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The optimal amount of air for the natural ventilation of classrooms as a function of the rate of outdoor air leakage from windows

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ABSTRACT:
In the last few years there has been a tendency towards the air-tight sealing of buildings. This phenomenon can be seen both in older buildings being refurbished, as well as in those that are new or thermally-upgraded. The use of excessively air-tight windows in educational buildings with gravity (natural) ventilation system limits the inflow of external air to classrooms. The analysis covered 50 educational buildings in Częstochowa, which are used by primary and middle schools. Windows in those buildings were in a bad or very bad technical condition and their air-permeability was very high. Their defects cause excessive heat losses from heated rooms. It turns out, however, that the high air-permeability of windows (rate of outdoor air leakage (a) at the level of 6-7 $m^3/(h \cdot m \cdot daPa^{2/3})$ allows for a relatively beneficial level of natural ventilation and sufficient inflow of fresh air in the absence of other inflow of outside air solutions. Unfortunately, as a result of the replacement of old windows with new ones and no changes in the existing system of natural ventilation, a considerable deterioration of microclimate in classrooms can be expected, especially due to non-compliance with the requirements related to the sufficient supply of fresh air. To prevent this, it is necessary to take action to improve existing ventilation systems.

KEYWORDS:
educational building; outdoor air leakage; air infiltration; natural ventilation

1. Introduction

Excessive and uncritical airtight sealing of buildings as well as attempts to drastically reduce the fresh air changes which results from implementation of a heating energy saving programme have a negative impact on the quality of air in rooms and thus on their microclimate. In the longer term such a situation brings about the so-called sick-building syndrome which causes many health problems [1]. The term sick-building syndrome refers to the condition of rooms and buildings which causes and intensifies the symptoms of poor well-being in their occupants, leading to weakness or even illness. This combination of ailments, known collectively as a syndrome, includes irritation of the eyes, respiratory tract or skin, nausea and headaches, discomfort, irritation, fatigue and concentration problems. These symptoms are closely related to an improper microenvironment, especially poor air quality. Studies have shown that excessive airtight sealing of a building without ensuring a properly functioning ventilation system may cause illnesses and ailments in even 80% of the people staying in such a building

Excessive and uncritical airtight sealing of buildings as well as attempts to drastically reduce the fresh air changes which results from implementation of a heating energy saving programme have a negative impact on the quality of air in rooms and thus on their microclimate [2, 3, 4, 5].

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Proper room ventilation is of particular importance for the comfort of work in educational buildings. In this case limiting ventilation for the sake of reducing heat losses from heated buildings almost always has a negative impact on the quantity and quality of the fresh air [6, 7, 8] and thus on the microclimate of classrooms [1, 2, 3, 4, 5, 8, 9, 10] and effectiveness of the teaching process.

In the survey conducted by the author in educational buildings, the poor technical condition of old windows was the issue most commonly mentioned. Respondents noted, in first place, that the significant permeability of old windows and related problems were most detrimental. In the surveys, as well as in CO_2 concentration tests conducted in classrooms for verification purposes, there were no signals indicating long-term and progressive occurrence, in the heating season, of the symptoms suggesting poor air quality in the classrooms. Probably the windows in bad or very bad technical condition (so inconvenient to use, conducive to uncontrolled infiltration and exfiltration of air) do ensure, due to their air permeability, the inflow of a quantity of fresh air into classrooms sufficient enough to prevent or largely reduce the negative symptoms found in the occupants, caused by an insufficient amount of fresh air.

2. Research

The material presented in this paper is part of a broader study and analysis concerning a group of 50 educational buildings built in the 1913-1992. These buildings make up a complete urban statistical population of objects of this type. The theoretical analysis of natural (gravity) ventilation in the classrooms of the examined buildings was logically designed as follows:

- calculation of the cubature of an average classroom in a given object,
- establishment of the number of people occupying an average classroom in a given object,
- calculation of a normative quantity of fresh air with respect to the classroom cubature Q_{SC}, m^3/h (people outdoor air rate n = 1,5 ac/h taking into account Polish requirements) and calculation of a normative quantity of fresh air with respect to the number of students occupying the classroom QSN , m^3/h (adopted for the calculation $q_p=20\ m^3/(students/h)$,
- comparison of calculated values and establishment of which are higher,
- establishment of the number and location of windows in the school, including the windows considered to be typical for a given object,
- establishment of the number of typical windows per average classroom,
- establishment of the perimeter of windows and opening sashes per classroom,
- establishment of the length and dimensions of leaks in typical windows, found in an average (for a given building) classroom,
- calculation of the probable quantity of outdoor air flowing into the classroom with respect to the local climate and technical conditions,
- refinement of the comparison of requirements concerning ventilation of analysed rooms with the probable existing situation in this respect and drawing conclusions.

