Estimation and analysis of ventilation rates in schools in Indian context: IAQ and Indoor Environmental Quality

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Abstract. The prolonged exposure to indoor air pollution may affect the health, comfort and performance of the occupants. Failing to address Indoor Air Quality (IAQ) problems may lead to short-term and long-term health problems. The health effects may vary for different individuals depending on factors like age and medical conditions, children being young and sensitive to the environment, are more susceptible to the same. The primary focus of this research is to estimate the ventilation rates in schools in Ahmedabad by using carbon dioxide ($CO_2$) exhaled by the occupants, using steady state mass balance method. The air flow in the naturally ventilated classrooms was between 61.5 l/s per person to 15.6 l/s per person. The air flow in air-conditioned classrooms was 0.9 l/s per person and 1.0 l/s per person. The air flow in naturally ventilated classrooms are excessively high, more than meeting prescribed rates, while air flow in air-conditioned classrooms is far below the prescribed outdoor air rate per person as provided in ASHRAE 62.1: 2016 [1] and in the Bureau of Indian Standards [2].

1. Introduction
Air pollution is the contamination of the pure environment by various particles and gases. Pollution of the environment with harmful and life-threatening pollutants may result in making the air harmful to human health. Indoor air quality is the quality of air inside and around a built space. Indoor air gets polluted by both indoor and outdoor sources of air pollution. This also contributes to the comfort and performance of the occupants. Failing to address indoor air quality problems may lead to short-term and long-term health problems. It is also noted that increasing the ventilation rates with highly contaminated outdoor air is also risky to the health. In such a case, the outdoor air has to be cleaned using energy efficient air purifiers before introducing it into the indoor environment. Optimum ventilation rates may lead to high building operation cost, but this can be avoided by reducing pollution load in the indoor air [3].

This study is intended to make a preliminary determination of the distribution of the amount of ventilation supplied in classrooms. Providing adequate ventilation rates will keep the occupants comfortable. Hence the requirement of additional mechanical ventilation can be avoided which in turn will reduce the overall energy consumption of the building. Study of this topic is rare in India, and an improved knowledge of the environmental conditions in Indian classrooms can lead to better health and learning outcomes for the country. The aim of this thesis is to do in-school measurements of the $CO_2$ levels in classrooms in schools in Ahmedabad to determine the ventilation rate and fresh air supply per occupant in classrooms. A specific age group of children was selected and data was gathered in various schools in the city.
2. Purpose Statement

Despite the adverse health effects and impaired performance of people due to poor indoor air quality (IAQ) and considerably low ventilation rates in classrooms around the world [4] when compared to ASHRAE 62.1: 2016 [1], there is lack of research in this field in Indian context. The purpose of this study is to measure the ventilation rates in classrooms of a particular age group of 10 to 13 years of children in different schools and to analyse the conditions, risks and benefits of Indian classrooms based on the ventilation rates in schools in Ahmedabad.

3. Literature

Indoor environmental quality (IEQ) studies conducted in the past in schools conclude that there exists an association between ventilation rates in classrooms and student’s academic performance [5][6][7][8]. Studies in the past have been done on estimation and analysis of ventilation rates in schools, but none in Indian context. Haverinen-Shaughnessy [5] claims that an increase in academic performance of 13-14% is observed with lower classroom temperatures (<23°C) and high ventilation rates (>3.6 l/s per person). In the study done by Haverinen-Shaughnessy, Moschandreas, Shaughnessy [6], among the 84 schools in which ventilation rates was estimated, all the schools had ventilation rate of below 7 l/s per person. The study by Coley, Beisteiner [9], states that the average CO₂ concentration of all seven classrooms during the occupied period was 1957 ppm, and the maximum CO₂ measured in some classrooms during the occupied period was above 4000 ppm. The average occupied ventilation rate of all the classroom measurements for the occupied time is 1.38 l/s per person.

It is concluded from the above studies that the ventilation rates are much lower, and CO₂ concentrations are much higher than the prescribed standard ventilation rates (ASHRAE 62.1: 2016 [1], recommends minimum outdoor air rate per person in Table 6.2.2.1 of 5 l/s per person). This condition is observed both in private and government schools in the international studies. Hence, additional studies in this field will help the school authorities understand the needs of the students to improve the quality of learning.

