Improving the Effectiveness of Stack Ventilation by Supplying an Outdoor Air Stream

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Abstract. Stack ventilation is the most common ventilation in public utility buildings and residential homes. Its task is to remove contaminated air from the room and thus maintain good indoor air quality. The aim of the study was to determine the effectiveness of the natural ventilation of one classroom and determine the impact of the additional air supply to the room on the stack ventilation effectiveness. The effectiveness of stack ventilation was tested in a classroom during winter months. The improvement of the effectiveness of stack ventilation was analyzed as a function of the number of open windows. An increase of 80\% was obtained in the effectiveness of stack ventilation, when one window is opened. Lower increments were obtained when the number of windows opened were 2 or more. The maximum air change per hour during the tests was only 0.73 h\textsuperscript{-1}. Despite of the influence of outdoor conditions on stack ventilation, the maximum air change per hour was lower than the recommended number of exchanges in classrooms. As a result, recommended ventilation rates in school classes were not achieved when using stack ventilation.

1. Introduction

Stack ventilation is the most common ventilation in public utility buildings and residential homes. Its task is to remove contaminated air from the room and thus maintain good indoor air quality. The aim of the study was to determine the effectiveness of the natural ventilation of one classroom and determine the impact of the additional air supply to the room on the stack ventilation effectiveness. The effectiveness of stack ventilation was tested in a classroom during winter months. The improvement of the effectiveness of stack ventilation was analyzed as a function of the number of open windows. An increase of 80\% was obtained in the effectiveness of stack ventilation, when one window is opened. Lower increments were obtained when the number of windows opened were 2 or more. The maximum air change per hour during the tests was only 0.73 h\textsuperscript{-1}. Despite of the influence of outdoor conditions on stack ventilation, the maximum air change per hour was lower than the recommended number of exchanges in classrooms. As a result, recommended ventilation rates in school classes were not achieved when using stack ventilation.

Stack ventilation operates on the principle of pressure difference at the inlet and outlet of the channel. This is caused by the difference in air density, which depends on the temperature difference. The condition of proper operation of stack ventilation is to bring outdoor air into the room. According to PN-83/B-03430 \[9\], “stack ventilation ducts can only be individual, the cross-section should be determined at an outdoor temperature of + 12\degree C”. At lower outside temperature, and therefore with a larger temperature difference, there should be better chimney draft. This will cause a larger stream of air removed from the room \[2,6\]. The larger stream of air removed is not improving indoor air quality. A larger stream of removed air can lead to the cooling of air in the room and this will definitely lead to energy losses in the building \[3,5,7,10-16\].

Research on the effectiveness of natural ventilation, and above all the effectiveness of periodic airing of rooms was carried out, inter alia, by Heiselberg & Perino \[17\]. They showed that with the appropriate frequency of short-term ventilation, the quality of indoor air and the thermal comfort felt in accordance
with Directive 2002/91/EC [18] are improved. Stack duct ventilation will work properly if we bring outside air into the room.

Due to the fact that stack ventilation is the most unreliable installation [5]. Many authors are considering improving its effectiveness [17,19].

The studies on the effectiveness of stack ventilation in kindergarten in Bialystok before cleaning the channels and after their purification showed an improvement in the effectiveness of stack ventilation by a minimum of 10%, a maximum of 100%. However, the supply of air through a permanent unsealing of windows, increased the effectiveness of stack ventilation by 30% [20,21].

The aim of the study was to determine the effectiveness of stack ventilation in one classroom and determine the impact of additional air supply to the room in the stack ventilation effectiveness.

2. Methodology and research
The research on the effectiveness of ventilation in the didactic room (room for technical classes) was carried out in December. The room volume is 168.58 m³ (Figure. 1). The room is located on the lowest floor of the building. It is not tight room because there was a 2 cm gap under the door. The length of the ventilation duct is 12 m.

