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Rethinking Classroom Ventilation in post pandemic Situation

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Abstract. This paper aims to contribute in outlining the latest findings and formulating a simple practice in providing sufficient air circulation for classroom activities in preparation for the post-pandemic era. During this pandemic, remote learning over the internet has been a viable solution everywhere, including adopted by education institution to keep serving the learning process. However, as more and more people involved and the time elapses, several disadvantages of e-learning are realized. In addition, education institution should be prepared for the upcoming offline learning activity in post-pandemic era. This paper aims to refine the minimum airflow requirement for the classroom, finetuned based on student activity, ceiling height. Student activity is being the focus rather than teacher because student represents the majority of classroom occupant. In addition, a discussion on how it can be achieved using simpler ventilation system is presented. ON/OFF scheme for the usage of the active ventilation is also elaborated.

Keyword:
classroom, post-pandemic era, ventilation system, air circulation.

1. Introduction

1.1. The pandemic

The Covid-19 pandemic is an event that spreads the 2019 Coronavirus Disease throughout the world for all countries. This disease is caused by a new type of coronavirus called SARS-CoV-2. The Covid-19 outbreak was first detected in Wuhan City, Hubei, China on December 1, 2019, and was declared a pandemic by the World Health Organization (WHO) on March 11, 2020. As of November 14, 2020, more than 53,281,350 cases have been confirmed and reported in more than 219 countries and territories worldwide, resulting in more than 1,301,021 deaths and more than 34,394,214 recoveries [1].

The SARS-CoV-2 virus is thought to spread between people mainly through respiratory droplets produced during coughing. These droplets can also be produced from sneezing and normal breathing. In addition, the virus can be spread by touching a contaminated surface and then touching someone's face. Covid-19 is most contagious when the person suffering from it has symptoms, although it is possible for spread to occur before symptoms appear. The time period between exposure to the virus and the appearance of symptoms is usually about five days, but can range from two to fourteen days. Common symptoms include fever, cough, and shortness of breath. Complications can include pneumonia and severe acute respiratory illness. There is no specific vaccine or antiviral treatment for this disease. The primary treatment given is symptomatic and supportive therapy. The recommended preventive measures include washing hands, covering the mouth when coughing, keeping a distance from others, as well as monitoring and self-isolation for people who suspect they are infected.

1.2. Preventing the spread

Efforts to prevent the spread of the coronavirus include travel restrictions, quarantines, curfews, event delays and cancellations, and facility closures. These efforts include the quarantine of Hubei, the national quarantine in Italy and elsewhere in Europe, the imposition of restrictions on community activities in a number of major cities in Indonesia, as well as the imposition of curfews in China and South Korea, various national border closures or restrictions on incoming passengers, screening at airports and train stations, as well as travel information about the area with local transmission. Schools and universities have closed either nationally or locally in more than 124 countries and affected more than 1.2 billion students [1]. Every country is not alone in finding solutions for students to continue to learn and fulfill their educational rights. Until April 1, 2020, UNESCO recorded at least 1.5 billion school-age children affected by Covid 19 in 188 countries.

1.3. Pandemic accelerates ICT adoption

Pandemic accelerates the adoption of information and communication technologies (ICT). Growth in digital product/service offerings has jumped ahead by an average of seven years in just a few months of 2020 [3]. Many education institutions are pivoting massively to e-learning. The pandemic has caused a huge increase in the demand for e-learning platforms around the world as children have been instructed to attend online classes from their homes to maintain the continuity of formal learning. Students and teachers are engaging through e-learning platforms more intensely than before [2].

1.4. Issues in E-Learning

Being a new partner in their mode of education, e-learning poses adaptation risks for the young brain. Brain plasticity explains how neural circuits in the young brain respond to digital learning, given the fact that the formation of higher-order functions occurs during childhood. Several studies have shown that multi-method screen exposure causes structural changes such as a reduction in cortical volume with loss of integrity related to the white matter region and a decrease in gray matter in the prefrontal regions, namely the right frontal pole and anterior cingulate cortex. Such changes, in effect, impede attention competence, processing speed, verbal intelligence, and sustained attention, respectively. In addition, searching, finding, and reading online content reduces the functional connectivity of the area around the temporal gyrus, which is responsible for long-term memory formation and retrieval of learned material. It can also be noted that excessive use of visual modalities and long hours of exposure to computer screens can produce adverse effects on the visual system [2].

