The Impact of Outdoor Air Ventilation in School Corridors

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In the United States, students spend on average 6.64 hours in school,[1] making the need for improved indoor air quality (IAQ) in school buildings highly critical. About 55.4 million students were enrolled in U.S. elementary and secondary schools in 2021.[2] Worldwide, there were about 614 million secondary students and 739 million primary students,[3] representing more than 17% of the global population.[4] As the U.S. Environmental Protection Agency (EPA) reports, school environments affect attendance, concentration and performance of everyone inside school buildings, including students and educators.[5] In this article, the authors present simulation results using the U.S. Department of Energy (DOE) Secondary School prototype building to demonstrate the impact of providing outdoor air ventilation to the corridors above the current required rate in ASHRAE Standard 62.1-2022.

Background

At 9:49 a.m., you can hear a pin drop in school corridors at a middle school in Anywhere, U.S.A. At 9:50 a.m. the bell rings and a surge of students blasts into hallways with voices and laughter as they congregate and rush to their next class. In some schools, corridors account for as much as 30% of the overall school's floor area.[6] Students can spend more than an hour each school day in school corridors.* Despite this heavy use, Standard 62.1-2022 does not define a space type for corridors in Educational Facilities. Corridors are defined in Standard 62.1-2022 for general use, but school corridors are not ordinary corridors. Typically, general use corridors have relatively low occupancy and are not used for long-term storage. On the other hand, corridors in Educational Facilities (ages 5–8, ages 9-plus) have periodically high occupant density and can have higher levels of space-related contaminants due to long-term storage (i.e., school lockers).

Haverinen-Shaughnessy, Moschandreas and Shaughnessy[7] showed that schools in the U.S. are often underventilated compared to the version of Standard

* This is true for an eight-hour school day consisting of one-hour blocks of 50 min instruction and 10 min transition time.

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62.1 to which they were designed. This would support that corridors may also be underventilated along with the classrooms. It is possible that corridor ventilation is either provided separately or by classroom ventilation when classroom doors are open. However, the authors used airflow simulations below to show these approaches may not be the most effective means of providing outdoor ventilation to corridors.

School Corridors

IAQ in any space is impacted by a multitude of factors, including outdoor air ventilation rate, number of occupants, occupant activity and contaminant sources. Since the COVID-19 pandemic, additional attention is being paid to reducing virus transmission risk as key to an effective IAQ strategy. These strategies have been explored using simulation (mathematical, multizone and computational fluid dynamics)[8 - 11] and measurements.[8] The good news is that a concerted effort to control for indoor particulates will have a positive impact on IAQ whether the particulates are dust, cleaning or cooking emissions or sources of infectious viruses. A basic understanding of the transmission of particulates indoors and the role of HVAC systems in schools can help decision-makers in school design, operation and retrofits to make schools better environments for their occupants.

Standard 62.1-2022 contains the following rate rationale (in an informative appendix to the standard) to support the required outdoor air ventilation rate of 0.3 L/s·m^2 (0.06 cfm/ft^2) in corridors as "persons passing through the corridor are considered transitory and thus not occupants. There are no significant space-related contaminants." While this condition may be true when classrooms are in session, it is not the case at the start and close of the day, lunchtime and between classes. During these times, corridor occupants are often more active and vocal, resulting in higher metabolic rates in corridors than when classes are in session. Because school corridors are also often used for long-term storage (e.g., lockers in secondary schools), test-taking and gathering spaces for extracurricular activities, they merit consideration as a separately defined space type in Standard 62.1 with an outdoor air ventilation rate to support acceptable IAQ given their actual use.

Increased outdoor ventilation is needed in school corridors for three reasons:

1. While corridors are not used as frequently as classrooms, their occupancy is highly concentrated at times (e.g., at the start and close of the day, lunchtime and between classes) and the time spent in corridors can amount to more than an hour in a single school day. This jump in occupancy means improper ventilation would likely result in higher contaminant concentration in the corridors.
2. As the authors will show using airflow simulations, relying on classroom ventilation alone to ventilate the corridors is not an effective approach.
3. Proper ventilation is essential to controlling contaminant levels, especially in school corridors where elevated levels are likely present during transitional times and at all times when used for long-term storage.

All new schools should therefore provide corridor ventilation rates that are above the current rate in Standard 62.1-2022. The authors will present data to demonstrate the need to address corridor ventilation as part of best design practices. However, improving ventilation in school corridors is just a part of a holistic solution for improving IAQ in schools. Reducing contaminant sources,[12] increasing overall outdoor air ventilation throughout the building, using higher efficiency filters, adding localized air cleaning and controlling relative humidity can lead to improved IAQ and health outcomes.