![Image of the room where the measurements were made.](image)

**Figure. 1.** The room where the measurements were made.

Measurements of the inlet air velocity through the windows and the exhaust air velocity through grilles were made with an anemometer probe connected to the TESTO 435-4 measuring instrument. Measurements of the dimensions of grilles, dimensions of the window aperture, volume of the room were made with the Bosch 50 laser rangefinder. The parameters and accuracy of the measuring instruments are given in literature [22,23].

The volumetric exhaust air flow rate, \( \dot{V} \) was calculated by using the equation of continuity (eq. 1):

\[
\dot{V} = AV
\]

Where:
- \( A \) - cross-sectional area of the air stream outflow from the room (cross-sectional area of the stack ventilation grid) [m²]; in the tested room is 0.0121 m².
- \( V \) - velocity of air outflow from the room [m/s].

During experimental tests, outdoor air temperature was 0°C, and the indoor air temperature was 22°C. The results of the measurements are shown in Table 1.

The exhaust air flow rate was higher when the number of open windows increased, as shown in Figure. 2. An important increment was obtained in the exhaust air flow rate when one window was opened.

It should be stated that in the case when there was no additional air supply, a low value of exhaust air flow rate, 19.6 m³/h, was obtained by stack ventilation. In this case, air flow was flowing through the gap under the door and through leaks in the building woodwork and through the structure of the wall material [7].
Table 1. Measured and calculated air parameters.

| Parameter / variant                  | 0  | 1  | 2  | 3  | 4  |
|-------------------------------------|----|----|----|----|----|
| Number of open windows              | -  | 0  | 1  | 2  | 3  |
| Inlet air flow rate through window  | m³/h| 0  | 131| 262| 393| 524|
| Mean air velocity through grid 1    | m/s| 0.25|1.13|1.35|1.35|1.37|
| Mean air velocity through grid 2    | m/s| 0.20|1.2 |1.39|1.45|1.45|
| Mean air velocity through grilles   | m/s| 0.225|1.165|1.37|1.4 |1.41|
| Exhaust air flow rate through grilles| m³/h|19.60|101.49|119.35|121.97|122.84|
| Air changes per hour                | h⁻¹ | 0.12 | 0.60 | 0.71 | 0.72 | 0.73 |
| Increased ventilation efficiency    | %  | -  | 80.69 | 14.96 | 2.14 | 0.71 |

Figure. 2. Exhaust airflow rate and number of opened windows.

An increase of 80% was obtained in the effectiveness of stack ventilation, when one window was opened, as shown in Figure. 2 and Table 1. The opening of a second window resulted in an increase of the stream of air supplied to the room by 100% to the value of 262 m³/h and an increase in ventilation efficiency of 14.96%. Opening the third or fourth window leads to an increment of 2.14% and a 0.71% in the effectiveness of stack ventilation respectively.

An effectiveness of stack ventilation of 0.12 h⁻¹ was obtained in the case with closed windows (in the absence of outdoor air supply). This value is in the typical range than other case studies where the effectiveness of stack ventilation should range from 0 to 0.2 h⁻¹ [24]. In the case study with one opened window, a value of 0.6 h⁻¹ of air exchange was obtained. This value is in the range than other reported in the literature where the number of exchanges with tilted windows should range from 0.3 to 3 h⁻¹ [24]. Nevertheless, the recommended number of exchanges in classrooms should be between 3 and 5 h⁻¹ [24]. However, the maximum air change per hour during the tests was only 0.73 h⁻¹.

In summary, further increasing the incoming air flow is not recommended. It will only cool the room. In this particular room, one should consider: whether to bring the room to the air stream through one window, which will improve the efficiency of the exchange by more than 80%, or by two, which in total will result in a 95% improvement in the effectiveness of stack ventilation.

3. Conclusions

Experimental tests were made to analyze the effectiveness of stack ventilation in a classroom. The experimental tests analyzed the influence of opening windows in the effectiveness of stack ventilation.
A low value of exhaust air flow rate was obtained by stack ventilation in the case with closed windows. An increase of 80% was obtained in the effectiveness of stack ventilation, when one window was opened. Lower increments were obtained when the number of windows opened were 2 or more.

