A Practical Study on Reducing CO_2 Density in Educational Buildings in North-East China

Abstract

Indoor air quality is a major contributor to the quality of people's lives. Notwithstanding pollutants that are becoming increasingly prevalent from new building materials, furnishings and consumer products, CO_2 density in educational buildings has been identified as a significant issue affecting students' performance. This paper presents the results of monitored CO_2 levels in differing educational facilities in north-east China during the winter period when windows have remained typically always closed to minimise heat loss. The negative impacts of CO_2 density is demonstrated to affect students' decision-making capabilities, and also the relevant Chinese building regulations related to the requirements of indoor air exchange have been reviewed. Finally, this research proffers practical solutions to improve indoor air quality, specifically related to CO_2 density in educational buildings.

Keywords: Indoor air quality (IOQ), CO_2 density, educational building, classroom

1. Introduction

Approximately, 90% of our lives is spent within indoor environments (Ott, 1989; Klepeis, et al. 2001; Jacobs et al., 2007). Thus, the quality of indoor air is a major contributor to human health (WHO, 2010). Indoor air pollution may cause or aggravate illnesses (Daisey et al., 2003; Mendell, 2007), increase mortality (WHO, 2010), and have a major economic and social impact (Fisk et al, 2007). Further, it has been proven that a number of respiration related diseases are directly caused or developed by poor indoor air quality (IOQ) by means of pollutants (Allen, et. Al., 2016; Daisey et al., 2003; Mendell, 2007). Exposure to pollutants may cause a variety of effects ranging in severity from perception of unwanted odors through to cancer (ECA, 2003). Examples of health effects are dispersal of airborne infectious disease, micro-organisms in air humidifiers causing pneumonia and humidifier fever, mould increasing risk of allergy, and an increased risk of lung cancer through exposure to environmental tobacco smoke (ETS) and radon. Sensory effects include:

- Adverse health effects on sensory systems
- Adverse perceptions such as annoyance reactions and triggering of hypersensitivity reactions
- Sensory warnings of harmful factors such as irritation due to formaldehyde.

The rapid development of new building materials, furnishings and consumer products over the past 50 years has resulted in a subsequent increase in new chemicals in the built environment (Weschler, 2009). The increase is an accumulation of the number of chemicals manufactured and used in household and building products, including construction materials, interior finishing materials, cleaning agents, furnishings, computers and office equipment, printers and supplies. In addition, buildings and HVAC (heating, ventilation and air conditioning) systems have deteriorated as a result of ageing and inadequate maintenance, or become obsolete as a result of technological advances. Added to this, the amount of fresh air being brought into buildings has decreased in order to reduce the amount of energy needed to heat or cool it. Thus, there is less fresh air available to dilute indoor air contaminants/ pollutants. Indoor concentrations are largely uncharacterised, but they have likely increased over time as a wider mix of chemicals are used and air exchange rates in the buildings decrease to improve energy efficiency (Weschler, 2009). Chemical concentrations are often highest indoors because many of the sources are indoors, and because of limited degradation indoors compared with outdoors. In addition, people who may be exposed to indoor air pollutants for the longest periods of time are often those most susceptible to the effects of indoor air pollution, and are namely the young, the elderly, and the chronically ill.

There have been many definitions provided for appropriate IAQ, one definition describes the absence of air contaminants which may impair the comfort or health of building occupants (Rousseau, 2003). Jacobs et al. (2007) define indoor air pollution as chemical, physical or biological contaminants in the breathable air inside a habitable structure or conveyance, including workplaces, schools, offices, homes and vehicles. Other general factors influencing IAQ to those aforementioned includes temperature and humidity comfort, lighting and acoustic condition. A popular method to measure IAQ is to measure CO_2 levels in indoor air using CO_2 meters or monitors. CO_2 is commonly used as a sentinel indicator of IAQ to demonstrate relative levels of other pollutants, typically like NO_2, CO, SO_2, and VOC (volatile organic compounds) and body odor (Johnsona *et al* 2018; Krawczyka & Wadolowskab, 2018; Huang, *et al*, 2018). It has to be clarified that the CO2 in general outdoor air is around 400-600ppm. This is no harmful to human health. However, there are some regulations regarding CO2 level in certain types of buildings in the world. For instance, the British Health and Safety Legislation (HSE, 1999), which apply to school and educational buildings (ibid), state that long term exposure (less than 8 hours) to CO_2 should not exceed 5000ppm, and short term exposure (15 minutes or less) should not exceed 15000ppm.

Notwithstanding pollutants, many researchers have investigated the relationship of IAQ with regards to CO_2 levels. A significant study in this area was carried out at the Lawrence Berkeley National Laboratory and SUNY Upstate Medical University (Satish, *et, al.* 2012). The research demonstrated that the density of CO_2 in indoor air significantly affects people's decision-making performance whereby 2500 ppm CO_2 is reached in an indoor environment (Figure 1). Satish *et al*. (2012) demonstrated that when the CO_2 level is between 1000ppm and 2000ppm, occupants may feel that the air is un-fresh and often start to feel drowsy; when the CO_2 level is raised to between 2000ppm to 4000ppm, occupants in this environment may feel difficultly breathing, their faces often turn red and they may start to feel convulsion; when CO_2 levels reach between 4000 ppm and 6000ppm, occupants may experience permanent brain damage, and often lose consciousness, and more seriously, may die if they stay in such an environment for a period of time.