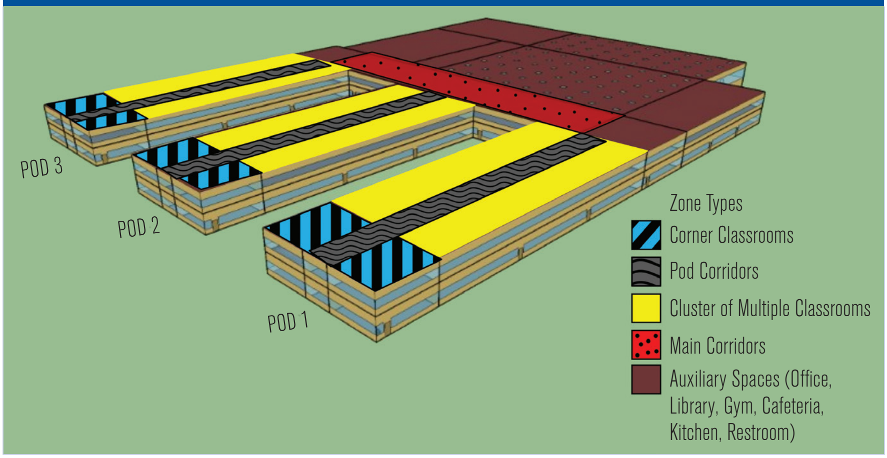
Building Simulations

The impact of continuous outdoor air ventilation in school corridors was demonstrated using the National Institute of Standards and Technology's (NIST) CONTAM multizone airflow software[13] and the Secondary School prototype building developed by the U.S. DOE.[14] Because students typically rotate between classrooms at this age, and lockers are typically present, corridors are densely occupied at times and have constant sources of contaminant emissions.

Figure 1 shows the layout of the two-story school, where the classrooms and their associated corridors are grouped into three "pods." Only the corridors and classrooms are labeled because they were the focus for this study. Other zones in the school included the restrooms, gymnasium, kitchen and cafeteria. The school has a floor area of 19 592 m^2 (210,900 ft^2).

All classrooms (both "corner" and "cluster" types) were served by simulated dedicated terminal units that

FIGURE 1 Secondary School prototype building zone types.



recirculate conditioned air in these zones. Outdoor air to the classrooms was simulated at the minimum rate specified by Standard 62.1-2022 (5 L/s per person plus 0.6 L/s·m^2 [10 cfm per person plus 0.12 cfm·ft^2]) by dedicated outdoor air systems (DOAS).

The main corridors (1F and 2F) were served by a balanced HVAC system that also served the pod corridors, lobbies, offices and library/media center. The pod corridors only had supply vents. HVAC returns for this system were in the lobbies and main corridors. This HVAC system provided heating, cooling and outdoor air.

It was assumed that the design occupancy of the school was 2,700, which included students, teachers and staff. The simulated occupancy was assumed to be 88% of the design occupancy to account for absences (*Figure 2*). The building was open between 7 a.m. and 9 p.m., and outdoor ventilation was provided during these hours. The core school hours were 8 a.m. to 3:50 p.m. It was assumed that during core hours, students rotated between classes in one-hour blocks with a 10-minute transition time. This schedule meant that students spent 50 minutes in classrooms every hour. During the transition time, classroom doors were open. The doors were closed during instruction.