The maximum air changes per hour, 0.73 h⁻¹, was obtained with four windows opened. However the obtained value is lower than the recommended [24] number of air changes per hour in classrooms. So, despite outdoor conditions influence on air exchange by means of stack ventilation, insufficient ventilation air stream recommended in school classes was not achieved [24]. The described method of supporting stack ventilation can be used, during short periods of time in similar rooms, when the stack ventilation is the only ventilation system.

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4. References
[1] A. Acred, and G. R. Hunt, Build. Environ. vol. 72 (2014), p. 44.
[2] K. Arendt, M. Krzaczek, and J. Tejchman, Build. Simul. vol. 10(2) (2017), p. 229.
[3] M. Ferrucci and M. Brocato, Build. Serv. Eng. Res. T. vol. 40(1) (2019), p. 109.
[4] T. Gaczol, J. Civil Eng., Environ. Arch. vol. 62(2) (2015), p. 81.
[5] G. C. da Graça and P. Linden, Build. Environ. vol. 107 (2016), p. 263.
[6] M. Krzaczek, J. Florcuk, and J. Tejchman, Energ. Buildings vol. 103 (2015), p. 48.
[7] R. Tamašauskas, J. Šadauskiene, P. Buzgevičius and D. A. Krawczyk, Energies vol. 12(11) (2019), p. 2145.
[8] P. Kapalo, H. Klymenko, V. Zhelykh and M. Adamski, Lecture Notes in Civil Engineering vol. 47 (2020) p. 168-173.
[9] PN-83/B-03430.
[10] V. V. Pudikov, N. B. Litvinova and P. A. Grushkovskiy, in 2018 International Multi-Conference on Industrial Engineering and Modern Technologies (FarEastCon), Vladivostok, Russia, p. 18393101 (2018). 10.1109/FarEastCon.2018.8602840.
[11] A. M. Rodrigues, M. Santos, M. G. Gomes and R. Duarte, Buildings vol. 9(5) (2019), p.123.
[12] D. A. Krawczyk, Energy Procedia vol. 95 (2016), pp. 216.
[13] D. A. Krawczyk and T. J. Teleszewski, Energies vol. 12(6) (2019), p. 1012.
[14] A. M. Marina Domingo, J. M. Rey-Hernández, J. F. San José Alonso, R. Mata Crespo and F.J. Rey Martínez, Energies vol. 11(10) (2018), p. 2826.
[15] A. Mikola, R. Simson and J. Kurnitski, Energies vol. 12(13) (2019), p. 2633.
[16] A. Tejero-González, D. A. Krawczyk, J. R. Martin-Sanz García, F. J. Rey-Martínez and E. Velasco-Gómez, Energies vol. 12(15) (2019), p. 3033.
[17] P. Heiselberg, M. Perino, Indoor Air vol. 20 (2010), p. 126.
[18] Directive 2002/91/EC of European Parliament and the Council of 16 December 2002 on the Energy Performance of the Buildings.
[19] K. Gladyszewska-Fiedoruk, V. Zhelykh and A. Pushchinsky, Energies vol. 12(15) (2019), p. 2845.
[20] T. Teleszewski, E3S Web Conf., 44, (2018), 00177.
[21] A. Asif, M. Zeeshan and M. Jahanzaib, Atmos. Pollut. Res. Vol. 10(2) (2019), p. 531.
[22] K. Gladyszewska-Fiedoruk, E3S Web Conf., 49, (2018), 00032.
[23] K. Gladyszewska-Fiedoruk and M. Niciecki, Energy Procedia vol. 95 (2016), p. 132.
[24] H. Recknagel, E. Sprenger, and E.-R. Schramek: Taschenbuch für Heizung + Klimatechnik 07/08, einschließlich Warmwasser- und Kältetechnik Gebundene Ausgabe, 73 ed. Vulkan-Verlag GmbH, Dec. 2006.