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RETRACTED: Simulation and Analysis of Various Ventilation Systems Given in an Example in the Same School of Indoor Air Quality

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Abstract: The quality of internal air is one of the factors that affect the pace and quality of knowledge acquisition. Therefore, it is important that classrooms have high quality of air. Using computer simulation, the effect of various building ventilation variants on air quality in classrooms was analyzed. Two criteria were analyzed and six variants of ventilation. The analysis was carried out using the CONTAMW program, used for multi-zone analysis of ventilation and air quality in a building. As an indicator of air quality, the concentration of carbon dioxide in school halls was adopted. The analyses show that natural ventilation is not able to provide proper air exchange. Regular airing of classrooms during breaks can reduce the carbon dioxide concentration to 2500 ppm, however, there is a significant reduction in indoor temperature (even below 10 °C). The best control over the internal environment can be obtained by using a supply–exhaust ventilation system with heat recovery. Obtaining a higher stabilization of ventilation is achieved by supplying additional energy to drive fans, however, this is only a small amount of energy compared to the cost of heat for heating the building (maximum 2%).

Keywords: indoor air quality; ventilation systems; concentration of carbon dioxide

1. Introduction

The quality of internal air is one of the factors that affect the pace and quality of knowledge acquisition. Therefore, it is important that classrooms have high quality of air [1–5].

The problem of internal air quality has gained significance along with changes in construction technology and interior furnishings. Tight windows are on the one hand very desirable for energy-saving reasons, but on the other hand they limit the inflow of external air, often below the minimum hygienic level. Modern, tight windows limit the natural exchange of air and in tightly sealed buildings with insufficient ventilation, pollutants from carpets, furniture, and cleaning agents accumulate. Through open windows and gaps in the walls external pollution (car exhaust, pollen) gets into the building. Increasingly, medicine links symptoms (headache, fatigue, drowsiness, irritation of the eyes and nose, dry throat, nausea, inability to focus) not only with viruses and bacteria, but also with the factors that occur in a given environment. Research into health effects related to indoor air pollution has become more and more important in recent years [1,6].

In Poland, the indoor environmental quality requirements specified for educational buildings are contained in the Polish standard PN-EN 13779:2008 [7]. According to the standard, the following climate comforts have the most important impact: air temperature, air humidity, physical and biological quality of air, and CO_2 concentration [8].

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According to Smedje et al. [9] half of the students say their mental work is worse due to poor air quality. Other authors drew similar conclusions [10,11]. Jędrzejewska-Ścibak [12] reports that 1% of school-age children suffer from chronic respiratory diseases, i.e., as many as 70,000. In closed rooms, most of the pollutants are natural gases produced by humans and volatile organic compounds from the furnishing of rooms, as well as bacteria and fungi.

Educational buildings are characterized by the significant density of people staying in a single room (the only source of CO_2). This situation makes it particularly important to provide pupils with appropriate conditions [12–14]. Administrators of educational buildings attach importance only to the temperature and cost of heating the teaching rooms compliant with the standards, without focusing on other parameters of air quality defined by the Polish Standard PN-EN 13779:2008 [7]. Therefore, most of the thermo-modernization works aimed at reducing the costs of educational building use are limited only to improving the insulation of external partitions, replacing windows with energy-efficient ones, and increasing the insulation layer of external walls. Increasing the tightness of rooms affects the operation of the ventilation system, which reduces heat loss through ventilation and reduces the heating costs of the building, however, it causes too little air exchange and results in a significant deterioration of air quality in the teaching rooms [15–17].

Analyses of the variations in CO_2 concentration under different ventilation systems are also presented in other publications [18–20].

Analyzing the ventilation in educational buildings concerns maintaining the required parameters in accordance with the indoor air used for large groups of people resident, in accordance with PN EN 13779:2008 [7], in particular the three basic parameters of indoor air:

- carbon dioxide concentration. World Health Organization (WHO)—1000 ppm [21],
- air temperature, which according to the norm [7] in the winter season is 20–22 °C, and in the summer 24–26 °C,
- indoor air humidity, in summer the recommended relative humidity is 30%–50%, and in winter 45%–60% [7].

Taking into account the above recommendations, tests were carried out to determine the ventilation parameters of the teaching rooms, which guarantee comfort in these rooms.