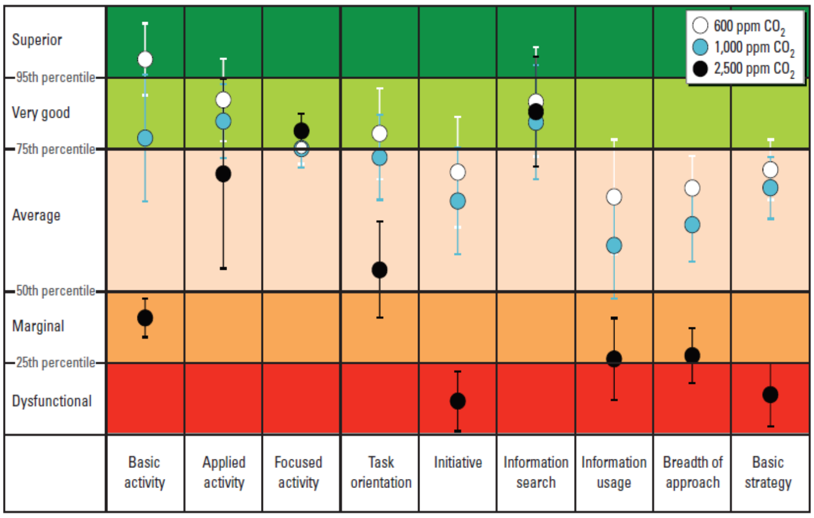


Figure 1: Impact of CO_2 on human decision-making performance (Satish, *et al.* 2012)

In recent years, the indoor air quality issues have been addressed as a very important factor to the building performance, especially in school and education buildings which may affect collective young people. Some similar research have been done around world, such as central Italy (Stabile *et al*, 2017), USA (Johnsona *et al*, 2018) Finland (Slezakova *et al*, 2019), USA (Majda, et al, 2019).

Johnsona *et al* (2018) demonstrated that school classrooms, especially those located in extremely cold or hot weather, whereby windows are usually kept closed during teaching sessions, often face poor air IAQ. Thus, IAQ has been proven to impact upon students' performance, and as such, many countries around the globe have indoor air quality management (IAQM) strategies for educational facilities that aid the management of IAQ during occupancy (Hall et al., 1995, Beaulieu, 1998, EPA, 2011). Whilst such strategies exist, they are not commonly monitored as in the case of China. The Chinese Indoor Air Quality Standard (GB/T18883-2002) states that the CO_2 level should be kept below 1000ppm. As one adult usually exhales about 22.6 litres of CO_2 per hour, how are classrooms affected, whereby are large quantity of persons are expected to concentrate for fixed time periods? This research investigates CO_2 density in educational facilities in north-east China. Data collection will involve measurements on CO_2 levels in learning facilities, and calculated against student numbers, size of facility and window openings. Analysis of the results against the relevant building regulations will then be used to proffer practical design solutions.

2. Research methods:

Building Performance Evaluation (BPE) is a practical method of evaluating a buildings performance with a Post Occupancy Evaluation (POE) being a major component. A Building Performance Evaluation may be carried out on new, refurbished or existing buildings. It can test building fabric, building services, energy use, water use, user satisfaction to name a few. The outcomes may be used to better understand how to make the building more efficient.

Post Occupancy Evaluation is becoming recognised as an important tool to develop better designs and to obtain important feedback on a building and how well it performs, in many cases buildings do not meet their expectations and this can have an impact on human comfort, running costs, user satisfaction, health and safety. Post Occupancy Evaluation is defined as "the process of evaluating any type of building in a systematic and rigorous approach after they have been built and occupied" (Preiser et al, 1988). The RIBA also defines a Post-occupancy Evaluation in the RIBA Plan of Work as an "Evaluation undertaken post occupancy to determine whether the project outcomes, both subjective and objective, set out in the Final Project Brief have been achieved." (RIBA, 2019).

In this research, the POE exercise mainly focuses on the human comfort and health and safety issues, specifically the indoor air quality, including CO2 density and associated temperature and humidity. Two detailed methods were applied. One was mainly environmental data collection with equipment, another was to gather user experience feedback.

For the indoor air quality environmental data collection. Following 3 types of data logs with integrated sensors were used:

- Tinytag CO2 TGE-0011, which can be setup for collecting CO2 density (ppm) for minimum each minute. As this CO2 data log needs a power supplier, it has to be placed near to a power socket.
- Tinytag Ultra 2 TGU-4500 is an indoor thermal data loggers which can capture both temperature and humidity data for minimum each minute in indoor environments. It is powered with a battery. So it can be placed anywhere.
- Tinytag Plus 2 TGP-4500 is an outdoor thermal data loggers which can capture both temperature and humidity data for minimum each minute in outdoor environments. It is also powered with a battery.

The users' experience investigation was mainly via a questionnaire survey of students in the classrooms, and a semi-structured interview to the people in the facility management team. The questionnaire mainly covers the students' feeling on air quality, temperature and humidity, class and break time, and their concentration in classes. The semi-structured interviews mainly focus building operation management, especially for the ventilation systems in the buildings.

3. Sample area

Dalian is one of the largest cities in north-east of China, located at the south most point of the Liao-Dong peninsula. The coordinate is 121.44 and -121.49. Dalian is classified as a Class A Cold Zone area according to the Chinese Building Regulations, and requires at least 152 days heating supply per year. The lowest average outdoor temperature for 5 days per year (heating calculation temperature) is - 9.8°C. The average outdoor temperature during the winter period is - 0.7°C. In winter, usually all windows of all buildings in Dalian remain shut to minimize any heat loss. With the ever increasing standard of energy efficiency for buildings, the air tightness of windows has been improved significantly over the years. The Design Standards for Public Building (GB50189-2005) requires that the air tightness of a window must not be below Level 4 (2.0< & <2.5 M^3/M.H), which means that the cold air penetration for each metre of window gaps in each hour is 2.0-2.5 M^3. However, contrary to this, the National Energy Efficiency Standards for Public Buildings (GB50189-2015) request the air tightness not below Level 6 (1< & <1.5 M^3/M.H).