Not to mention the influence of online learning is very disturbing psychologically for students. Online use during a pandemic is indeed very effective because the platform is not only online learning, but for online learning like this, sometimes the schedules that have been arranged from schools or universities are simply changed with the clock colliding with other lessons. For example, lesson A uses the platform via live Instagram and at the same time lesson B uses the platform via Zoom. Not only that, there is Google Classroom which has the same function. This is a very disturbing focus in learning. Sometimes the study schedule is ahead of the time that has been made. Students are required to be able to monitor information from mobile phones. And there are many other obstacles in online learning like this. The psychological impacts of students due to social distancing include decreased immunity, lack of social interaction in the surrounding environment which results in a decrease in learning effectiveness. A weak body will have an impact on a person's focus in learning so that it will have a major impact on the achievement of the student. Therefore, a learning method that focuses on the psychology of students is needed so that the teaching and learning process can take place effectively.

This paper aims to contribute in outlining the latest findings and formulating a simple practice in providing sufficient air circulation for classroom activities in preparation for the post-pandemic era. Additional factor such as cooling, and moisture control of the ventilation system is excluded to allow the reader easily focus on our contribution. The rest of this paper is organized as follows. Section 2 discusses the importance of offline classroom that is realized more by many amid the pandemic and new normal of learning remotely via internet. Section 3 presents important considerations and reasoning for providing adequate classroom ventilation. Section 4 points out a simple and intuitive thinking framework to evaluate and design classroom ventilation. Finally, Section 5 delivers the conclusion. All manuscripts must be in English, also the table and figure texts, otherwise we cannot publish your paper.

2. Post-pandemic Education Activity

2.1. Importance of offline classroom

All affected countries have tried to make their best policies in maintaining the continuity of education services. Several real challenges include (i) technological disparities between schools in big cities and regions, (ii) limited competence of teachers in the use of learning applications, (iii) limited resources such as e-learning platform, learning materials, and adequate internet infrastructure, (iv) teacher-student-parent relations in online learning that are not yet integral.

The study found that for some who have high levels of academic procrastination had low levels of student readiness for online learning (SROL), leading to high perceived ineffectiveness of online learning [4]. An instrument with four competency subscales (online student attributes, time management, communication, and technical) that measures SROL required and as previously described, barriers and different scales of barriers to overcome in each country.

Traditional (face-to-face) learning procedures are preferred by most of the respondents (50.56%). Traditional procedures of learning are followed by the blended method (35%) and finally, only a few respondents (14.44%) preferred the online method of learning [5]. Most of those who support face-to-face learning give several reasons, including assuming that interaction and communication are easier to establish, learning resources and media are more familiar, do not have to be connected to the internet, easy to characterize, less stressed and more focused, more controlled, and will it is easier to carry out technology and natural science practicum, as well as higher psychological health because it can interact directly with teachers, lecturers, and friends.

Many education institutions are embracing remote online education as it also frees students and teachers from commuting, increases on-time attendance rate, and has better retention of learning materials including teacher's recording. Among them, 81.6% of the respondents claimed that online reduced the risk of catching COVID-19 virus [6]. However, many also experienced that pedagogical effectiveness in knowledge transfer and learning efficacy in some cases is lowered during online delivery, or at least needs more effort to sufficiently achieve the learning objective. This happens especially for psychomotor aspects. The report on students' dissatisfaction from the online learning experience during COVID-19 Pandemic in USA per January 2021 further states that more than half (52.6%) of the students claimed that the delivery covers less than 50% of the course syllabus [6]. The majority of respondents (82.5%) reported that the workload with online learning increased compared to traditional learning. 77.7% of respondents were distracted and could not remember focus during online classes. Nearly two thirds (61.3%) of respondents reported that they have technology and Internet connectivity issues such as poor connectivity, lack of adequate devices, and lack of technological literacy [6].