The aim of the article was to analyze various ventilation systems with regard to the quality of indoor air in educational buildings. More specifically, the aim of the research was to determine the value of ventilation airflow and distribution of carbon dioxide in classrooms. The analyzed classes had different insolation and were located on different floors. The article presents an estimate of the ventilation costs of an exemplary classroom depending on the ventilation system. The cost of heating the air stream for the analyzed school is given (for a given climate zone)—the operating cost and the investment cost. This work was performed to aid the decision of selecting a ventilation system for a particular school. It can also be a model for other educational buildings.

2. Materials and Methods

Using computer simulation, the effect of various building ventilation variants on air quality in classrooms was analyzed. The analyses were carried out using the CONTAMW program, used for multi-zone analysis of ventilation and air quality in the building [22]. As an indicator of air quality, the concentration of carbon dioxide in school halls was adopted.

For the study, a three-story building, a separate house, which was inaugurated in the 1960s was selected. The building had not been subjected to any reconstruction either in the area of thermal protection of the building's structure, or in the replacement of window frames.

Output data for calculations:

- location of the building: Wroclaw,
- temperature: −18 °C,

- relative humidity: 100%,
- computational parameters of the internal air: +20 °C.

The analyses were carried out using the CONTAMW program. The program is used to determine the indoor air quality performance of buildings before they were constructed and occupied, to investigate the impacts of various design decisions related to ventilation systems and building material selection, to evaluate indoor air quality control technologies, and to assess the indoor air quality performance of existing buildings. Predicted contaminant concentrations can also be used to estimate personal exposure based on occupancy patterns.

Model Implementation

The experimental simulation model was created using CONTAM's model editor ContamW. It offers a wide variety of tools for implementing a simulation model. Figure 1 portrays this editor. It consists of a single window, containing a large sketchpad area, toolbar, and a status bar. The simulation model is drawn on the sketchpad by using the tools selected from the toolbar. The most important tools available include walls and boxes for drawing floorplan layouts, ducts for designing ductworks and air handling systems, and controls for attaching an adjustable control signal to various elements to control their behavior during simulation.

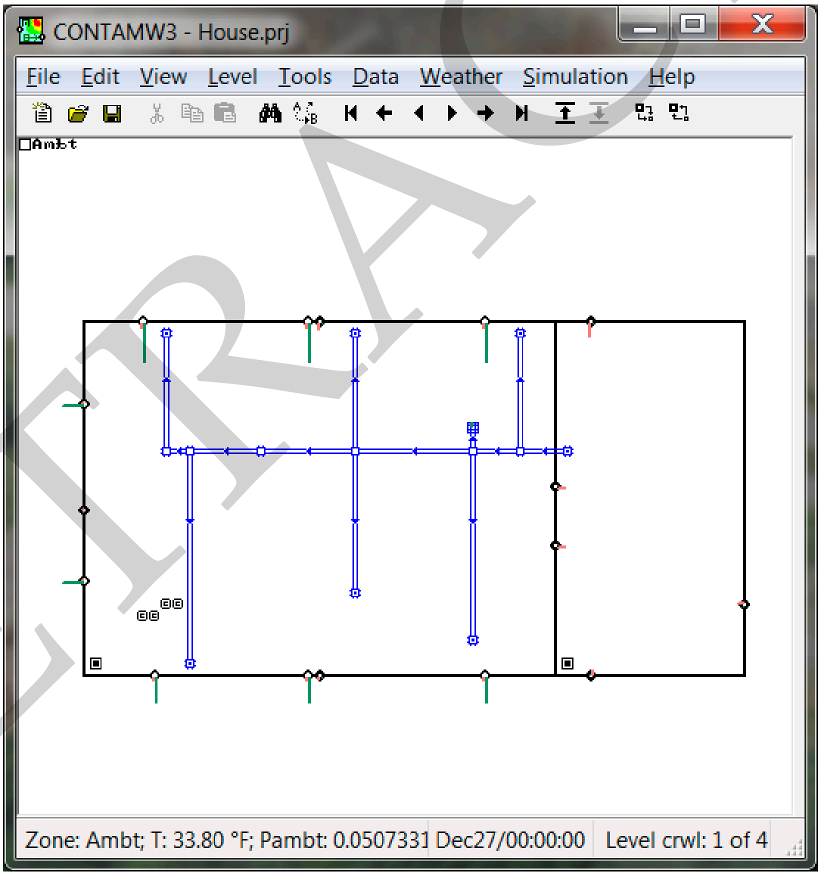

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Figure 1. ContamW graphical simulation model editor. The experimental simulation model depicts a classroom with ventilation ductworks.

