C. During the operation of the air conditioning equipment, the temperature was within the range required by Decree No. 210 (2016). The relative humidity was at the lower end of the range of 30–70 %. The concentration of CO_2 (635 ppm) was within the required range of 400–900 ppm. It can be concluded that the air conditioning system ensured sufficient ventilation of the lecture room when the room was occupied by 75 people.

The average value of the volumetric air flow provided by the air handling equipment was calculated according to the equation that characterizes the tracer gas decay test (Persily, 1997, Persily, 2006). The calculation procedure is also published in Kapalo et al. (2018), Bullová et al. (2021), Kapalo et al. (2023)

articles. The resulting value of the volume flow of ventilation air calculated during the operation of the air conditioning equipment is 1.967 m^3/h. After recalculation, it is 26.22 m^3/(h.pers). Determination of the dose of fresh air based on the development of the CO_2 concentration can also be calculated using the methodology published by Persily et al. (2022).

The maximum values of volumetric air flow was calculated according to decrees No.: 210/2016, 35/2020, 527/2007 and norm STN EN 16798-1. The results were compared with the calculated volumetric air flow according to the measured CO_2 concentration.

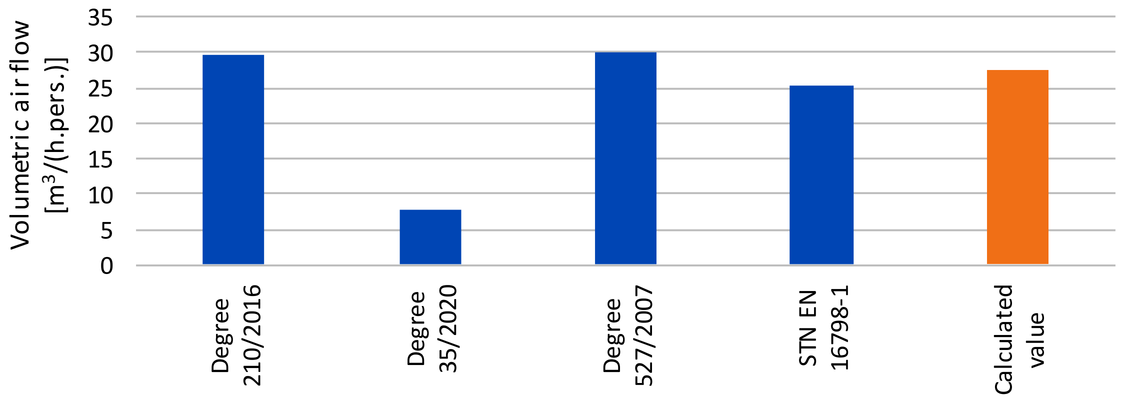

Fig. 3. The comparison the volumetric air flow for the selected lecture room

The comparison volumetric air flow for lector room with 75 students is documented in Fig. 3. Volumetric air flow calculations are calculated with an assumed CO_2 concentration of the outside air of 400 ppm.

Conclusion

The regulations in Slovakia and Poland are very similar. However, there are differences in some details, which are presented in Table 1. Similar, but slightly different values of temperature and air velocity are used in Slovakia and Poland.

When designing the ventilation equipment, it is necessary to calculate the necessary volumetric air flow. According to decree No. 210/2016, from 11 to 30 m^3/(h. pers) of fresh ventilation air is needed for the selected lecture room. Decree No. 532/2002 does not specify the values necessary for room ventilation. Decree No. 35/2020 gives us the resulting value of 7.65 m^3/(h. pers), which is an obviously unsatisfactory value. So, according to the given decree 35/2020, it is not possible to design an air handling device – decree serves only for the purposes of energy certification of buildings. According to decree No. 527/2007, from 20 to 30 m^3/(h. os) of fresh ventilation air is needed for the selected lecture room. According to the methodology stated in the standard STN EN 16798-1, 27.53 m^3/(h. pers) are needed for the selected lecture room. The presented results of volumetric air flow are valid only for the mentioned lecture room at the given considered time. The significant impact of ventilation on indoor air quality was also confirmed in the study by Kapalo et al. (2020), which has an impact on the human organism Kapalo et al. (2023).

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АНАЛІЗ ВЕНТИЛЯЦІЇ В ВИБРАНІЙ ЛЕКЦІЙНІЙ КІМНАТІ: ПРИКЛАД

Діти та шкільна молодь проводять більше годин на день у класах і, залежно від кількості людей, піддаються впливу погіршення якості повітря в приміщеннях. Різноманітні дослідження, які спостерігають за умовами внутрішнього середовища, вказують на необхідність збільшення рівня вентиляції в класах. Чинні стандарти та рекомендації щодо вентиляції в шкільних класах здебільшого зосереджуються на сприйнятій якості повітря, тоді як доступна вентиляція в багатьох школах вже не відповідає цим критеріям, що призводить до поганої якості повітря в приміщенні. У шкільних класах потрібні нові способи вентиляції, де дизайн має бути перенесений з комфорту на здоров'я.

Документально визначено необхідну об'ємну витрату повітря вентиляційної установки для провітрювання обраної аудиторії. Коротко охарактеризовано законодавчі вимоги, що діють у Словаччині та Польщі. Особливу увагу було приділено постановам Міністерства охорони здоров'я, Міністерства навколишнього середовища, Міністерства транспорту та будівництва Словацької Республіки та постановам Міністерства освіти та спорту, Міністерства інфраструктури та європейським стандартам. Задокументовано також експериментальне вимірювання, виконане в аудиторії. Отримані значення об'ємної витрати повітря, необхідної для вентиляції аудиторії, розраховані відповідно до вимог законодавства, порівнюються зі значенням, розрахованим на основі виміряного ходу концентрації вуглекислого газу.

Ключові слова: аудиторія, повітря в приміщенні, температура, відносна вологість, концентрація вуглекислого газу, об'ємна витрата повітря.