While holding classes online amid pandemic, education institutions are steadily seeking better delivery methods for such cases. In addition, ideas on how to resume the normal activities and interactions in the classroom safely, when the situation permits, are being taught by experts.

3. Classroom Ventilation

3.1. Indoor air quality

Humans need good quality air to sustain a healthy life. Air quality is usually represented by the amount of O2, the amount of hazardous (or unwanted, e.g due to its odor) substances, the amount and the size of solid pollutants, humidity, and temperature. To be categorized as a healthy air for breathing, there are certain thresholds for those quantities.

But more than just being healthy, humans also seek convenience. Humans need the air that can be perceived to be convenient. More stringent requirements shall be applied to realize both healthy and convenient air. For example, although both O2 and CO2 concentrations in the air meet the health and safety requirements, people in tropical regions need the air to be at a temperature around 25-28^{o}C for them to feel that the air is fresh.

Let us narrow down the discussion to the indoor air quality, which should be one among the major concerns now, as many industries are preparing to restore the activity in the office (or school, campus, and other localized workplace) again soon after pandemic-derived restrictions are relieved. Healthy and convenient air is important to support and sustain personal mood and productivity. Articulating this into the notion of classroom design in post-pandemic education brings us to several challenges.

Let us take an example of buildings in tropical climates. In such a region, the air from open space outside the building is often not preferable. In the dry season, the temperature is considered to be too hot and makes it too easy to sweat. In the rainy season, the humidity is too high which can be harmful to the furniture. In addition, not-so-ideal land management or building placement often leave the classroom exposed to road noises or dusty gusts. Hence, many buildings, including classrooms in many schools or campuses, were designed with the previous ‘modern’ trend of using air conditioners (ACs). Even in the room where window is possible (i.e. the room is directly adjacent to the outside, separated by a wall), the window is rarely opened, or completely sealed during construction (i.e. fixed, not openable window), allowing only light to pass.

Turning on the AC is more preferred by building occupants than opening the window. This habit has become the norm, including for rooms that have openable windows to access the outside air, and are not risked by excessive noise and dust from outside.

Several heating, ventilation, and air conditioning (HVAC) installations are not functioning or installed properly. With the tropical climate, the heating function in HVAC is not required. However, the ventilation function is still important. Nonetheless, sucking hotter air from outside of the building to be cooled and then blown into the room (ventilation is activated) causes higher energy consumption compared to cycling and re-cooling the already-cooled air from inside of the room (ventilation is disabled). Thus, aiming to reduce the electricity bill for HVAC, the ventilation function is turned off all the time. Even worse, to reduce the construction cost, the HVAC is not installed with a proper ventilation duct path in some cases, rendering the ventilation function completely disabled.

To accommodate classroom activities at campus post pandemic, a serious attention should be made by campus leaders to realize good indoor air quality. Precautions should be taken considering the safe distance between people in the classroom and adequate air circulation. Nonetheless, such effort needs to be performed with as minimum cost as possible, and without sacrificing architectural and functional components of the building.

3.2. Natural Ventilation to prevent the Covid-19

With good air quality outside provided by the nature, natural ventilation is a viable solution to decrease the concentration of indoor air pollutants, and is an effective way to increase Indoor Air Quality (IAQ) without excessively increasing energy consumption in buildings [8]. Note that a good outdoor air quality of a region can be indicated by a lower air quality index (AQI). Meanwhile, ventilation is implemented to achieve better IAQ. Both AQI and IAQ may vary numerically for different places or standards, but the concept remains the same.

Circulating outside air inside should only be done when AQI is low. Additionally, such ventilation implementation must consider IAQ standards to maintain the comfort and safety of the occupants. There are at least standards from The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and Federation of European Heating, Ventilation and Air Conditioning (REHVA) which provides guidelines to confirm safety and comfort of building’s air quality.

To monitor the goal achievement of the ventilation system for rooms with human occupants such as classrooms, CO_2 monitoring can be implemented [10] as CO_2 sensors are cheaper and widely available. Even though CO_2 is not an indoor air pollutant, it is frequently taken as a measurement of ventilation adequacy and can be a marker for transmission risk of the disease which can be transmitted airborne [11]. The concentration of indoor CO_2 from time to time is on average proportional to the duration and number of occupants indoor. It is also affected by airflow rates due to ventilation, CO_2 levels outdoors, and room size [12].