The adopted two criteria [23] were as follows:

I. the concentration of carbon dioxide during the lesson (net) on average in classrooms throughout the heating season for a 50% air distribution should not exceed 1000 ppm;

II. the average concentration of carbon dioxide during the lesson on average in classrooms in the all heating season for a 90% air distribution should not be higher 1200 ppm.

The calculations were carried out on the school model (see Figure 2).

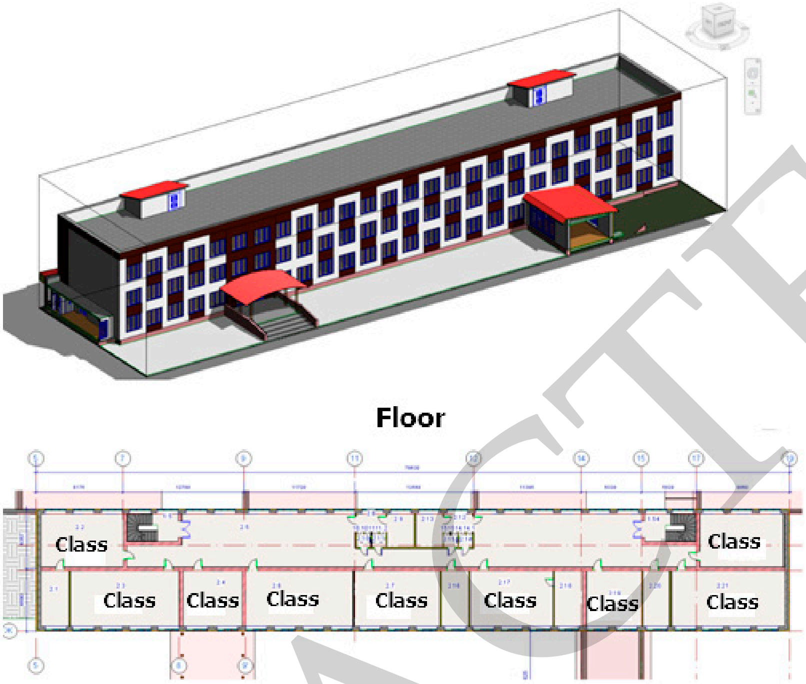

Figure 2. Analyzed school building. Arrangement of rooms on the level.

It is a compact, cuboidal, 3-storey building (3.5 m level) with a basement level (floor level of ground level 2.5 m), with a 4 m wide corridor with two-sided enclosed classrooms and recreational halls on each floor. The main entrance is from the east side of the building.

Six variants of the building ventilation were analyzed:

A: stack ventilation system; building before replacing windows (window tightness ratio a = 1.0 m^3/(mhPa0.67—old windows without gaskets);

B: stack ventilation system; building after replacing windows (window tightness coefficient a = 0.2 m^3/(mhPa0.67—new windows with a system of unsealing);

C: stack ventilation system, building after replacing windows as in option B, classrooms are additionally ventilated during breaks by opening a window with dimensions of 0.8 m × 1.4 m, in other rooms windows are closed;

D: stack ventilation system, building after replacing windows as in option B, windows of all rooms are equipped with roof fan, rooms are ventilated during breaks, in other rooms windows are closed; between 17:00–7:00 and on days off from work, the baffles are closed to 20% of capacity;

E: mechanical exhaust ventilation system, windows are equipped with roof fan, which operate as in option D, stack ventilation ducts in classrooms and in toilets are equipped with constant flow fans: rooms 470 m^3/h, toilets 360 m^3/h; the fans operate on working days from 8:00 to 16:30, and the gravitational ventilation works for the remaining time;

F: mechanical ventilation system for supply and exhaust, rooms are equipped with individual air handling units with heat recovery; the units operate between 8:00–16:30 on variable air flow controlled by CO_2 concentration, while for the remaining time the gravitational ventilation works.

The calculations were carried out for the entire heating season including the so-called average weather conditions (October to April) taking into account breaks in learning and the daily variation of the room loads. It was assumed that people do a light job when sitting with about 13 dm^3/h of carbon dioxide emission [24,25]. The carbon dioxide background in the external air was assumed to be 400 ppm [26,27] and the temperature of the inside air 20 °C [28].

3. Results and Discussion

As a result of the calculations carried out, results of the values of ventilation air streams in each zone and the distribution of carbon dioxide concentration in the classrooms were obtained. In buildings with natural ventilation, the air exchange is very diverse. The air flow caused by wind force and heat displacement depends on the location of the rooms depending on the geographical side and levels [29]. The rooms on the third floor with a western exposure are characterized by the largest air exchange. In turn, the smallest airflow occurs in the rooms on the end floor with eastern exposure (Figure 3).

