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Michał Michalik[1], Grzegorz Mizera[2], Adrianna Podbielska-Kubera[1], Henryk Kowalski[2], Adam Cenian[2*]

[1] Centrum Medyczne MML w Warszawie
[2] The Szewalski Institute of Fluid-Flow Machinery, PASci
*cenian@imp.gda.pl

Problems with microclimate in classrooms — results of measurements and proposed solution

Abstract
The paper deals with the issue of air quality in classrooms and its possible influence on educational performance and health, especially related to allergy problems and respiratory diseases. It is discussed how climate change and the smog resulting from increased automobile traffic (NOx, SO2, dust, etc.) can exacerbate factors like allergens, tobacco smoke, etc., causing airway inflammation. Therefore, the subject of air quality should be placed high on the list of problems to be considered at the planning stage of thermomodernization of existing school buildings. The distributed ventilation systems incorporating efficient filtering should be given priority in those regions with high smog levels and elsewhere during times of pandemic.

Keywords: microclimate, smog, classrooms, allergy, respiratory diseases, thermomodernization ventilation system.

1. Introduction

There is an increasing evidence that bad air quality and pollution caused by human activities can lead to serious health problems (Deng et al., 2020), including children working in badly ventilated classrooms (Satish et al., 2012; Zhang et al., 2016; 2017a; 2017b; Mizera et al., 2020; Karnauskas et al., 2020). Climate changes and smog increase intensity and frequency of air pollution episodes, which aggravate allergy problems and respiratory diseases. Global changes and weakening of atmospheric circulation influence air transport and pollution diffusion (Deng et al., 2020). It is known that extreme temperature and air pollution act synergistically, increasing respiratory symptoms in patients suffering chronic lungs diseases. Loss of fluids, perturbation of lung perfusion as well as increased ventilation and lung volumes can intensify under thermal stress. Moreover, thermal stress under conditions of air pollution intensify dyspnoea problems.

Lately, increased use of air-conditioners due to strong heat waves and comfort expectations presents a new risk factor for allergenic and respiratory diseases. When entering rooms with air-conditioners, a fall of temperature of 2–3°C without gradual adaptation may negatively influence the respiratory system. Cold air waves trigger fast contraction of bronchial tubes for patients with asthma. Poor ventilation in closed spaces can lead to increased chemical and infectious air pollution, which in turn can intensify pathogenic action of cold and dry air (Deng et al., 2020).

Although average global temperature grows, climate change may also lead to sporadic extremely low temperatures which cause overacting of the bronchial tube, contraction of smooth muscle of trachea and decreased lung circulation. For example, it has been shown that low temperatures in Finland lead to intensification of respiratory symptoms in patients with asthma and allergic rhinitis (Deng et al., 2020). Extreme weather events lead also to aeroallergen symptoms. For example sandstorms and strong wind enable easy transmission of spores and dust. On the other hand, there might be a negative correlation between strong precipitation and drought and dust transport (Ziska, 2020).

Epidemiologic and clinical research shows immunology effect, resulting from simultaneous exposure to aeroallergens and pollution; these lead to inflammatory reactions with recruitment of inflammatory cells, cytokines and interleukins. It has also been shown that pollutions can whet allergic symptoms (Naclerio et al., 2020). Besides, it has been found that increased temperature and CO_2 concentrations influence allergic symptoms (their triggering and duration) due to seasonal dustiness as well as aeroallergens concentration in airways.

Increased concentration of dust in the air might be related to several factors such as: source of dustiness, faster growth of some plants and increased blooming (Naclerio et al., 2020). Intensified allergenic response of dust allergens is also observed. Increased density of dust, moulds and spores observed in various countries stimulated by climate change results in a growing probability of asthma development (Deng et al., 2020). These changes lead to prolongation of allergic symptoms and their intensification which leads to increased demand for medication (Naclerio et al., 2020).

It is generally accepted that geographic factors influence the frequency of appearance of fungal sinusitis especially often reported in regions of high humidity, where fungi spores have favourable conditions (Awan et al., 2020). Populations living near the sea are at higher risk as there are more humid conditions leading to increased risk of mould and spore infections. A meta-analysis of 33 epidemiological studies showed an increase of 30–50% in negative effects on the respiratory system of humans related to growing exposure to humidity and mould (Ziska, 2020).