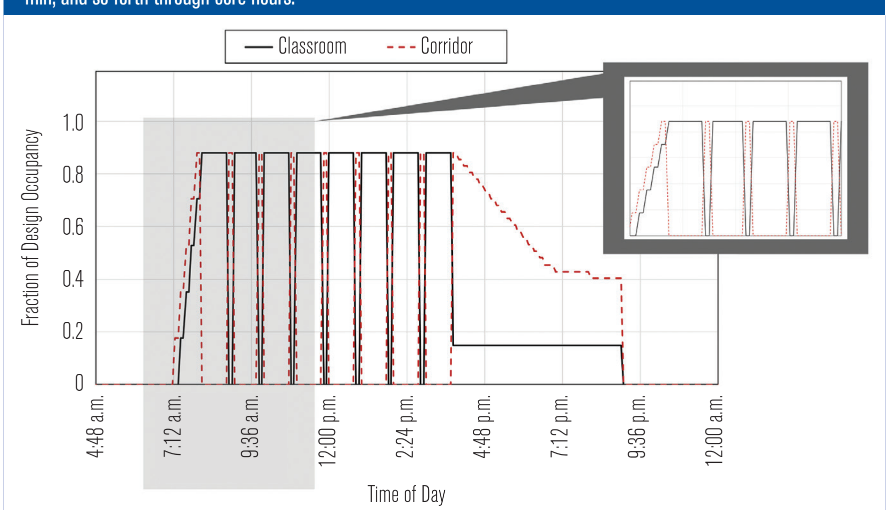
The total outdoor air ventilation rate would include both mechanical ventilation and infiltration (i.e., unintended air leakage through the building envelope). Infiltration rates would depend on weather conditions, HVAC system operation and other factors. In this study, the impact of infiltration on the total outdoor air ventilation rate was reduced by simulating near-zero leakage through the building envelope.

IAQ Simulations

IAQ cannot be defined by a single metric because indoor air contains a mixture of contaminants, the composition of which is dynamic and which has a health impact that is unique to each occupant. Nonetheless, the use of carbon dioxide (CO_2) as an IAQ metric and indicator of outdoor ventilation rates has increased recently. The "ASHRAE Position Document on Indoor Carbon Dioxide"[15] clarified what CO_2 measurements in indoor environments can be used for—they can be used to assess and evaluate IAQ but are not an overall indicator of IAQ.

In this study, annualized CO_2 exposure (i.e., the summation of the average concentration, $ppm_{v,i}$, over time interval *i* (h) over a school year, expressed as ppm_v·h)† is used only to compare the exposure in the corridors relative to the classrooms. The annualized CO_2 exposure should not be used as a single indicator of overall IAQ. It is not a direct metric of infection risk, but may be useful for understanding the impacts of

FIGURE 2 Typical daily occupancy schedule of students. Occupancy ramps up around 7 a.m. and ramps down after 4 p.m. There is a smaller population of students in classrooms after 4 p.m. to account for classroom use for after-school activities. The enlarged graphs shows the students in the classrooms for 50 min, then in the corridors for 10 min, and so forth through core hours.



increasing outdoor air ventilation in corridors.

The CO_2 generation rate of each teacher was assumed to be 0.45 L/min (0.016 cfm)[16] to account for their moderate activity level. The CO_2 generation rate of each student was assumed to be 0.27 L/min (0.0095 cfm) while in the classroom to account for their sedentary activity level during instruction, and assumed to be 0.72 L/min (0.025 cfm) while transitioning between classes in the corridors to account for their increased activity (e.g., walking, talking).

The annualized exposure to CO_2 either in the classroom or in the corridor over the course of a school year during core hours (8 a.m. to 3:50 p.m.) was calculated using CONTAM simulated CO_2 concentrations. Three levels of outdoor air ventilation rates were simulated for the corridors: (a) no ventilation, meaning no outdoor air was directly supplied to the corridors mechanically. Classroom doors had undercuts to passively ventilate corridors, and classroom doors were open at transition times; (b) the Standard 62.1-2022 required rate for general corridors (0.3 L/s·m^2 [0.06 cfm/ft^2]); and (c) double the requirement (0.6 L/s·m^2 [0.12 cfm/ft^2]). The outdoor CO_2 concentration was held constant for all simulations at a value of 412 ppm$_v$.[17] It should be noted there may be an outdoor air ventilation rate less than 0.6 L/s·m^2 (0.12 cfm/ft^2) that would meet an objective of matching the annualized CO_2 exposure in the corridors to that of the classrooms. Double the Standard 62.1-2022 required rate was a conservative value to simulate here.

To demonstrate the impact of changing outdoor air ventilation in the corridors, where constant sources of a variety of contaminants would be present, a total volatile organic compound (TVOC) emission rate was taken from a study of 144 classrooms.[18] Thus, an emission rate of 32 µg/(m^3·h) was simulated in the classrooms. In the corridors, the emission rate was assumed to be 30% of the classroom emission rate based on floor area.

Simulation Results and Real-World Solutions

At 7 a.m., the outdoor air ventilation system turns on and people start to occupy the building. At 8 a.m., classes are in session. *Figure 2* shows the simulated indoor minus outdoor CO_2 concentration in the Secondary School on a typical day during core hours (8 a.m. to 3:50 p.m.). The cyclical nature of the CO_2 concentrations during core hours was due to the simulated one-hour blocks.