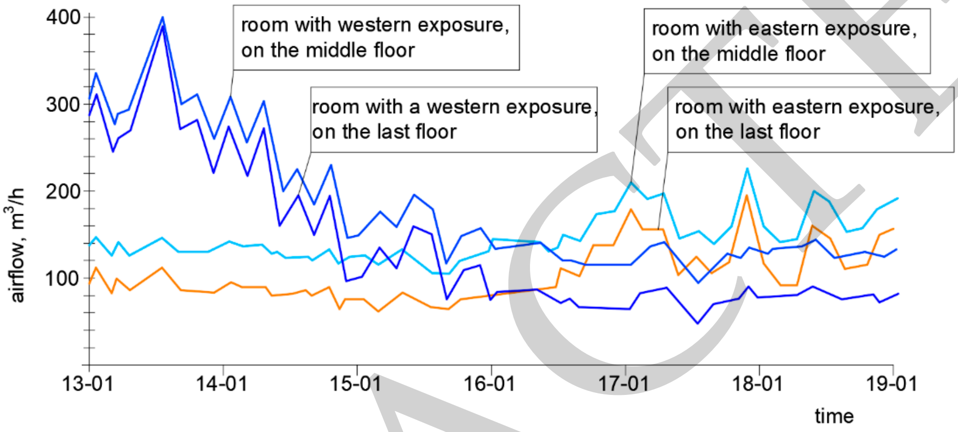

Figure 3. The course of variability of the air stream for a selected week of the heating season (variant A) for four example classrooms with different exposure.

The obtained variability average in the heating season (from October to April) of the amount of exchanges and the ventilation airflow for the considered variants is presented in Table 1.

A varied air exchange is reflected in the concentration of pollutants in the rooms. The course of variation in carbon dioxide concentration and its cumulative distribution in the heating season for a selected room are shown in Figure 4.

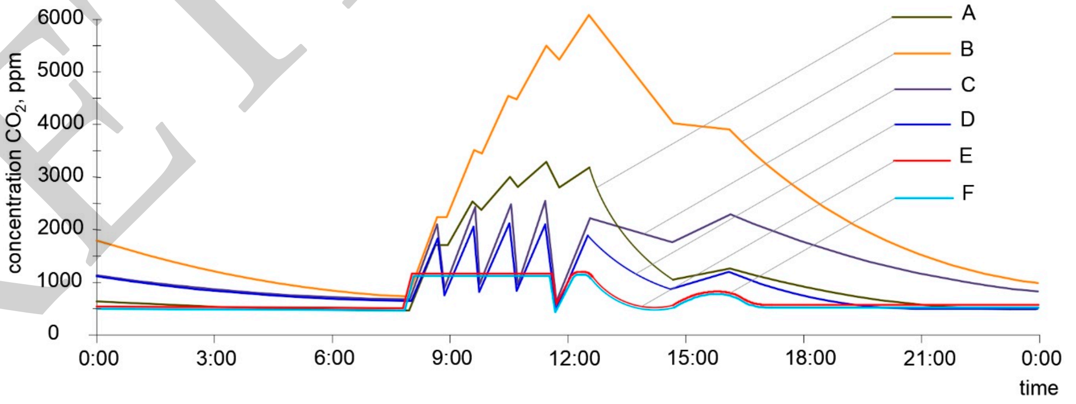

Figure 4. The course of variation in the concentration of carbon dioxide in the classroom (room located on the last level on the west side of the building) on one January day for the six variants considered.

Table 1. Amount of ventilation air changes in the school.

Variant			**A**	**B**	**C**	**D**	**E**	**F**
Amount of exchanges, n/h^{-1} (fresh air flow on person, m^3/h)	Working days from 8:00 to 16:30	Classrooms	1.0 (6.1)	0.3 (1.8)	0.8 (4.9)	1.6 (9.8)	2.6 (15.4)	1.7 (10.4)
		WC	1.1	0.2	0.2	2.0	3.1	2.4
		Other rooms	0.8	0.3	0.3	0.5	0.6	0.5
		Average in the entire building	**1.0**	**0.3**	**0.4**	**1.4**	**2.1**	**1.5**
	Working days from 16:30 to 8:00 Days are free from 0:00 to 24:00 Time with no people in the building	Classrooms	0.9	0.3	0.3	0.5	0.5	0.3
		WC	1.0	0.2	0.2	0.6	0.6	0.4
		Other rooms	0.8	0.2	0.2	0.3	0.3	0.3
		Average in the entire building	**0.9**	**0.2**	**0.2**	**0.5**	**0.5**	**0.3**

Case A shows the status of the school before upgrading windows and to the modernization of the ventilation system. Air exchange at the level of 1.0 h^{-1} provides poor air quality, at which the concentration of carbon dioxide exceeds 3000 ppm (at the average value of 1640 ppm) as in the literature.