From the end of 1990s, due to the growing demand of students, there was a significant surge in the refurbishment and construction of new universities across Dalian; notably, only 6 out of a total 42 university buildings in Dalian which stand today were constructed before 2000. The 6 pre-2000 university buildings have no mechanical or passive ventilation systems in place. Of the remaining 36 university buildings, most do not have mechanical ventilation systems. Only one building has a mechanical ventilation system, but it is rarely used as no one thinks it is necessary. Notably, the majority of the lecture theatres windows have large divisions, and therefore, it is usually impossible to operate/ open windows easily. In addition, the majority of school buildings in Dalian are not equipped with any ventilation systems, and too consist of large windows that are difficult to operate/ open.

4. CO_2 measurement in classrooms

CO_2 measurements were carried out during winter 2018, where the outdoor temperature ranged between 1°C and 6°C. Measurements were taken in a ‘typical’ large lecture theatre (A) with 250 seats in a university building constructed in 2007 (Figure 2), and another was in a ‘typical’ classroom (B) with 40 seats of a high school building constructed in 2005 (Figure 3). Although the measurements were taken across a whole week, the CO_2 density results were averaged for a typical day, as per Figure 4 and 5.

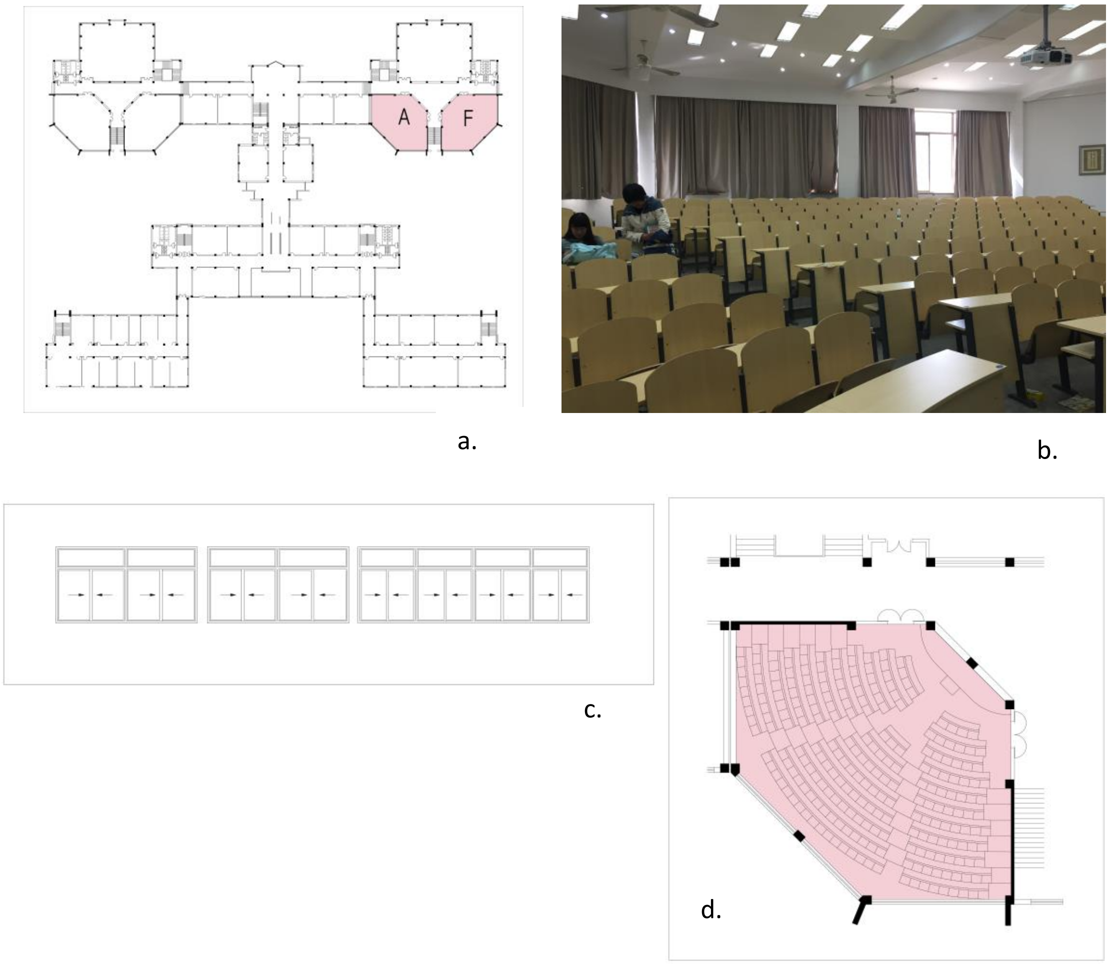
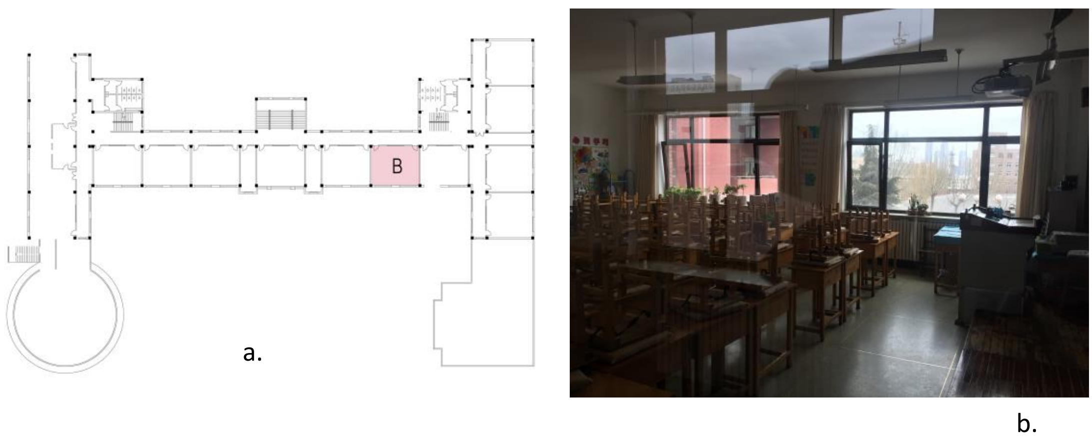