The international studies done on estimating ventilation rates use steady state mass balance method to estimate ventilation rates. This method uses the occupant generated CO₂ to estimate ventilation rate. This is because, this method is reliable and not expensive. Hence, steady state mass balance method was used in this research for estimating ventilation rates [10].

4. Research Methodology

Estimation of ventilation rates in this study is done by continuous monitoring of indoor CO₂ levels for occupied period using the IAQ mass balance method as mentioned in ASHRAE 62.1: 2016 [1] and ASTM [11]. The objective of field measurements is to test a methodology that can be used in future studies in IAQ, which may contain a larger sample, that can act as a representative study for a region. For this study a convenience sampling strategy has been implemented rather than random sampling, due to the time constraint. The schools identified for the study were primary and upper primary schools because the measurements were to be conducted only in fifth and sixth grade classrooms, this is due to the age group selected for the study. It is preferable to choose the fifth graders and classes below that for taking measurement as the children will be at an age before attaining puberty with hormonal changes, leading to varying metabolic rate [12]. The aim of this research is to conduct measurements at least in ten classrooms. A total of 11 classrooms have been done for this study.

The instruments used were Airveda CO₂ logger and HOBO CO₂ logger. The CO₂ measurements were taken in two classrooms simultaneously using two loggers, one in each room. Two loggers from two manufacturers were used for the measurements, due to availability of equipment. One HOBO CO₂ logger and one Airveda CO₂ logger. All the instruments used were calibrated before field measurements. The aim of the calibration was to adjust for any inaccuracy of the loggers and to improve the accuracy during calculation of the measured data.
The field measurement was done in three parts. First, the school and the classrooms were observed, and school/classroom related information was recorded manually. Second, a personal interview of the principal or the class teacher was conducted to get general information of the school. Third, measurements of the indoor and outdoor CO2 concentration were conducted using loggers during the duration of a school day. Measurements were taken in a minimum of two classrooms from each of the three categories of schools, government schools (naturally ventilated), private schools with naturally ventilated classrooms and private schools with air-conditioned classrooms. Figures 1, 2, 3 and 4 shows the measurement setup in the classrooms.

The measurement setup was at a height of 1.6m from the finished floor level, which is the breathing height. The ideal location to place the sensor in the classroom to get a representative concentration of the CO2 is at the center of the classroom, but this could not be done in all the classrooms due to practical issues.

5. Application Theory

The food consumed by living organisms is oxidized into CO2 and H2O. The waste components after breaking down of food are eliminated from the body by various means. CO2 is eliminated by the respiratory system. Hence, the rate at which CO2 is generated from the body of a human being depends on the diet, physical activity and age of the person. CO2 generated by the occupants in a built indoor space was used to monitor ventilation rates and IAQ in the building. Hence, estimating the CO2 exhaled by the occupants is a key step in this study. The estimation of CO2 generation rate is explained in the ASHRAE Fundamentals Handbook [13] and ASTM [11].

5.1. Estimating CO2 generation rate using equation 1:

For the calculations in this study, CO2 generation rate, Vco2 is derived from [14]. The CO2 estimated in this paper considers one adult (female) along with the number of students that were present during measurement in all the classrooms in which measurements were conducted. The Vco2 of students of age group (11 to 15) years along with one female teacher is .0034 L/min for the physical activity of 1Met.

\[
S = \text{CO2 generation rate per person (cc/min)} \times 60 \text{ (min/h)} \times \text{no of occupants (persons)} \quad (1)
\]
5.2. Estimating air exchange rate using equation 2:
To estimate the air exchange rate, the following equation is used, where, a is the air exchange rate in (h\(^{-1}\)), S is the CO\(_2\) generation rate (cc/h) (estimated above), V is the volume of the space (m\(^3\)) and Css is the difference in outdoor and steady state indoor CO\(_2\) concentration (ppm).

\[
a = \frac{S}{V} \times Css
\]  

(2)

5.3. Estimating ventilation rate using equation 3:
To estimate the ventilation rate using CO\(_2\) concentration, equation 3 is used. Where, Q\(_1\) (air flow estimated by using steady state CO\(_2\) and volume of space to derive the air exchange rate, a) is the air flow rate into the zone in liters per second (l/s), a is the air exchange rate in time inverse (h\(^{-1}\)) calculated in Equation 2 and V is the volume of the space in cubic meters (m\(^3\)).

\[
Q_1 = aV
\]  

(3)

6. Results and Analysis
The results and analysis of onsite measurements of CO\(_2\) concentration was compiled. After which the air flow in each classroom was estimated to compare the same with international studies and to that of prescribed outdoor air rate per person in ASHRAE 62.1: 2016 [1] and in the Bureau of Indian Standards [2].