Air pollution in cities results from a wide variety of emission sources, including car exhausts, oil fumes in households and industrial gases. In particular, Traffic-related Air Pollution (TRAP) can weaken lung performance, lead to development and intensification of asthma symptoms, eczema and allergic rhinitis (Hao et al., 2021).

Fire and dust storms increase the natural emission of suspended particulates. Increased temperature and sun radiation intensify photochemical reactions generating O_3 near the land surface. Excessive concentration of suspended particulates and O_3 can stimulate asthma development and intensify its symptoms. Exposure to high concentrations negatively influence lung performance, cause increased frequency of airway inflammation and inflammation of bronchial tubes. It has also been shown that air pollution, especially by O_3, suspended particulates and diesel engine exhaust increase the permeability of mucous membranes to allergens and intensify inflammation of airways caused by allergens (Deng et al., 2020).

There is some evidence that chronic rhinosinusitis (CRS) appears more often in some professions. Danish studies (Thilsing et al., 2012) prove more frequent appearance of CRS among blue-collar than white-collar workers, due to higher exposure to dust, gases or fumes. In the U.S. a higher frequency of CRS (9.1%) was found among firemen even 7–9 years after rescue actions in the World Trade Centre. In Canada, chronic rhinosinusitis with nasal polyps is more frequent among patients heating their houses with biomass. In Korea CRS was discovered more often among industrial and engineering workers and craftsmen (Beule, 2015). Allergic rhinitis (AR) can lead to problems in upper and lower respiratory tracts, including development of asthma and sinusitis.

Hao et al. (2021) studied how exposure to TRAP (including PM10, O_3, SO_2, CO and NO_2) in early childhood makes children more prone to development of allergic rhinitis. Suspended particulate matter is very harmful for lungs and bronchial tubes due to its ability to penetrate airways. Dusty particles in the PM10 category settle in upper respiratory tracts where they cause inflammation of the mucous membrane in nose and throat. Exposure to NO_2 molecules present in smog can cause pinkeye inflammation and cough as well as contribute to AR development. Also SO_2 strongly irritates airways and CO is generally highly toxic but its relation to AR is unclear. The relation between SO_2 and AR may depend on research region, nationality or race. It was also found that mental stress and sterner sex make children in preschool age more prone towards AR when they are exposed to PM10 particulates and NO_2 (Hao et al., 2021).

The problems discussed above should be considered when designing new buildings and planning thermomodernization and ventilation systems of existing ones. Fosatti et al. (2021) showed the existence of an association between microclimate parameters (indoor temperature and relative humidity) and endothelial function.

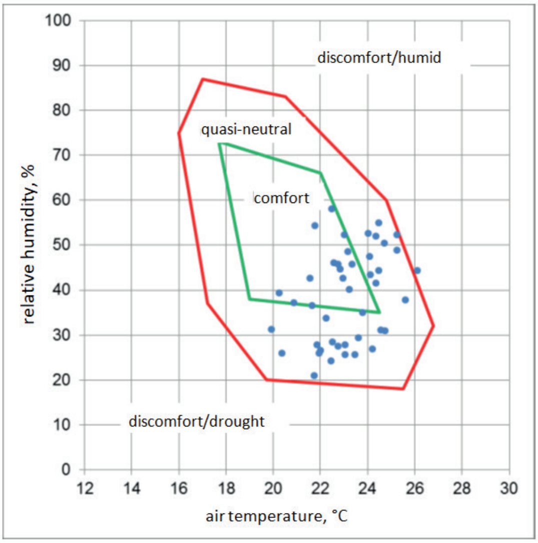

Fig. 1. Temperature and relative humidity of air guaranteeing to people inside comfort (inside green curve), discomfort (outside red) and quasi-neutral (between green and red curves) after Leusden and Freymark (1951)

However, the question is still open how these costly thermomodernization actions influence microclimate conditions in classrooms. This issue was tackled during works related to energy audits of schools in Gdynia performed as part of the Act Now! project financed by Interreg Baltic Sea Region Program.

What is microclimate in classrooms and how can it best be described? Here we focus on easily measured parameters such as: temperature, relative humidity and CO_2 concentration. There are other important parameters which should be considered including: PM2.5 and PM10, vapours and gases (including odorous) as well as microorganisms. Figure 1 presents the optimal conditions for people recommended by Lausden and Freymark (1951) namely a range of temperatures 21°C (±3°C) and 50–60% RH (±13%).