As expected, the CO_2 concentration in the corridors was higher than the concentration in the classrooms, no matter the outdoor ventilation rate in the corridors. Keep in mind that with CONTAM, as with all multizone models, the concentration of any contaminant is instantly dispersed throughout a zone at a given timestep since the zone is represented by a single node. This means that in *Figure 2*, the CO_2 concentration may be building up faster than it would under real conditions. Nonetheless, the relatively high density of students in schools and their thermal plumes may enhance mixing in the corridor. When the corridors were ventilated at double the required rate, indoor-outdoor CO_2 concentrations in the corridors reduced an average of 27%. The annual average indoor-outdoor CO_2 concentration in the classrooms reduced 2% with an increase in ventilation in the corridors.

As stated in the "ASHRAE Position Document on Indoor Carbon Dioxide," CO_2 concentrations should only be used to assess and evaluate IAQ. Because the students are only in the corridor 10 minutes out of every hour, the authors used an annualized CO_2 exposure to take into account the CO_2 concentration in the space as well as the time spent in the space. *Table 1* summarizes the average annualized CO_2 exposure in the classrooms and corridors at three levels of corridor ventilation. Simulation results showed that improvements to IAQ could be made in the corridor by doubling the per floor area outdoor air ventilation rate in the corridor. By doubling the corridor ventilation, the annualized CO_2 exposure in the corridors was about the same as that in the classrooms.

TABLE 1 Simulated annualized CO_2 exposure (ppm$_v$·h).

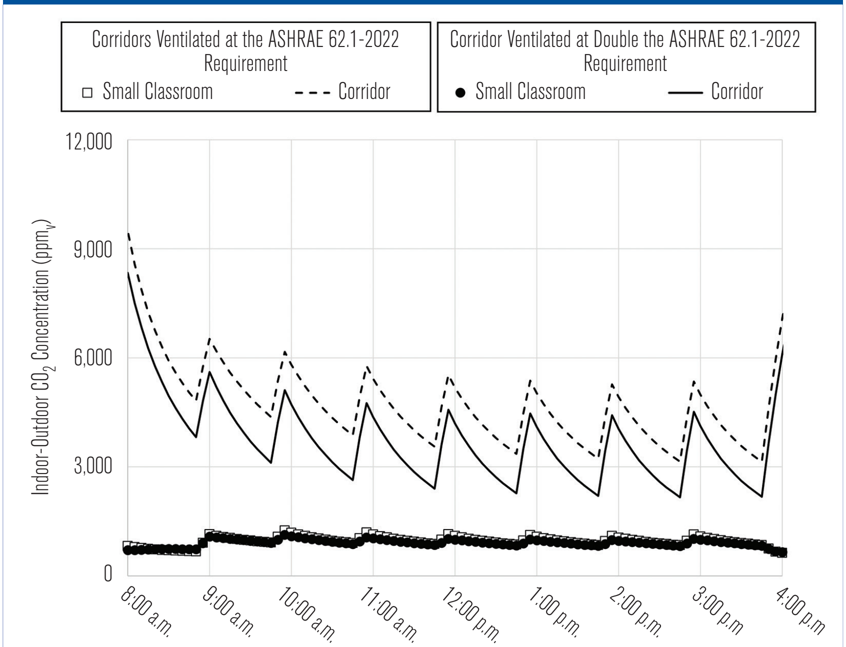
	CORRIDOR NOT VENTILATED	CORRIDOR VENTILATED AT REQUIRED RATE	CORRIDOR VENTILATED AT DOUBLE THE REQUIRED RATE
Classrooms	8900	8700	8500
Corridors	14 500	10 300	7500

Notes: Classrooms in all simulations were ventilated at the ASHRAE Standard 62.1-2022 minimum required rate. The CO_2 concentration is impacted by many factors, including the assumed CO_2 generation rates of the occupants.

The authors also noted that relying solely on classroom ventilation to ventilate the corridors is not an effective method for providing outdoor air to the corridors. In *Table 1*, with no ventilation provided directly to the

† In this work, CO_2 concentrations are expressed in ppm$_v$, which is equivalent to µL/L.

FIGURE 3 Typical simulated indoor-outdoor CO_2 in a classroom and adjacent corridor during core hours of 8 a.m. to 3:50 p.m. with corridors ventilated at (1) the required ASHRAE Standard 62.1-2022 rate and (2) double the required rate. The CO_2 concentration is impacted by many factors, including the assumed CO_2 generation rates of the occupants.



spaces. Both can be applied to retrofit existing buildings to improve corridor ventilation.