On the one hand, replacement of window frames improves the energy consumption of a building (variant B), the other five, however, with reduced coefficient of tightness of windows resulted in a significant deterioration of air quality in the classrooms. The CO_2 concentration on average reaches 2800 ppm, reaching up to 6000 ppm at the top (see Figure 4).

Such an increase in CO_2 concentration is caused by very low air exchange with windows with a much better heat transfer coefficient, but unfortunately too tight.

The situation is slightly improved by airing the classrooms during breaks (option C), the average exchange of external air in school halls increases then from 0.3 to 0.8 h^{-1}. However, it should be remembered that the use of ventilation requires a lot of discipline, and in practice it is done very irregularly.

The stream of external air, obtained during the airing time of about 10 h^{-1}, causes in periods of low values of outside temperature significant lowering of the internal temperature, even below 10 °C, which may be a source of great discomfort in the initial periods of the lesson. In practice, intermediate levels between variant B and C are used in schools. For this reason, the replacement of windows should be accompanied by the modernization of the ventilation system.

The cheapest way is the use of window pressure air intakes [30,31]. In the case when the window tightness (U_w = 0.1 W/m^{2}K) a is within 0.5–1.0 m^3/(mhdPa0.67), i.e., 0.11–0.21 m^3/(mhPa0.67), the Polish standard PN-83/B-03430/Az3:2000 [28] allows air to be supplied only through windows. However, because this ventilation proved to be insufficient, it was checked how additional unsealing of windows, through the use of diffusers, would improve the air quality. The air quality criterion in this case was not met, even with weathering of the rooms. Such a system improved air exchange by almost four times as compared to the windows sealed (see Table 1), however, it is still insufficient.

Installation of roof fans at the outlet of stack ventilation ducts (option E) is the easiest (least invasive) way to introduce mechanical ventilation in an existing building [32,33]. Air exchange in classrooms on average at the level of 2.6 h^{-1} gives an air flow per student within 15 m^3/h. It is slightly lower than the normal value (20 m^3/h) [28] but sufficient to maintain good air quality. Window leakage, through the use of ventilators, improves air quality. The air quality criterion in this case was not met, even with weathering of the rooms.

The mechanical ventilation system used allowed the required internal air quality to be obtained. It was relatively easy to make, but there are some flaws in it. Unsealing of the window casing may cause an increase in noise penetrating into the rooms and allow the inflow of dust pollution. One should also take into account the possibility of local draughts caused by the direct influx of cold air into the school rooms [34,35].

The solution offering the greatest control over the environment is the use of mechanical ventilation. Such a system allows for effective air filtration and the use of heat recovery from the removed air, which has a positive effect on reducing heat consumption. Because this school is an existing school, individual systems were proposed with the use of compact air handling units, with positive displacement of air (variant F) with the efficiency controlled by the concentration of carbon dioxide. The introduction of a system that takes into account variable room loads is a source of additional energy savings [35–37]. We are here talking about ventilation system DCV (Demand Controlled Ventilation). Such a system guarantees constant coverage of the demand for fresh air, with minimal energy consumption.

The average distribution of carbon dioxide concentration in classrooms for all the discussed ventilation options is shown in Figure 5.