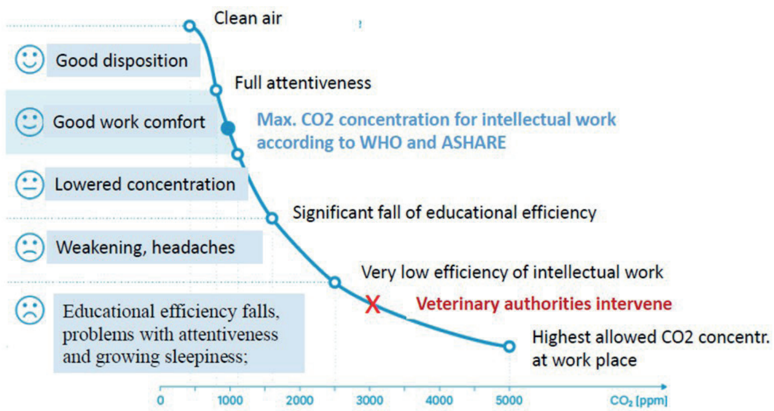

Fig. 2. Influence of CO_2 concentration on health and human activity, modified after Duda (2020) presentation "Not obvious consequences of classrooms ventilation methods"

The third basic parameter of microclimate (air quality) in classrooms is CO_2 concentration. In 2019 the global average atmospheric carbon dioxide concentration was determined as 409.8 parts per million. Exhaled human air (16–20 times a minute and a volume 500 cm^3) contains even 2–3% of CO_2 i.e. 20 000–30 000 ppm. In a poorly ventilated room occupied by several people, the CO_2 concentration increases rapidly, which badly influences their activity, educational efficiency and people's health — see Fig. 2.

As the effect of CO_2 is difficult to discern from other factors like chemical and biological pollution, the CO_2 concentration is treated as an indicator of pollution in general, see e.g. (Zhang et al., 2017a). Taking into account the negative influence of all these pollutants on work efficiency, educational process and health of pupils and teachers various countries introduced norms describing the acceptable CO_2 level. And so, the US Air Force advise a level below 700 ppm CO_2; 100 ppm more is accepted in offices by the California State. The ASHRE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) standard, supported also in Sweden, Japan and Canada, is 1000 ppm. In Italy and Finland acceptable CO_2 concentration is 1500 ppm. Interestingly enough, anything over 3000 ppm of CO_2 in animal farm building may result in veterinary intervention in Poland; even though no such intervention is likely in the case of educational institutions!

This paper aims at determining the microclimate state of art typical in Polish schools and at describing some solutions especially at the times of pandemic.

2. Results of measurements

Figure 3 presents the results of measurements in one of Gdynia's schools, which was among the best in the program "Each Watt worth its weight in gold" and which probably influenced the ventilation habits; at some moments in the school day the CO_2 concentration exceeded even 4000 ppm. It shows that all recommended norms/targets are exceeded and this results in deteriorating educational effectiveness. Therefore it is advisable to monitor the CO_2 concentration to indicate to the teacher when the target value of CO_2 (set by Regional Departments of Education) is exceeded. Whenever the CO_2 concentration exceeds the accepted level in classrooms without mechanical ventilation system the teacher should initiate intensive airing of the room by opening windows and possibly doors at least during breaks.