One of the primary functions of a packaged RTU or air-handling unit (AHU) is to provide a prescribed amount of outdoor air (OA) to the conditioned space to comply with the outdoor air ventilation requirements of Standard 62.1. When weather conditions are favorable, an economizer can be used to increase the amount of OA introduced into the system to offset mechanical heating or cooling energy.

An exhaust provision in the RTU or AHU prevents the pressure in the space from increasing to unacceptable levels. There are three primary types of economizer systems available to control building pressurization by exhausting excess air from the space: barometric relief dampers, powered exhaust fans or powered return fans. An engineering analysis of these systems is required to determine which is best for a given application.

corridors, the annualized CO_2 exposure in the corridor was 41% higher than if the corridor were ventilated at the required minimum rate.

Simulations also showed that ventilating corridors at the required minimum rate resulted in 26% less TVOC exposure in the corridors compared with not ventilating corridors. Similarly, ventilating corridors at double the minimum rate resulted in 41% reduction in TVOC exposure compared with not ventilating corridors.

As with any simulation, all results are under ideal conditions where systems are performing and operated as intended and occupancy behavior is predictable. Nonetheless, the simulations illustrate a justifiable benefit to including (and increasing) outdoor air ventilation in the corridors, and there are practical solutions to do so.

While energy efficiency and IAQ are sometimes perceived as divergent goals, there are in fact many strategies than can achieve both ends.[19] Economizers can be useful to improve ventilation and to help reduce energy consumption. Two of the most popular methods for providing better ventilation in school corridors are with rooftop units (RTUs) or a dedicated outdoor air system (DOAS).

RTUs are generally used to serve single-zone spaces and DOAS are generally used to serve multizone

Because RTUs are self-contained, thus requiring a relatively minimal setup and simple installation, they provide efficient cooling, heating and ventilation at a cost that is often lower than most other commercial HVAC systems, including DOAS. The simplicity of having everything in one package provides a cost and operational advantage over more complex systems. This characteristic reduces the burden on maintenance personnel and reduces maintenance costs over time. Additionally, their small footprint makes them an excellent choice for tight spaces with limited area on the roof.

A DOAS is a type of HVAC system that consists of two parallel systems: a dedicated system for delivering outdoor air ventilation that handles both the latent and sensible loads of conditioning the ventilation air and a parallel system to handle the (mostly sensible heat) loads generated by indoor/process sources and those that pass through the building enclosure. A DOAS is installed outside and is often used with other HVAC equipment. DOAS units bring the outdoor air into interior spaces independently from heating or cooling efforts. Addressing ventilation and air conditioning separately can save fan energy while improving IAQ.

The type of equipment used with a DOAS may vary depending on brand name and building type. In some instances, a chilled water network is used to supply the DOAS cooling coils with cold water. Other DOAS models may use a refrigeration cycle to heat, cool and dehumidify air.

Conclusion

Students, educators and staff can spend 1/4 of their day inside a school building. While a majority of student time is in classrooms, they can spend up to an hour each school day using the corridors between classes and potentially additional time in corridors for school-related and extracurricular activities. Corridors in schools are also often used for long-term storage, which is less common in general buildings.

Because of these characteristics, there is good reason for defining school corridors as a separate space type in Standard 62.1 with outdoor air ventilation requirements that are different from general corridors. Increasing ventilation in corridors serves to reduce exposure to contaminants in corridors but can improve overall IAQ in school buildings. Contaminants include particulates, aerosols and volatile organic compounds (VOCs) that can be diluted with outdoor air that generally has a lower concentration of these contaminants.

Addendum *a* to Standard 62.1-2022 was passed on Oct. 31, 2023. It includes a new space type (Corridors [ages 5+ plus]) under Educational Facilities that requires a minimum ventilation rate of (0.6 L/s·m^2 [0.12 cfm/ft^2]). This means corridors ventilated at this higher rate could help reduce CO_2 exposure by 11% when compared with ventilating at the general corridor requirement. This could also reduce TVOC exposure by 15%.

Defining IAQ is a complex task. Contaminant concentrations are a single piece to determining overall IAQ and may be useful for understanding the impacts of increasing outdoor air ventilation in corridors. The solutions available to schools include retrofits to existing RTUs or DOAS or installing new RTUs or DOAS.

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