The essential value for the present analysis should be estimated to determine the amount of air which may enter a room through window air leakage. The quantity of infiltrating air Q through leaks in windows can be calculated from the following equation:

$$Q = a \cdot \sum l \cdot \left(\frac{\Delta p}{10}\right)^{2/3} \tag{1}$$

where: Q - quantity of infiltrating air through leaks in windows –, m^3/h; – calculated air leakage rate, $m^3/(h \cdot m \cdot daPa^{2/3})$; $\sum l$ - total length of leaks in windows - total length of all edges of opening sashes of the window frame opening, together with the frame perimeter (frame perimeter introduced to the definition by the author), m; Δp_a – difference in the pressure to the power of 2/3 on both sides of the analysed barrier caused by the wind blowing with certain speed, Pa (1 Pa = 10^{-1} daPa), (on the basis of own data (and other sources [4]) it was assumed that the average speed of wind in Czestochowa in the heating season is between 3.5-4.0 m/s. The wind blowing with such a speed causes a differential pressure of 7-10 Pa.)

3. Research results and discussion

Calculation results of the necessary quantity of the air delivered through the ventilation system into a standard classroom, which results from applicable norm requirements in this respect and may depend on the cubature of the room (air change rate) or on the number of people occupying the room (volume of air per person), are presented in fig. 1. To complete fig. 1, fig. 2 shows the amount of outside air that can be supplied to the classroom with good quality windows with an average rate of outdoor air leakage a = 0.6 $m^3/(m\ h\ daPa^{2/3})$. The values resulting from the demand for fresh air of a group of people occupying the classrooms are approximately 50% higher than those resulting from room cubature and assumed numbers of air changes per hour. Such a situation was expected since it is typical for the majority of public buildings which are temporarily occupied by large numbers of users.

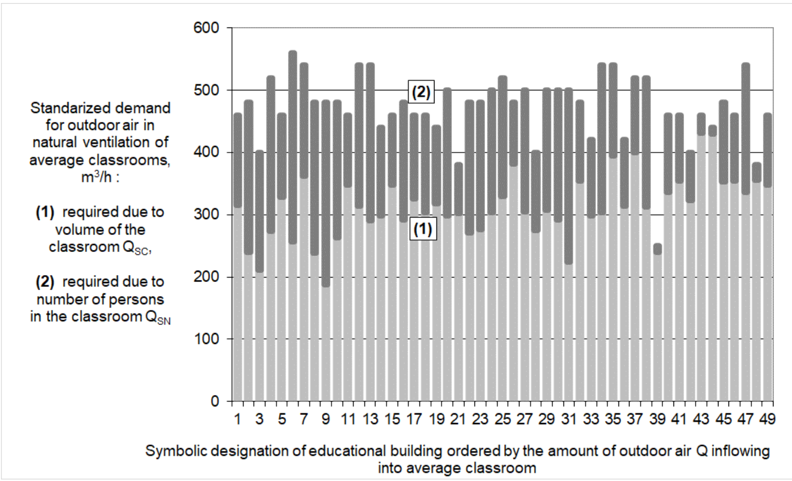

Fig. 1. Standardized demand for outdoor air in natural ventilation of average classrooms in the analysed educational buildings