Following AQI which provides thresholds to categorize the amount of several substances in the air and map it to simple color codes and qualitative phrases, the following discussion assumes that a threshold to decide whether a certain concentration of airborne viruses are categorized harmful is known. It is acknowledged that different types of viruses and different climates or regions may have different thresholds, and thus it will be generalized using a variable herein.

In taking advantage of outside air, a common ground idea is that the outside air can be used to normalize the concentration of unwanted substances, i.e. airborne viruses, inside the classroom. I.e. the outside air, although it may contain those unwanted substances, it should not be exceeding the safe threshold. In the case where this condition is not satisfied, the suitable filter should be used, which prevents the usage of passive natural ventilation such as an openable window.

4. A simple thinking framework

In the case of Covid-19, the virus may be transmitted from people to people via the air. Hence, it is important to consider the air exhaled by the occupant, as well as distances between occupants during interactions. The moving, everchanging, air caused by ventilation is expected to help reduce the risk of virus transmission.

The amount of exhaled air per person is affected by person's activity and age. For classrooms in higher education institutions, the discussion can be focused on adults with normal to hard work activities. Normal work represents activities such as casual chatting, students attending the class, having discussions, and working on simple to moderate assignments. Hard work represents activities such as students delivering oral presentations (comparable to teaching for teachers), students having debate simulation, and undergoing deep-thinking exams. From [13] we obtain that respiration products for adult with normal and hard works are around 2 to 3 and 7 to 8 m3/h, respectively. Meanwhile, CO_2 emissions produced by adult respiration during normal and hard works are around 0.08 to 0.13 and 0.33 - 0.38 m3/h, respectively. Since currently there is no published data on the average amount of aerosol containing Sars cov-2 exhaled by an infected person, let us assume that it is the same as CO_2, since it is also a byproduct of the respiratory system.

Social distancing has been promoted in countries around the world. Campuses should limit the maximum number of occupants for each classroom. Some governments may have already mandated to limit the number of students attending the classroom to be only 50% or less from the actual room capacity. A better method to decide this number can be made by considering room dimension.

After students' position inside the classroom is determined and their minimum distance is known, e.g to ensure social distancing, we can estimate the indoor air volume per student. Initially, this personal volume around each student contains air to sustain the respiration. As student activities in the class continue, the concentration of aerosol/droplets (which may contain virus) there may rise beyond the safe category. Eventually, the air there needs to be replaced by the fresh one. We need to determine how often this volume of air needs to be circulated.

The simpler approach to estimate indoor volume per student is by directly dividing room volume by the number of students. However, this approach may not be suitable for a common classroom where the front area (e.g near the screen/blackboard) is not used for seating. In addition, room volume may be large due to a high room ceiling, not due to large area which is useful in social distancing. Thus, this does not really help prevent the spread of the virus as the aerosol is denser than the air and has a small probability to fly higher.

A more reliable method is by multiplying the personal area of the student with the ceiling height. Personal area can be perceived as the area which will not be invaded by other students, which in this case is due to social distancing. Student's personal area can be estimated from their seating distance, neglecting the vacant area in front of the classroom. In the case where student's seat distance from each other is not uniform, the minimum one can be considered.

A simple division between the indoor air volume per student and the amount of aerosol produced due to their activity reveals how long the air can be used before the aerosol concentration reaches an alarming level. Let us further illustrate this with a simple case as follows.

Consider a classroom full of fresh air from outside, which has 0.03% of CO_2 concentration. The ventilation is not activated, leaving the air unchanged. Assume that the seat arrangement of a classroom causes each student to have a minimum personal area of 2x2m. Room ceiling is 4m and thus creating indoor air volume per student of 16m3. Students are working on simple assignments. Each of them produces 0.12 m^3 of CO_2 per hour, or about 0.002 m3 of CO2 per minute. Relative to the air volume per student, 0.002 m^3 is 0.0125% in concentration. With the addition of an initial CO_2 concentration of 0.03%, CO_2 concentration in the air volume per student will reach 0.0925% within 5 minutes of activity. This number comes from 0.03 + (5 x 0.0125) = 0.0925. If the suggested maximum concentration of indoor CO_2 is 0.1%, the ventilation needs to be activated right after about 5 minutes since the activity starts.