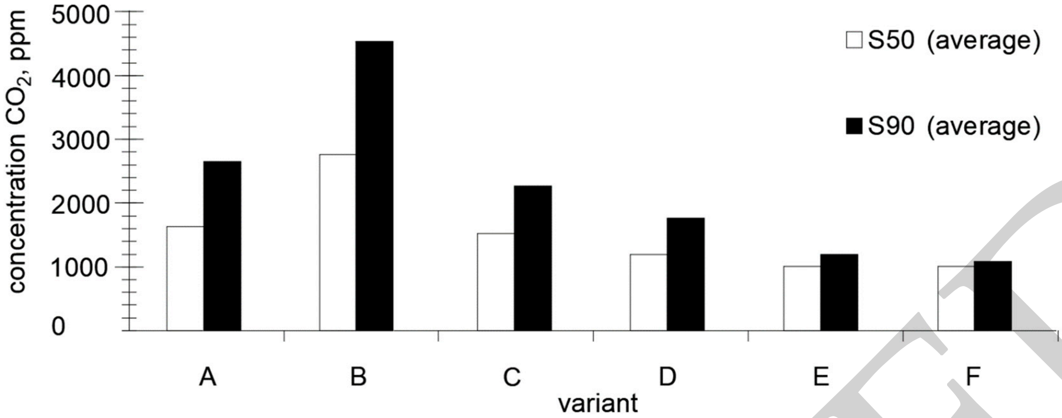

Figure 5. Average concentration of carbon dioxide during the lesson in classrooms throughout the heating season, with different variants of building ventilation.

Because the rooms are characterized by variable load during the day, the use of mechanical ventilation with a variable air stream gave good results and allowed the average supply air stream to be reduced (see Table 1), while maintaining the same high air quality as in the E variant.

The cost of heating the air stream for the analyzed school-operating costs and the cost of equipment purchase are presented in Table 2.

Table 2. The cost of heating the air stream for the analyzed school.

Variant	Unit	A	B	C	D	E	F
Amount of exchanges	n/h^{-1}	1.0	0.3	0.8	1.6	2.6	1.7
Cubature of the room	m^3	140	137	141	141	136	140
Air stream	m^3/h	140	41	113	225	354	238
Energy demand max	MJ	7405.44	2168.74	5977.25	11,901.6	18,725.18	12,589.25
Energy demand average	MJ	4741.43	1388.56	3827.01	7620.16	11,989.05	8060.43
Cost max	EU	222.16	65.06	179.32	357.05	561.76	377.68
Cost average	EU	142.24	41.66	114.81	228.60	359.67	241.81
Investment cost	EU	0	0	0	60	160	1500

The calculations were made with the assumption of 30 EU for 1 GJ [38] and assuming a maximum temperature difference of 38 °C and an average temperature difference of 24.33 °C [39]. Under normal conditions, the average costs should be accepted. The maximum costs occur rarely and they are momentary. Caring for the quality of internal air has always been associated with additional financial expenses.

4. Conclusions

The analyses from the simulation show that natural ventilation is not able to provide proper air exchange. Even with leaky old-type windows, the concentration of carbon dioxide exceeds 1000 ppm (PN-EN 13779:2008). The installation of sealed windows causes the air exchange to become abnormally low ($n = 0.3\ h^{-1}$). Also, the use of windbreakers does not improve the situation to the necessary degree. Regular airing of classrooms during breaks can reduce the carbon dioxide concentration to 2500 ppm, however, there is a significant reduction in indoor temperature (even below 10 °C).

Only the use of exhaust fans with the simultaneous use of window ventilators allows the concentration of carbon dioxide to be kept at an average level of 1000 ppm (PN-EN 13779:2008). Admittedly, obtaining a higher stabilization of ventilation is achieved by supplying additional energy to drive fans, however, this is a small amount compared to the cost of heat for heating the building (maximum 2%). The best control over the internal environment can be obtained by using a supply–exhaust ventilation system with heat recovery. The use of positive airflow creates an additional opportunity to improve the air cleanliness in the students' breathing zone.

Achieving effective ventilation in educational buildings is not easy. As shown in the above analyses in the coductance of modernization works and in newly built buildings, it is advisable to install supply–exhaust ventilation with heat recovery. At the same time, the costs associated with this undertaking should be taken into account. Taking into consideration the potential health effects and deterioration of mental work caused by bad ventilation, adaption of educational buildings should be a necessary and worthwhile investment.