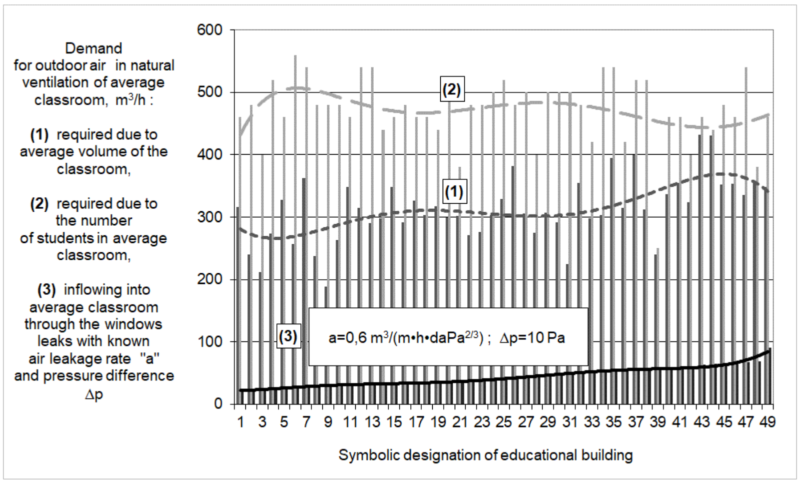

Fig. 2. The quantity of air flowing into the classroom from the outside through windows in good technical condition, rates of outdoor air leakage a = 0.6 m^3 / (m h $daPa^{2/3}$), in $m^3/(m\ h\ daPa^{2/3})$ for Δp = 10 Pa

The graphic analysis covers the situation of windows with different rates of outdoor air leakage (fig. 3, 4). Rates of outdoor air leakage a = 3.5 - 7.0 $m^3/(m\ h\ daPa^{2/3})$ apply to windows in bad or very bad technical conditions. The analysis, in particular, takes into account the dimensions and lengths of leaks through which the air infiltrates into classrooms.

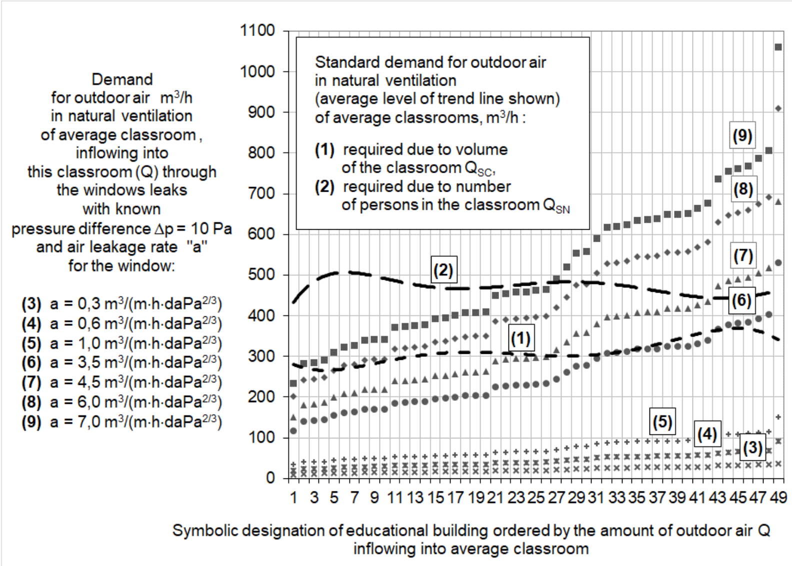

Fig. 3. The quantity of air flowing into the classroom from the outside through the windows with different rates of outdoor air leakage a, in $m^3/(m\ h\ daPa^{2/3})$ for $\Delta p = 10$ Pa