6.1. Measured CO\(_2\) concentration
School A is a private school that is naturally ventilated. Figure 5 is the plan of classroom A1 with the logger position marked in red, which has occupancy of 52 people. The occupancy time in which the measurements were conducted is from 11 to 13:30. Figure 6 is a graph showing the indoor CO\(_2\) concentration of Classroom 1 from School A. The area highlighted on the graph is the area in which the average of Cin was estimated. This is because, for these data, steady state is attained almost immediately as the air change rate is as high as 86.4 h\(^{-1}\). Hence the data without disturbances is considered to estimate Cin. The average CO\(_2\) concentration in the classroom was 513 ppm. The outdoor air rate per person in the classroom was 33.6 l/s per person.

![Figure 5. Plan of classroom A1 in school A](image)

![Figure 6. Graph of CO2 concentration on day 1 in classroom A1](image)

**Table 1. Results of classroom A1**

| Result                  | Value | Unit |
|-------------------------|-------|------|
| Average CO\(_2\)        | 513 ppm |
| concentration           |       |      |
| Air change rate         | 86.4 h\(^{-1}\) |
| Air flow                | 33.6 l/s |
6.2. Comparison of VR of Ahmedabad to ASHRAE 62.1: 2016 and in the bureau of Indian standards

Figure 7. Graph showing the airflow in all the schools in which measurements were conducted

Legend:
- Naturally ventilated private schools
- Naturally ventilated government school
- Air conditioned private school

The Figure 7 shows the air flow in the classrooms in which the measurements were conducted. Classrooms A1, A2, B1 and B2 are naturally ventilated private schools. The classrooms C1, C2, D1 and D2 are naturally ventilated government schools. The classrooms F1 and F2 are airconditioned classroom in private school.

7. Conclusion

The primary motive of this study to conduct in-school measurements in classrooms in Ahmedabad is done in naturally ventilated and air-conditioned classrooms. Studies related to IAQ in schools are being conducted internationally due to the impact it has on the performance and health of the students which is why, examination of IAQ in Indian classrooms becomes a necessary measure. The results from this study are the primary set of data which describes the operation of the classrooms in India. Further, the results from this study is the first set of data for Indian context from which we can understand the conditions, risks and benefits of these classroom environment.

In the estimation and analysis of the energy consumption of buildings, characterisation of buildings is a primary and most important part. This leads to analysing and optimising buildings with improved performance. The naturally ventilated classrooms are examples of low energy consumption, but prolonged time spent in such highly polluted environment may cause additional health risks. These classrooms do not meet the adaptive thermal comfort model, which may impact the ability of the students to learn and the teachers to teach. Hence these classrooms do not protect the occupants from heat and air pollution. On the other hand, the air-conditioned classrooms are high energy consuming buildings, but they protect the occupants from heat and air pollution. These classrooms may also cause IAQ risks to the occupants as the air flow in these classrooms are below the prescribed ventilation rates in ASHRAE 62.1: 2016 [1] ventilation for acceptable indoor air quality and in the Bureau of Indian Standards [2].

The estimated air flow in the naturally ventilated and air-conditioned classrooms in Ahmedabad had vastly different results. The air flow in the naturally ventilated classrooms was between 61.5 l/s per
person to 15.6 l/s per person. The air flow in air-conditioned classrooms was between 0.9 l/s per person to 1.0 l/s per person. The air flow in naturally ventilated classrooms are excessively high, more than meeting prescribed rates, while air flow in air-conditioned classrooms is far below the prescribed outdoor air rate per person as provided in ASHRAE 62.1: 2016 [1] and in the Bureau of Indian Standards [2].

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