Figure 2: a typical university lecture theatre (A) – a, the floor plan; b, internal photograph; c, window openings of the lecture theatre; d, indoor layout of the lecture theatre



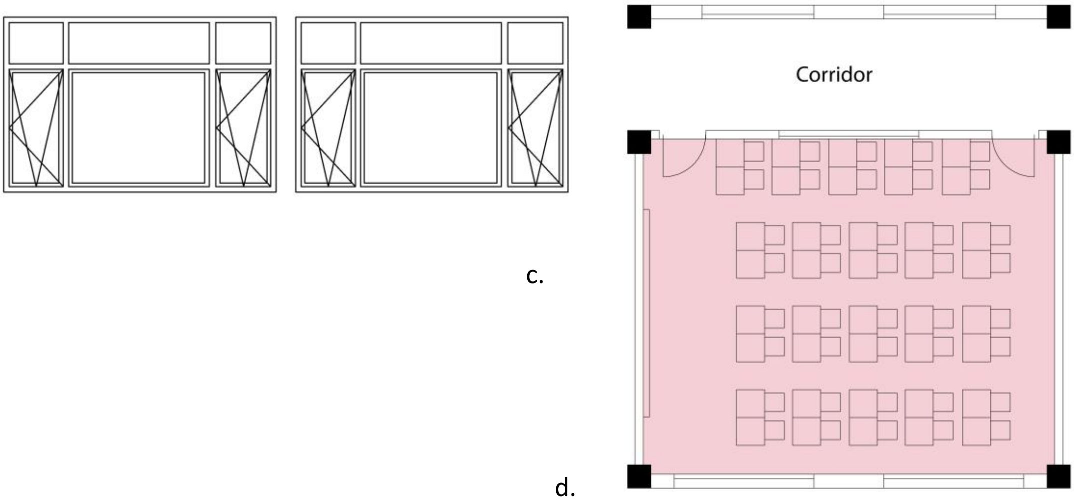


Figure 3: the school classroom (B) – a, floor pıan; b, internal photograph; c, window openings of the classroom; d, indoor layout of the classroom

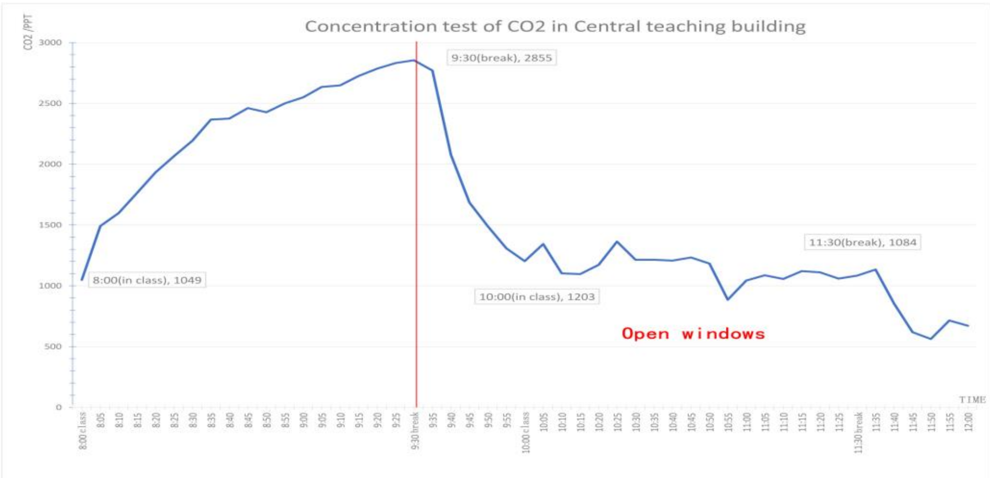


Figure 4: CO_2 measurements in a university lecture theatre (A) across a typical day during winter 2018

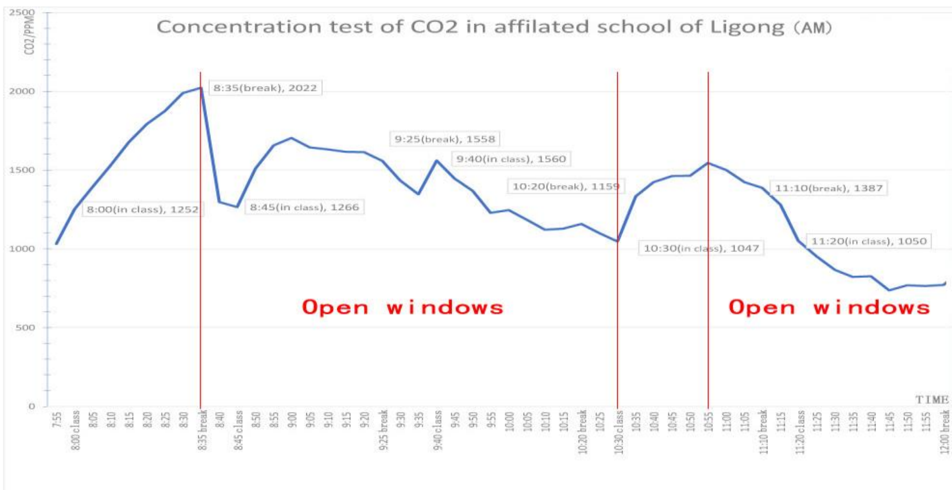


Figure 5: CO_2 measurements in a school classroom (B) across a typical day during

winter 2018

The results presented demonstrates that CO_2 levels vary significantly during lesson times, and this is also impacted by the opening of windows. The CO_2 in the university lecture theatre (A) increased rapidly from around 600ppm to 2855 ppm during the first 90 minutes of the session, with all of the doors and window shut (Figure 4). Meanwhile, the CO_2 level in the secondary school classroom reached to 2022ppm within 35 minutes (Figure 5). The height of the lecture theatre (A) is 5.1m and the designed density is 1.22 person/m^2, with each person occupying 4.18m^3 of space; the height of the secondary school classroom (B) is 3.6m, and the designed density is 0.8 person/m^2, with each person occupies 4.5m^3 space. The windows of the lecture theatre (A) are aluminum-framed double-glazed sliding windows, with an overall window opening area of 42.2m^2. The rate between the window areas to the floor area of the theatre is 1:4.8, and the window opening length is 77m; the window's opening area to the floor area is 5.97%. For the school classroom (B), the windows are aluminum-framed double-glazed windows. The overall window area is 11.895m^2. The rate between the window areas to the floor area is 1:5.29, and the window opening length is 8.4m; the window's opening area to the floor area is 5.05%. The comparable results are presented in Table 1.