The above finding also means that for each student, their indoor air, whose volume is $16m^3$, should be completely changed every 5 minutes. This air exchange rate should be multiplied by the number of students in the classroom. If there are 30 students in the room, the minimal exchange rate is 30 x $16m^3$ = $480m^3$ per 5 minutes, or 96m3 per minute. Now let us extend our discussion on how to realize this ventilation requirement.

Notice that balanced ventilation is suggested for better air circulation flowing through the room. Passive ventilation such as an openable window can be used if the smallest air speed, i.e between the inlet and outlet window, is equal to or greater than the required flow rate. Ensuring this rate on nature-driven airflow is rather cumbersome, so the theoretical average may be used. The air speed outdoor may not be the same as indoor. In this case, removing obstacles, enlarging, or balancing the opening area between inlet and outlet shall be attempted. If the air speed outdoor is not sufficient, active mechanical ventilation can be applied to help.

Passive ventilation using window have the advantages over the active one of being cheaper to operate and simpler to maintain. Active mechanical ventilation such as exhausts fan, AC, HVAC, HRV, and ERV consumes electricity and needs periodic cleaning and maintenance. Among them, the more complex one may even cause inconvenience or harm if not maintained/cleaned properly, such as the growing molds, dust, and construction debris in the air paths.

For active mechanical ventilation, one can control its on/off duration and even flow rate in some cases. Hence, an intermittent duty cycle can be implemented. In such cases, the ON duration of the ventilation fan can be shortened when the airflow rate is increased. Meanwhile, the OFF duration of the ventilation is limited by the indoor volume per student. For the previous example, Figure 1 provides a simple illustration of two settings.

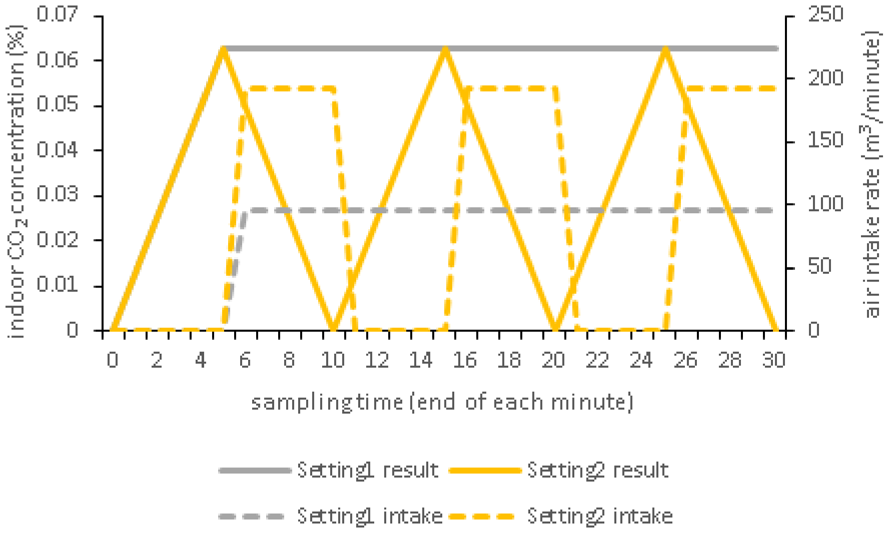

Figure 1. Comparing always on slower fan (Setting1) and on/off faster fan (Setting2)

Figure 1 depicts the condition of the previous example but with 0.03% initial CO_2 concentration omitted. In this case, the threshold for safe indoor CO_2 concentration is 0.07%. For simplicity, air quality is sampled at the end of every minute. From the 0th until 5th minute, ventilation is off and thus CO_2 concentration increases due to occupant respiration. In Setting1, the ventilation fan is turned immediately at the beginning of the 6th minute. In this setting, the fan's flow rate is 96 m3/minute, such that after 5 minutes (i.e., at the end of the 10th minute), 480m3 of outside air has entered the room. However, from the 6th to 10th minute, those 30 students are producing CO2 at the same rate. Thus, the total CO_2 concentration in the room is balanced at about 0.0625% and the fan cannot be turned off until the room is emptied.