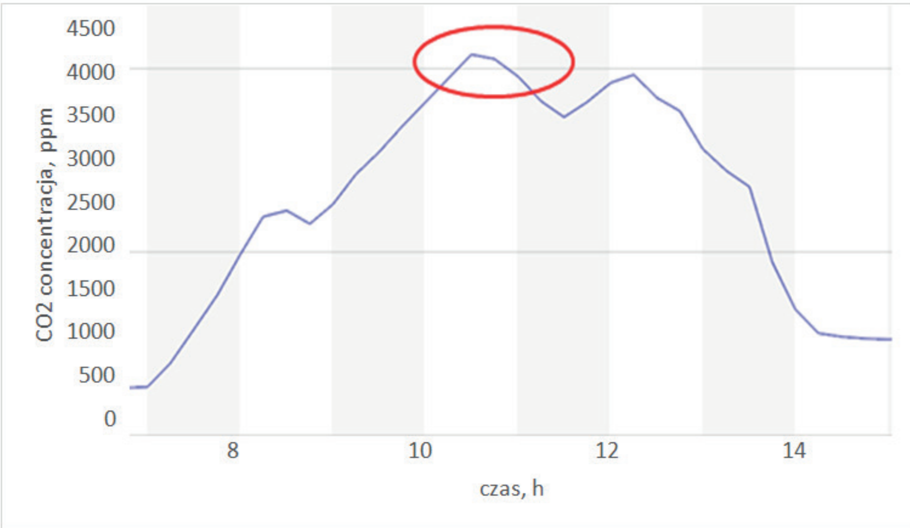

Fig. 3. CO_2 concentration measurements on 14.05.2019 in chosen Gdynia school

In order to assess in a more systematic way the situation in schools in the Gdynia municipality, as part of the "ActNOW!" project, a series of monitoring and control setups using the COMET 4400M system, which can use GSM net and internet to monitor and register air quality parameters such as temperature, CO_2 concentration and humidity. It was placed in several classrooms — see Fig. 4. It should be underlined that teacher awareness alone and intensive airing of the room by opening windows can improve air quality substantially. However, this simple system could not help in respect to SMOG problems, especially when schools are located close to major roads.

There are also problems related to air humidity and sterilisation, especially in the face of pandemic threats.

Fig. 4. Air quality control system applied in classrooms

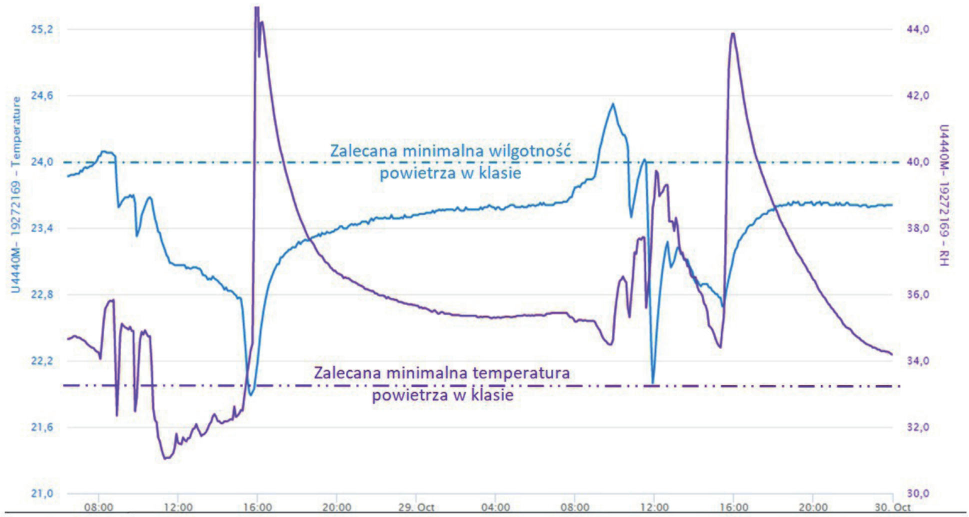

Fig. 5. Temperature and humidity monitored in a classroom in the period 29.10–1.11 2020 and registered in "cloud system" using a COMET 4400M device

Figure 5 presents temperature and humidity in one of Gdynia's schools measured in the period 29.10–1.11 2020 using the COMET 4400M system. Results show tendency to overheating in classrooms and attenuated (in relation to comfort) relative humidity, which may negatively influence the health of children and even more teachers, causing problems with vocal cords. The importance of right humidity was discussed by Ojanen (2014).

3. Why microclimate in classrooms is often not healthy?

Nowadays in Poland, large numbers of thermomodernizations are accomplished aiming at energy saving issues related to building heating. The effectiveness of thermomodernization projects is assessed taking into account investment payback time. Most often the process is limited to additional insulation of buildings, exchange of windows and doors of higher thermal resistance and sealing. When properly designed and performed the actions can increase heat savings — often even larger than planned. However, such thermomodernization radically reduces rooms' self-ventilation. Lower ventilation means low heat demand but on the other hand it often results in the target value of CO_2 concentration being exceeded. Even trickle vents installed in the window frames do not lead to any significant effects as they are often blocked by the occupants.

4. Proposed solution

Accomplishment of proper ventilation in existing buildings is often not an easy task. Central ventilation systems are generally not feasible in existing buildings due to the wide range of works and associated costs. Sometimes the local administration does not allow ventilation systems on roofs or outside of buildings for aesthetic reasons. So, autonomous systems of ventilation with heat recovery might be the best solution, especially in classrooms. The separation of ventilation systems for various classrooms is especially important during pandemic, since any source of microorganism transmission from room to room should be avoided.