	Highest recorded density of CO_2	**Density of space**	**Person occupancy density of space**	**Overall window opening area**	**Rate of window area of floor area**
Lecture theatre (A)	2855 ppm during 90 minutes	1.22 person/m^2	4.18m^3	42.2m^2	1:4.8
Secondary school classroom (B)	2022ppm within 35 minutes	0.8 person/m^2	4.5m^3	11.895m^2	1:5.29

Table 1: Comparable CO_2 density results of classroom facilities in typical day during winter 2018

According to the Chinese Building Regulations (GB50352-2005), in order to ensure that there is adequate natural ventilation in a building, the window opening area of a room against that of the floor area of the room should be greater than 1:20, of (A) 1:4.8 and (B) 1:5.29 respectively. Thus, both the university lecture theatre and the primary school classroom meet this criterion. However, as the windows are not usually opened during the winter, the exchange of fresh air cannot be guaranteed. In this case, the lecture theatre had 288.75m^3 air exchange over 90 minutes; the school classroom had 26.8m^3 over 40 minutes. According to the building regulations for building services (GB50736-2012), every person in a classroom should have at least 22 to 24 m^3 fresh air. Based on this standard, the lecture theatre should have at least 5500m^3 fresh air exchange over 90 minutes and the school classroom should have at least 880m^3 air exchange as well. Neither facility met this standard, as windows largely remained closed and there were no additional mechanical ventilation systems present.

In the North-East of China, occupants very rarely open any windows during the entire winter period. Therefore, it is foreseen that the results presented in Figure 4 and 5 are typical of educational facilities whereby there is a high CO_2 density during use/ operation. Although CO_2 is not an air pollutant that directly causes harm to people's health, it does indicate the presence of other pollutants including human odor, and is associated with uncomfortable temperature and humidity which affect students' concentration as concluded by Satish, *et, al.'s* research (2012); Satish *et al*. (2012) demonstrated that when the CO_2 level is between 1000ppm and 2000ppm, people may feel that the air is un-fresh and often start to feel drowsy (see Figure 1). Further, such high levels of CO_2 in educational facilities can also cause headaches, stomach aches, and other irreversible damage to people's health. Thus, good indoor air quality and artificial/ mechanical ventilation is essential for educational buildings in the north-east of China. The following section proffers a number of practical solutions to address this concern.

5. Users' experience

5.1 questionnaire survey

The following five questions are designed to collect the students' experience in the classrooms:

1. Do you feel the air quality getting bad over the class time?	• Yes • No	• 78 • 5
2. If so, in terms of what? (allow multiple selection)	• Breathing problem including block nose, • headache, • sleepy, • can't concentrate • Other, specify ________________________	• 17(20.5%) • 27(33%) • 43(51%) • 56(67%) • 5 (6%)
3. If so, when you start to have such symptom?	• Within first 30 mins • Within first 60 mins • After 1 hour • After 1.5 hours • Or specify _________mins	• 5 • 24 • 37 • 17 • 0

4. You think how long of each session you should have a break?	• 30 mins • 45 mins • 60 mins • 90 mins • Or specify _____ mins	• 12 • 27 • 37 • 7 • 0
5. What do you feel about the temperature in the classroom?	• Fine • Good • Sometimes too hot • sometimes too cold • from cold to hot • from hot to cold	• 22 • 13 • 24 • 3 • 20 • 1

Table 5.1 The questionnaire surveying in the lecture theatre

1. Do you feel the air quality getting bad over the class time?	• Yes • No	• 28 • 7
2. If so, in terms of what? (allow multiple selection)	• Breathing problem including block nose, • headache, • sleepy, • can't concentrate • Other, specify _(no above feeling)_ _____	• 3(0.85%) • 2(6%) • 9(26%) • 27(77%) • 8(23%)
3. If so, when you start to have such symptom?	• Within first 30 mins • Within first 60 mins • After 1 hour • After 1.5 hours • Or specify ___120______mins	• 1 • 7 • 22 • 3 • 2
4. You think how long of each session you should have a break?	• 30 mins • 45 mins • 60 mins • 90 mins • Or specify _____ mins	• 9 • 17 • 11 • 1 • 0
5. What do you feel about the temperature in the classroom?	• Fine • Good • Sometimes too hot • sometimes too cold	• 15 • 12 • 4 • 1

	• from cold to hot • from hot to cold	• 2 • 1

Table 5.2 The questionnaire surveying in the school classroom

83 questionnaire forms were collected from the university lecture theatre (Table 5.1) and 35 were collected from the school classroom (Table 5.2). Although the students in both classrooms could feel the indoor air quality getting worse over their class time, the students in the university theater had stronger reaction to such changes. This was because that more people (proportions) had the listed symptoms. This outcome is also consistent to the collected data that the CO_2 density, temperature and humidity in the lecture theatre were relatively higher than the school classroom. It also can be identified that the length of each class session should not be more than 45-60 minutes. The temperature of the classroom looks like another key factor affecting the students' human comfort. As all of these classrooms are heated with community heating systems, the temperature in the classroom with full of the students, the temperature and humidity can easily go up to over 24^{o}C, and 70% humidity. Based on the Chinese design regulations, the designed temperature and humidity in classroom should be 20^{o}C -22^{o}C and the humidity should be 30-70%, ideally 50%-60% (Huang, et al. 2018). In this study, it has been identified that the temperature and humidity will increase when the CO2 density increases in these classroom. It was observed that when the CO2 density was over 1400ppm, the temperatures in both the lecture theatre and the classroom are over 24^{o}C.