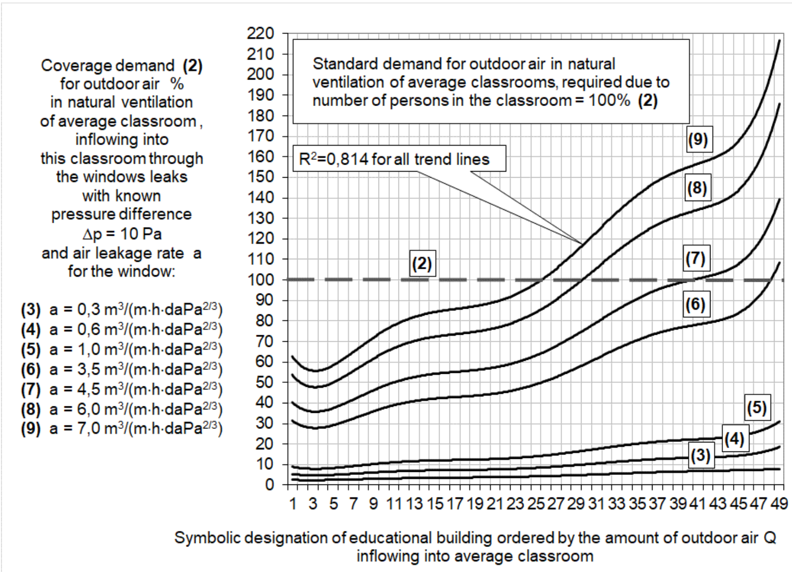

Fig. 4. Coverage of the demand for sufficient (with respect to the requirements) quantity of air flowing into the classroom from the outside through windows with different rates of outdoor air leakage *a*, in $m^3/(m{\cdot}h{\cdot}daPa^{2/3})$ for $\Delta p = 10$ Pa

Rates of outdoor air leakage, on the other hand, a = 0.3 $m^3/(m\ h\ Pa^{2/3})$ and a = 1.0 $m^3/(m\ h\ Pa^{2/3})$ (fig. 2, average a = 0.6 $m^3/(m\ h\ Pa^{2/3})$) refer to new windows (e.g. replaced windows), the air-permeability, which is defined in the requirements applicable in Poland, should fall within the range of a = 0.3 $m^3/(m\ h\ Pa^{2/3})$ to a = 1.0 $m^3/(m\ h\ Pa^{2/3})$.
Location points presented in the charts depend on the regulatory quantity of the amount of air delivered to classrooms related to the number of people occupying the classroom and the estimated theoretical quantity of the air infiltrating into the analysed rooms through window leaks at a certain wind force and direction. The regulatory quantity of air delivered to classrooms depending on the number of people occupying the classroom (Q_{SN}) in each of the analysed cases is greater than the regulatory quantity of air related to the cubature of the classrooms and air change rate per hour (Q_{SC}). Therefore, this requirement (Q_{SN}) is a point of reference for the values presented on fig. 3, 4.

4. Conclusions

The average technical condition of windows in the analysed educational buildings was bad. As a result, the inflow of outdoor air into the classrooms was considered conducive to the functioning of the natural ventilation of these rooms. However, only in the case of a significant technical deterioration of the windows resulting in a high rate of outdoor air leakage a = 6.0 $m^3/(m\ h\ Pa^{2/3})$ or a = 7.0 $m^3/(m\ h\ Pa^{2/3})$, that is above average in the analysed objects, the quantity of air coming through the leaks during favourable weather conditions is similar to or meets the ventilation requirements of the building. It should be noted that the rate of outdoor air leakage a estimated for the classrooms covered by the analysis amounted to approximately 4.5 $m^3/(m\ h\ Pa^{2/3})$. In the case of wind blowing from a favourable direction for the layout of windows on the building façade, at the speed of 4.0 m/s (though these winds are prevalent, they are not limited to the above conditions) the rate of outdoor air leakage only gives the possibility for the inflow of air similar to the quantity required by the criterion defined as the required amount of air changes per hour. This amount of fresh air is much less than that resulting from the average number of persons occupying the classroom. This situation may, of course, be changed by opening the windows occasionally, which, as follows from the research, is avoided by the users of the educational buildings during the heating season. Therefore, replacement of the windows is only a question of time which, if no changes are made to the existing natural ventilation system in this building will have a negative impact on the indoor air quality. In the case of new windows with the rate of outdoor air leakage a from 0.3 to 1.0 $m^3/(m\ h\ Pa^{2/3})$ (fig. 2), the infiltration of air is critically reduced. The quantity of air delivered to classrooms in this way is still on the level of 15%–50% of what is needed from proper ventilation requirements. Without installing additional vents in the rooms with the appropriate efficiency or better yet replacing the traditional natural ventilation system, meeting the normal requirements will be impossible.

Acknowledgments

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References

[1] Jenkins D.P., Peacock A.D., Banfill P.F.G.: Will future low-carbon schools in the UK have an over heating problem? Building and Environment 44 (2009), pp. 490-501.