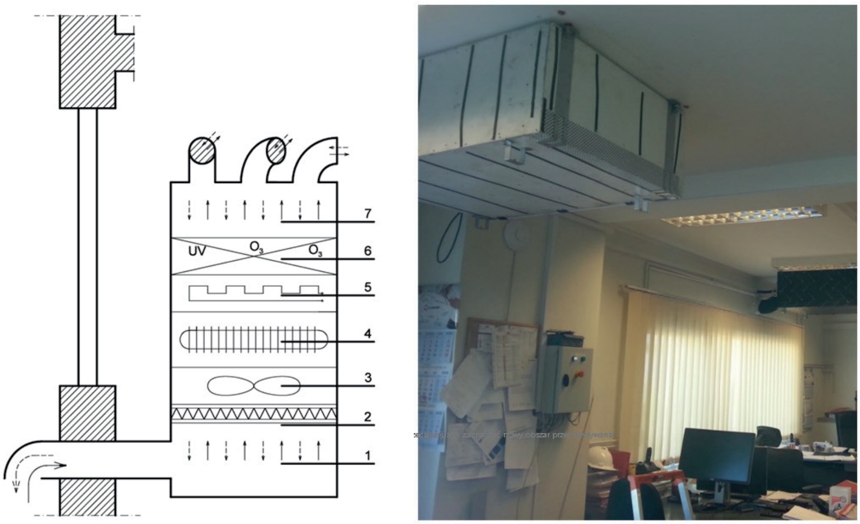

Fig. 6. Scheme of ventilation devise for distributed system for classroom application (a) and its realization (b); modules: 1 — external lower in/out module, 2 — filtration module, 3 — ventilation module with blower system, 4 — recuperation module (heat accumulation), 5 — heating module (for optional heating); 6 — sterilisation module (bacteria, viruses), 7 — internal higher in/out module

Figure 6 presents one version of an innovative solution (sent to Polish Patent Office) developed in cooperation between Klimawent Ltd and IMP PAN Gdańsk. The scheme for a complete ventilation system generating circulation of fresh air in the classroom is presented in Fig. 7. The system is based on two ventilation devices as presented in Fig. 6. placed in the corners of classrooms and controlled by the control unit denoted by number 302, which can be connected to school control systems via the internet.

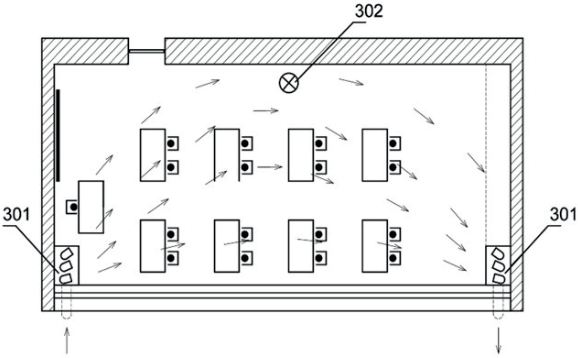

Fig. 7. Scheme of distributed ventilation system consisting of two ventilation devices generating in classrooms air circulation in classroom; 301 — ventilation devise as in Fig. 6; 302 — programmable control unit of ventilation system connected to main control setup for whole school building

Conclusions

Well-functioning nose and sinus helps to remove some pathogens and pollutants and defend upper respiratory tracts against infections. It is known that the smog resulting from increased automobile traffic (NO_x, SO_2, dust, etc.) can exacerbate factors like allergens, tobacco smoke, etc., causing airway inflammation. Therefore it is crucial to maintain high air quality in closed rooms, where people are spending a substantial part of their life: this includes classrooms in public (and private) schools. However, the typical assessment of energy efficiency and air quality in classrooms have shown that the issue of air quality is low on agenda of today's politicians. There must be more social pressure imposed to include the issue of air quality when planning school thermal modernization. Otherwise, the degradation of air condition will be a hidden long term cost resulting from the quest for increased energy/heat efficiency. The situation is even more complex in regions with high air pollution (smog) where airing the classrooms by window opening will often increase the problems. The use of efficient filtering systems is therefore necessary. Besides, distributed ventilation systems should be seriously considered in the times of pandemic.

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