5.2 Interview to the building management team

The building facility management teams of both the university and school were interviewed regarding the ventilation systems and the knowledge of the indoor air quality. The outcomes of the interview are very negative. Most people in the facility operation and management teams have no much knowledge about either indoor human comfort or the indoor air quality. As mentioned earlier the one building in this study has artificial ventilation system. The building facility management usually don't turn it on. There is no guidance about when the ventilation system should be turn on. The facility teams also claimed that they have never received any complaint about the indoor air quality issues or been asked to turn the ventilation system on, but they are very interested in the outcomes of this research. This interview has fully reflected that some conclusions addressed in other previous studies (
Bluyssen et al, 2010) that the reasons causing such issues are a lack of awareness of IAQ amongst all stakeholders (i.e. architects, users/ occupiers, general public etc.); a lack of responsibility; and a lack of communication between stakeholders during the building process.

6. Practical solutions to mitigate high density CO_2 in educational facilities

6.1 Window opening

Users/ occupants in educational facilities should open winders more frequently during the winter period. The frequency should follow the requirement of the air exchange rate for each person which stands at a minimum of 22 to 24 m^3 fresh air per person (GB50736-2012). Students should be also be encouraged venture out of the lecture theatre/ classroom as much as possible during break times, not just for them to personally enjoy fresh air, but also to reduce the CO_2 level in the learning environment. Based on the above calculated figures, it is proposed that educational facilities should open windows every half hour on average. The openable sections on windows should be designed appropriately so that they can be easily operated and are of an adequate scale, especially for very large windows. This can encourage people to open windows more frequently, but also ensure that those who sit close to windows do not feel too cold.

6.2 Reducing CO_2 density by improved timetabling

The results of CO_2 density in the lecture theatre (A), Figure 4, are more complex in nature than the secondary classroom (B). As typical in an university lecture theatre, classes are often timetabled consecutively with different groups of students in each timetabled lecture. It was witnessed that students of a following lecture were aware immediately of poor air quality on entering the lecture theatre, and often opened the window on entry. This action significantly reduced the CO_2 level. Therefore, the timetable of different classes in the same facility is encouraged to support adequate CO_2 levels.

Another noticeable finding in the CO_2 density measurement for the lecture theatre (A) was that the CO2 density increased rapidly for the last lesson before 5pm (Figure 6). This was concluded that the students thought they could bear the bad air quality in last hour before the class finished, and also coincided with the drop in air temperature externally. This indicates that poor air quality is also related to users' psychology and habit.

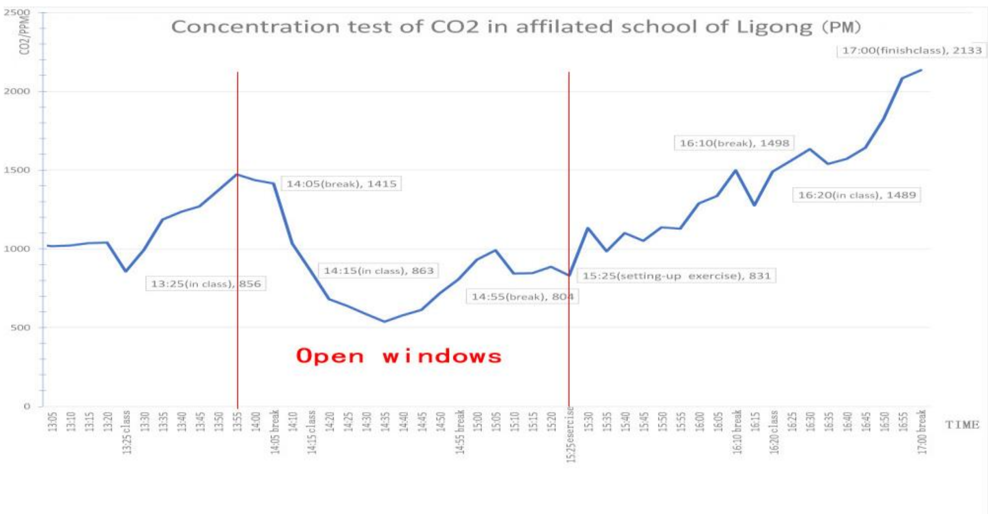


Figure 6: CO_2 density increased rapidly in late afternoon in the university lecture

theatre

6.3 Enable convectional currents

A separate measurement was carried out in two lecture theatres (Classroom A and Classroom F) with differing numbers of windows (Figure 2). The same group of students stayed in the two rooms for 90 minutes each with all windows and doors shut on same test-day. Classroom F has two more windows with 7.25% of the window opening area and the floor area rate, and 115m opening edges than the classroom A with the same variables of 5.78% and 77m. The highest CO_2 density captured in the classroom F within 90 minutes was 1842ppm; and the highest reading from the classroom A within the same time frame was 2882ppm.

In addition, the researchers observed that the majority of classrooms in the old buildings constructed before 2000 are rectangular in shape, with window opening located along both the longer walls of the classrooms. This arrangement of windows permit greater convective air flow, with no unapproachable corner. Thus, the air quality in such rooms will undoubtedly be greater, and should be encouraged for future designs. Further, the height of a classroom can affect the air quality, as larger headroom impacts upon air pressure affect ambient temperature which can also enhance air exchange in a room (Figure 7).