Meanwhile in Setting2, the ventilation fan has a faster flow rate of 192 m^3/minute, which is twice as fast as the one in Setting1. The fan is turned on from the beginning of the 6th minute until the end of the 10th minute, accumulating 960 m^3 of clean air from the outside. This amount of air gradually reduce CO_2 concentration. By the end of the 10th minute, indoor CO_2 concentration is normalized (similar to the initial condition at the 0th minute), and thus the fan can be turned off but only for the next 5 minutes, because after 5 minutes, CO_2 concentration will accumulate and almost reach the alarming level of 0.07%.

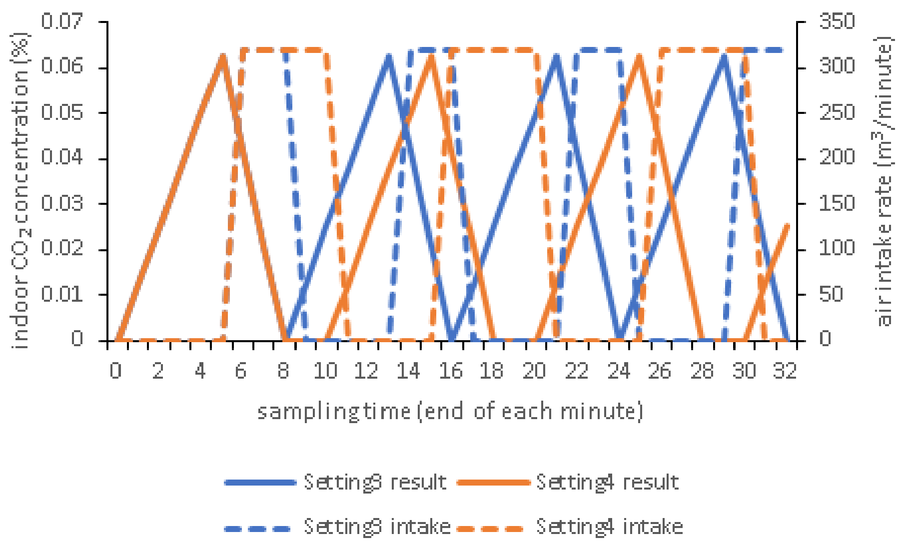

Figure 2. Comparing the same fan with shorter (Setting3) and longer (Setting3) ON periods

Figure 2 is included to highlight that the OFF duration cannot be prolonged by prolonging the ON duration. In both settings, the similar fans are turned on at the first time at the beginning of the 6th minute. Both have an air flow rate of 320 m^3/minute. Fan in Setting3 then delivers fresh air for the next 3 minutes, while the one in Setting4 continues the delivery until the next 5 minutes. The total volume of fresh air delivered in Setting3 and Setting4 are thus 3 x 320 = 960 m^3, and 5 x 320 = 1600 m^3, respectively. However, the room volume in this example is assumed to be only 960 m3. In this case, in Setting4, the fresh air flow in the 9^{th} and 10^{th} minutes are wasted, i.e., passed out the outlet fan again. Thus, if the fan in Setting4 is turned off at the end of 10^{th} minute, the inside air, i.e., 960 m^3 of fresh air, can only sustain healthy conditions for the next 5 minutes, which is the same as the one resulted in Setting3.

5. Summary/ Concluding Remarks

Providing quality air indoor is essential. For post pandemic education activities inside classroom, air circulation by ventilation is important to prevent the disease transmission and sustain the learning process and its expected performance. This paper mainly delivers a simple thinking framework for evaluating and planning the ventilation system for classroom. Intuitive discussions are presented with enough detail for the reader to look upon. Using the presented framework, one can infer the needs of fresh air circulation, its quantitative amount, as well as actionable items of minimum facility to realize it such as passive ventilation in term of openable window, or active mechanical ventilation that involves fan at the very minimum.

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