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References

1. Bogdan, A.; Chludzińska, M.; Koelblen, B.; Ogłodzinski, K.; Młynarczyk, M. Sensitivity of personalized ventilation air terminal device geometry with regard to a human thermal sensation. *Sci. Technol. Built Environ.* **2017**, *23*, 1105–1112. [CrossRef]
2. Griffiths, M.; Eftekhari, M. Control of CO_2 in naturally ventilated classroom. *Energy Build.* **2008**, *40*, 556–560. [CrossRef]
3. Liu, X.; Li, F.; Cai, H.; Zhou, B.; Shi, S.; Liu, J. A numerical investigation on the mixing factor and particle deposition velocity for enclosed spaces under natural ventilation. *Build. Simul.* **2019**, *12*, 465–473. [CrossRef]
4. Mendell, M.J.; Eliseeva, E.A.; Spears, M.; Chan, W.R.; Cohn, S.; Sullivan, D.P.; Fisk, W.J. A longitudinal study of ventilation rates in California office buildings and self-reported occupant outcomes including respiratory illness absence. *Build. Environ.* **2015**, *92*, 292–304. [CrossRef]
5. Frontczak, M.; Wargocki, P. Literature survey on how different factors influence human comfort in indoor environments. *Build. Environ.* **2011**, *46*, 922–937. [CrossRef]
6. Gładyszewska-Fiedoruk, K. Correlation of humidity and temperature in conference rooms-Preliminary tests. *E3S Web Conf.* **2018**, *49*, 00032. [CrossRef]
7. Ventilation of Not Residential Buildings. Requirements for the Properties of Ventilation and Air Conditioning. PN-EN 13779:2008. 23 September 2008. Available online: http://sklep.pkn.pl/pn-en-13779-2008p.html (accessed on 10 June 2019).
8. Ferrucci, M.; Brocato, M. Parametric analysis of the wind-driven ventilation potential of buildings with rectangular layout. *Build. Serv. Eng. Res. Technol.* **2019**, *40*, 109–128. [CrossRef]
9. Smedje, G.; Norback, D.; Edling, C. Mental performance by secondary school pupils in relation to the quality of indoor air. In Proceedings of the 7th International Conference on Indoor Air Quality and Climate, Indoor Air '96 1, Nagoya, Japan, 21–26 July 1996; pp. 413–418.
10. Axelrad, B.; Jones, B. Toward comprehensive federal guidelines for school environmental health. In Proceedings of the 9th International Conference on Indoor Air Quality and Climate, Indoor Air 2002, Monterey, CA, USA, 30 June–5 July 2002.
11. Feola, J.; Hiester, M.; Mcguinness, M. IAQ tools for schools network: An innovative approach to achieving good IAQ. In Proceedings of the 9th International Conference on Indoor Air Quality and Climate, Indoor Air 2002, Monterey, CA, USA, 30 June–5 July 2002.
12. Jędrzejewska-Ścibak, T. Jakość powietrza w budynkach szkolnych w Polsce-wymagania prawne oraz zakres odpowiedzialności za ich realizację. Air quality in school buildings in Poland-legal requirements and scope of responsibility for their implementation. In Proceedings of the VI Ogólnopolska Konferencja Problemy jakości powietrza wewnętrznego w, Warzsava, Poland, 31 October 2001; pp. 147–157.