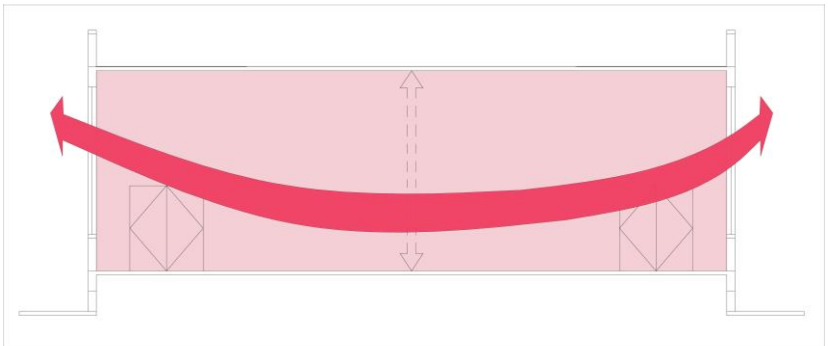


Figure 7: Classroom cross-section - convective air flow improves with windows located on both opposing sides of a classroom

6.4 Installing mechanical ventilation and passive ventilation systems

Generally, electric fans located on or by windows can improve air exchange in classrooms (see Figure 8), but this makes too much cold air coming into classrooms directly. Passive roof vents, based on air flow and thermal pressure, can also enhance air exchange (Figure 9). Another option if vents or openings are not permissible in the wall is to install electrical roof vents (Figure 10), but it is not necessarily convenient for users to manually control roof vents during classes; sensor controlled electric roof vents would be a better solution. The thermal collectors can be installed to compensate from heating lost during air exchange. In this case, the relevant costs and issues of maintenance and operation of such ventilation equipment should be carefully considered and managed at design and construction stages.

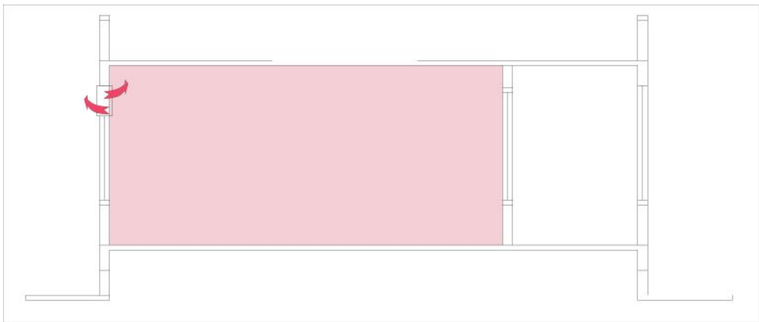


Figure 8: Classroom cross-section - electric fans located on or by windows can improve air exchange in classrooms

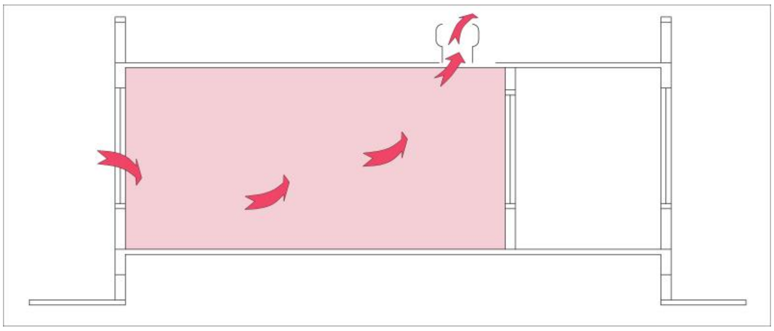


Figure 9: Classroom cross-section - mechanical or passive can also enhance air exchange

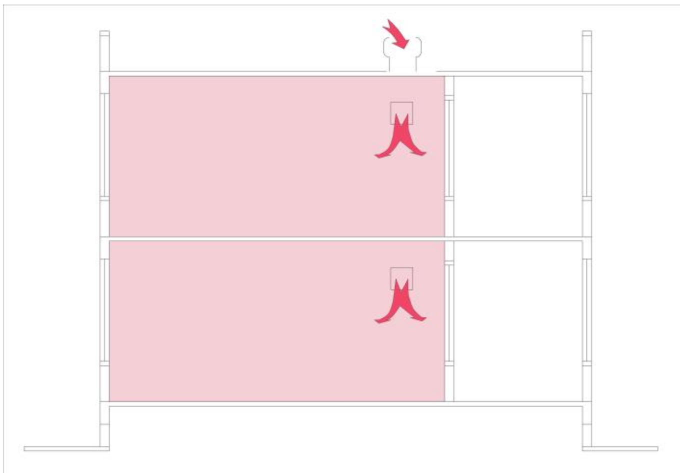


Figure 10: Classroom cross-section - electric roof vents

6.5 Compensating fresh via corridors

In very cold areas, if it is not possible to open windows during winter, particularly in educational facilities whereby those located close to the window will often find it too cold, another solution is to ensure that fresh air can come from corridors via the windows or doors in corridors. This has been identified an effective way in practice (Figure 11).

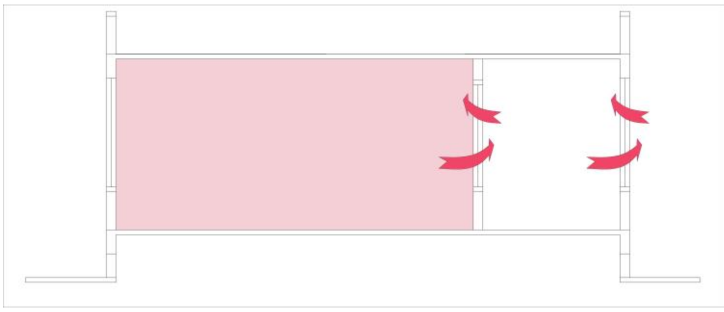


Figure 11: Classroom and corridor cross-section – openings in corridors can support air exchange in classrooms

6.6 Vent windows

In recently years, tilt and turn windows (Figure 12) have been widely incorporated in educational buildings across China. However, due to their large opening areas, they are rarely used/ opened during winter. It has been demonstrated in practice that small vent windows are effective and efficient for air exchange in winter in such cold zones (Figure 13). Vent windows, with small opening areas, are foreseen to be highly effective particularly if they are installed in high up on external walls. The advantages of vent windows are effective air exchange, easily controllable, and they prevent cold outdoor air being blown directly to those sitting adjacent to windows. However, such (small) window vents may not be able to support the large air exchange required in classrooms.