[2] Clements-Croome D.J., Awbi H.B., Bako-Biro Z., Kochhar N., Williams M.: Ventilation rates in schools. Building and Environment 43 (2008), pp. 362-367.

[3] Lis P., Seria Monografie nr 263, Cechy budynków edukacyjnych a zużycie ciepła do ogrzewania, Wydawnictwo Politechniki Częstochowskiej, Częstochowa 2013.

[4] Lis P.: Normatywna ilość powietrza do wentylacji sali lekcyjnej a możliwości infiltracji powietrza przez okna. Ciepłownictwo, Ogrzewnictwo, Wentylacja nr 1/47/2016, s. 22-29; ISSN 0137-3676.

[5] Lis P., Janik M.: Natural ventilation of classrooms in relation to air-tightness of window. W: Nowoczesne rozwiązania w inżynierii i ochronie środowiska. Praca zbiorowa. Wydawnictwo Instytutu Klimatyzacji i Ogrzewnictwa Wydziału Inżynierii Środowiska Politechniki Wrocławskiej, Wrocław 2014, s. 123-128, ISBN 978-83-929704-7-7.

[6] Sedlakova A.: Energy saving as a result of suitable design of building`s bottom constructions. Technical Magazine 103 n. 5-B (2006), pp. 531-536.

[7] Sowa J.: Ventilation and air quality in school buildings. Heating Sector, Heating and Ventilation 3 (2002), pp. 24-29.

[8] Nantka M. B.: Relations between the windows tightness and realization of the natural ventilation tasks in multi-family buildings. Heating Sector, Heating and Ventilation 1 (2004), pp. 21-24; 2 (2004), pp. 21-24.

[9] Ferdyn-Grygierek J.: Energy efficiency of heating and ventilation in the modernized school buildings. Heating Sector, Heating and Ventilation 10 (2005), pp. 28-31.

[10] Laskowski L.: Thermal protection and building energy performance. Publishing House - Warsaw University of Technology. Warsaw 2005.

[11] Meklin T., Reponen T., Toivola M., Koponen V., Husman T., Hyvärinen A., Nevalainen A.: Size distributions of airborne microbes in moisture-damaged and reference school buildings of two construction types. Atmospheric Environment 36 (2002), pp. 6031-6039.

Właściwa ilość powietrza dla wentylacji naturalnej sal lekcyjnych w funkcji wartości współczynnika infiltracji powietrza zewnętrznego dla okien

STRESZCZENIE:
Od kilku lat obserwuje się tendencję do uszczelniania budynków. Zjawisko to można zaobserwować zarówno w remontowanych starszych budynkach, jak i w nowych lub poddawanych termomodernizacji. Ponieważ większość budynków edukacyjnych jest wyposażona w systemy wentylacji naturalnej (grawitacyjnej), zastosowanie okien nadmiernie szczelnych znacznie ogranicza dopływ powietrza z zewnątrz do pomieszczeń. Z tego punktu widzenia zbadano kompletną statystyczną populację miejską 50 budynków edukacyjnych zlokalizowanych w Częstochowie. Okna w tych budynkach były w złym lub bardzo złym stanie technicznym, a ich przepuszczalność powietrza była bardzo wysoka. Ich wady powodują nadmierne straty ciepła z ogrzewanych pomieszczeń. Okazuje się jednak, że wysoka przepuszczalność powietrza okien (współczynnik infiltracji powietrza z zewnątrz (a) na poziomie 6-7 $m^3/(h \cdot m \cdot daPa^{2/3})$ pozwala na stosunkowo prawidłowe funkcjonowanie naturalnej wentylacji i wystarczający dopływ powietrza z zewnątrz przy braku innych rozwiązań np. nawiewników. Niestety w wyniku wymiany starych okien na nowe i braku zmian w istniejącym systemie wentylacji naturalnej można spodziewać się znacznego pogorszenia mikroklimatu w salach lekcyjnych , szczególnie z powodu niespełnienia wymagań związanych z dostarczaniem dostatecznej ilości świeżego powietrza, aby temu zapobiec konieczne jest podjęcie działań modernizacyjnych nstalacji wentylacyjnej.

SŁOWA KLUCZOWE:
budynek edukacyjny, sala lekcyjna, szczelność okien, infiltracja powietrza, wentylacja