13. Bluyssen, P.M.; De Oliveira Fernandes, E.; Groes, L.; Clausen, G.; Fanger, P.O.; Valbjorn, O.; Bernhard, C.A.; Roulet, C.A. European indoor air quality audit project in 56 office buildings. *Indoor Air* **1996**, *6*, 221–238. [CrossRef]
14. Al horr, Y.; Arif, M.; Katafygiotou, M.; Mazroei, A.; Kaushik, A.; Elsarrag, E. Impact of indoor environmental quality on occupant well-being and comfort: A review of the literature. *Int. J. Sustain. Built Environ.* **2016**, *5*, 1–11. [CrossRef]
15. Kapalo, P.; Voznyak, O. Experimental measurements of a carbon dioxide concentration for determining of a ventilation intensity in a room at pulsing mode. *J. Civ. Eng. Environ. Archit.* **2015**, *62*, 201–210. [CrossRef]
16. Cichowicz, R.; Sabiniak, H.; Wielgosiński, G. The influence of a ventilation on the level of carbon dioxide in a classroom at a higher university. *Ecol. Chem. Eng. S* **2015**, *22*, 61–71.
17. Semprini, G.; Marinosci, C.; Ferrante, A.; Predari, G.; Mochi, G.; Garai, M.; Gulli, R. Energy management in public institutional and educational buildings: The case of the school of engineering and architecture in Bologna. *Energy Build.* **2016**, *126*, 365–374. [CrossRef]
18. Stabile, L.; Massimo, A.; Canale, L.; Russi, A.; Andrade, A.; Dell'Isola, M. The effect of ventilation strategies on indoor air quality and energy consumptions in classrooms. *Buildings* **2019**, *9*, 110. [CrossRef]
19. Stabile, L.; Buonanno, G.; Frattolillo, A.; Dell'Isola, M. The effect of the ventilation retrofit in a school on CO_2, airborne particles, and energy consumptions. *Build. Environ.* **2019**, *156*, 1–11. [CrossRef]
20. Hänninen, O.; Canha, N.; Kulinkina, A.V.; Dume, I.; Deliu, A.; Mataj, E.; Lusati, A.; Krzyzanowski, M.; Egorov, A.I. Analysis of CO_2 monitoring data demonstrates poor ventilation rates in Albanian schools during the cold season. *Air Qual. Atmos. Health* **2017**, *10*, 773–782. [CrossRef]
21. WHO. *2000 Air Quality Guidelines for Europe*, 2nd ed.; European Series, No. 91; WHO Regional Publications: Copenhagen, Denmark, 1996.
22. CONTAM. Available online: https://www.nist.gov/services-resources/software/contam (accessed on 14 June 2019).
23. Słodczyk, E.; Suszanowicz, D. Optimization of carbon dioxide concentration in the didactic rooms by the regulation of ventilation. *Ecol. Chem. Eng. A* **2016**, *23*, 275–285.
24. Recknagel, H.; Sprenger, E.; Schramek, E.R. *Taschenbuch für Heizung + Klimatechnik 07/08*; Oldenbourg Industrieverlag: Munich, Germany, 2007.
25. Grygierek, K.; Ferdyn-Grygierek, J. Multi-objective optimization of the envelope of building with natural ventilation. *Energies* **2018**, *11*, 1383. [CrossRef]
26. World Meteorological Organization (WMO). The state of greenhouse gases in the atmosphere based on global observations through 2015. *WMO Bull.* **2016**, *12*, 1–8.
27. Azuma, K.; Kagi, N.; Yanagi, U.; Osawa, H. Effects of low-level inhalation exposure to carbon dioxide in indoor environments: A short review on human health and psychomotor performance. *Environ. Int.* **2018**, *121*, 51–56. [CrossRef]
28. Zhelykh, V.; Yurkevych, Y.; Savchenko, O. The investigation of external aerodynamics of building of unusal architectural form. *Bud. Zoptymalizowanym Potencjale Energ.* **2018**, *7*, 37–42.
29. Wentylacja w budynkach mieszkalnych zamieszkania zbiorowego i użyteczności publicznej—Wymagania [Ventilation in Residential Buildings of a Collective Residence and Public Utility—Requirements]. PN-83/B-03430/Az3:2000. 12 October 2012. Available online: http://sklep.pkn.pl/pn-b-03430-1983-az3-2000p.html (accessed on 10 June 2019).
30. Kosieradzki, J. Wentylacja pomieszczeń. [Ventilation of rooms]. *Rynek Instal.* **2009**, *6*, 75.
31. Jamiołkowski, A. Nawiewniki—Niezbędny element systemu wentylacji grawitacyjnej. Diffusers—An indispensable element of the gravity ventilation system. *Budujemy Dom.* **2017**, *11*, 50–53.
32. Chen, J.; Augenbroe, G.; Song, X. Evaluating the potential of hybrid ventilation for small to medium sized office buildings with different intelligent controls and uncertainties in US climates. *Energy Build.* **2018**, *158*, 1648–1661. [CrossRef]
33. Yang, L.; Liu, X.; Qian, F.; Du, S. Ventilation effect on different position of classrooms in "line" type teaching building. *J. Clean. Prod.* **2019**, *209*, 886–902. [CrossRef]
34. Breesch, H.; Merema, B.; Versele, A. Ventilative Cooling in a School Building: Evaluation of the Measured Performances. *Fluids* **2018**, *3*, 68. [CrossRef]
35. Sekret, R. Environmental aspects of energy supply of buildings in Poland. *E3S Web Conf.* **2018**, *49*, 00097. [CrossRef]

36. Park, S.; Seo, J. Bake-out strategy considering energy consumption for improvement of indoor air quality in floor heating environments. *Int J. Environ. Res. Public Health* **2018**, *15*, 2720. [CrossRef] [PubMed]
37. Kaminska, A.; Ozadowicz, A. Lighting control including daylight and energy efficiency improvements analysis. *Energies* **2018**, *11*, 2166. [CrossRef]
38. Polskie Górnictwo Naftowe i Gazownictwo S.A. Obrót Detaliczny80-858 Gdańsk, ul. Wałowa 41/43, tel. (58) 325-99-02. Available online: https://www.zlawies.pl/plik,24214,porownanie-cen-nosnikow.pdf (accessed on 10 June 2019).
39. Pogoda. Available online: https://freemeteo.pl/pogoda/?language=polish&country=poland (accessed on 10 June 2019).