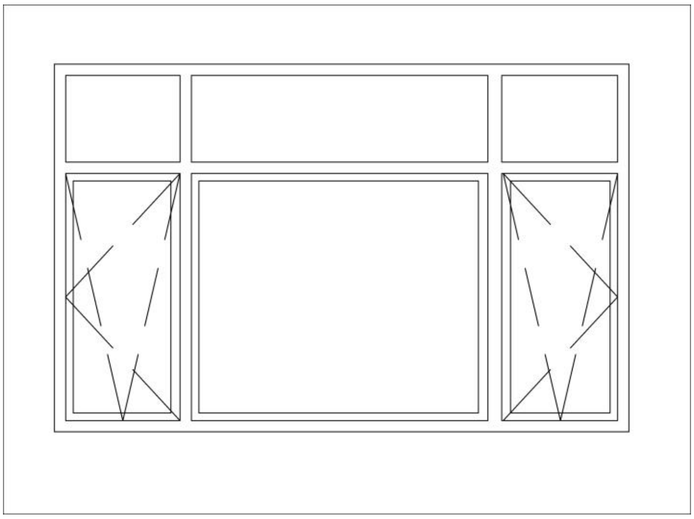


Figure 12: Profile of tilt and turn windows

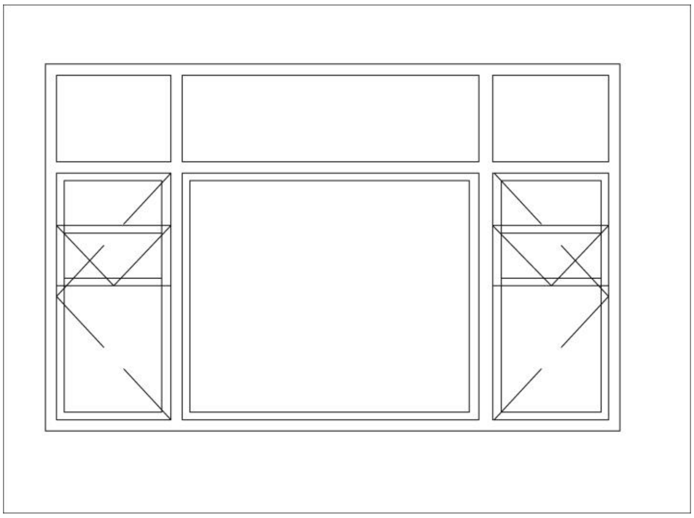


Figure 13: Profile of tilt and turn windows that incorporate a vent opening

6.7 Buffer areas on the north sides of classrooms

In Scandinavian countries, educational building designs often incorporate buffer areas on the north sides of classrooms (Figure 14) where wind direction is at its greatest, which can be used as cloakrooms, for instance. This can support fresh air exchange but also limit the degree of the cold air directly coming into the learning space.

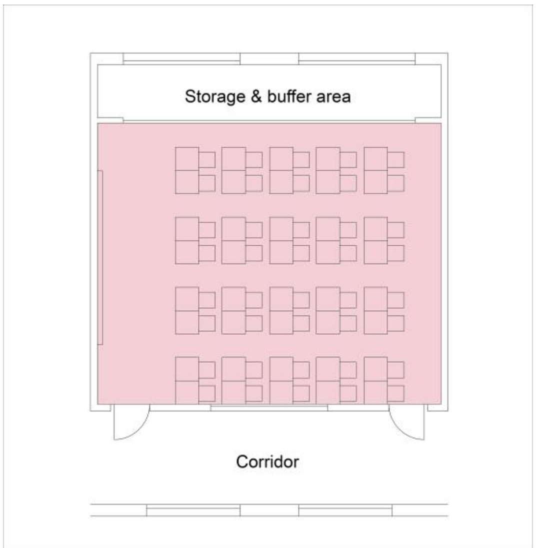


Figure 14: Plan of classroom with buffer area at north to support improved air exchange

7. Conclusion

It is more commonly accepted that outdoor air pollution can damage human health, but indoor air pollution can equally impact (Commission, 1996). The risk of poor IAQ is increased by a lack of proficiency and knowledge of how the numerous factors can contribute to poor IAQ, both during design and construction and after occupancy. In many cold zones across China, particularly north-eastern China, the windows in many high density educational facilities are rarely opened during winter months to minimize any heat loss. Further, the majority have no mechanical ventilation systems. This contributes to increased CO_2 density levels, which has been proven to effect students' performance and even their health. This research has provided the empirical evidence to substantiate this by conducting a series of CO_2 measurements in different teaching spaces. It reveals the serious situations (2800+PPM at peak) in the educational buildings in north-eastern China. Based on the literature review, the CO_2 density are normally not more than 2000PPM at peak points in the similar educational facilities in USA (Majd, *et al*, 2018), Finland (Vornanen-Winqvist, *et al*, 2017), Poland (Krawczyka and Wadolowska, 2018), New Zealand (Bennett, *et al*, 2019). The research also implicate that, although the designs of such educational buildings have fulfilled the relevant design and building regulations which are partially reviewed here, the actually usage of the buildings with their facilities, such as windows and artificial ventilation systems are matter to the indoor environment and human comfort of classrooms. This could be a driver to improve the relevant design principles and regulations, and to enhance the building facility management policies in future. This work also offers a number of practical solutions to address IAQ. Further studies on indoor air quality with the development of feasible and effective sensor controlled ventilation systems for education buildings is much needed.

6. References

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