ENGINEERING APPROACH TO DETERMINE INDOOR AIR QUALITY AT DIFFERENT SCHOOLS

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Abstract: Indoor Air Quality can be a major concern in workforce, schoolwork, and daily life. A major concern for Indoor Air Quality (IAQ) has arisen in the areas surrounding Saginaw Michigan. The research conducted involves testing for accelerated values of carbon dioxide, Toxic Volatile Organic compounds (TVOC), air flow, air exchange rates, and temperature. The IAQ testing is conducted inside classrooms at different schools using mechanical and electrical equipment. These testings determine if the air is an adequate level of lean outdoor air inside the work setting. The IAQ is compared to the ASHRAE 62.1 building standard. The electrical equipment used in the testing process is designed by undergraduate students as part of their capstone project. Deviation in the test results and observed concerns will be shared with building management. The other objective of this research is to introduce STEM learning into all levels of schooling through this process. The testing methods used in this process utilize mechanical and electrical equipment. The activities assigned to students demonstrates how to use mechanical and electrical testing devices, analyze the difference in the equipment and teach ASHRAE standards. Overall, this research is conducted to analyze the indoor air quality in different schools and try to influence several students to choose STEM as their career path.

Background:
Indoor air pollution was ranked top 5 among the public risk factors by EPA and its advisory board [1]. Indoor Air Quality (IAQ) investigation should be conducted in spite of any complaints from organizations. A work group from California recommend certain phases to conduct qualitative investigation of IAQ. They have provided Heat Ventilation and Air Conditioning (HVAC) data work sheets, IAQ management checklist, testing form, ventilation worksheet and analysis [2]. California energy commission has provided ventilation formulas, duct-sizing requirements, ventilation design criteria requirements to improve indoor air quality [3]. ASHRAE standard 62.1 specifies minimum ventilation rates and acceptable air quality standards to prevent and minimize adverse health effects [4]. Muller C et al compared the three IAQ calculation methods recommended by ASHRAE standard 62.1. These formulas helped them analyze air contaminations in a building [5]. Mass flow rate of air, temperatures and wind pressure differentials, ventilation systems play a major role in improving air flow distribution [6]. Air quality is significant due to impact of air pollution on human health, global environment and worldwide economy [7]. The contaminants can be in the form of carbon dioxide, carbon monoxide, volatile organic compounds. Manual testing can be conducted during specific times and calculations can be conducted from the acquired data. However, to improve the IAQ analysis

and provide better suggestions to organizations, sensors can be utilized to monitor the contaminants. A previous study developed air quality monitoring wireless sensor network using Arduino Microcontroller. This model could record the real time air quality data [8].

Methodology:

The system of methods used in the present study are divided into mechanical and electrical studies to determine if the IAQ is safe or if the air system may need to be adjusted. The mechanical aspect of the IAQ testing was conducted using three devices. The first device used was an Extech AN-200 which measures air flow in cubic feet per minute (CFM) and provide air temperatures using the anemometer or using the inferred thermometer. The second device used was an Extech CO240 (Figure 1) which measures carbon dioxide, room temperature, wet bulb, and dew point temperatures. The third mechanical device used was a General VOC08 (Figure 1) that measures the amount of Volatile Organic compounds in Parts per million and this device also measures temperature, dew point, and wet bulb temperatures. The indoor air quality was measured in classrooms with ventilation systems installed inside each classroom. In each room, the Extech CO240 was used to measure the temperatures of the supply and return diffusers.

Figure 1: Extech CO240 and VOC08 measurement devices

The amount of outdoor air is calculated using temperatures of return, mixed and outdoor air which is given below:

$Outdoor\ Air(in\ percent) = \frac{T_{Return\ Air} - T_{Mixed\ Air}}{T_{Return\ Air} - T_{Outdoor\ Air}}$; where T is in degrees Fahrenheit

The percent of outdoor air of carbon dioxide was found from measuring the CO_2 levels at the supply and return vents as given below:

$Outdoor\ Air(in\ percent) = \frac{C_s - C_r}{C_o - C_r} \times 100;$

Where: C_s = ppm of carbon dioxide in the supply air

C_r = ppm of carbon dioxide in the mixed air
C_O = ppm of carbon dioxide in the outdoor air

The air exchange rate (ACPH) was determined by finding the approximate volume of the room, followed by air flow measurement with the Extech AN-200 device from each duct to calculate the total amount of air placed into the room.

$$ACPH=(60*CFM)/Volume$$

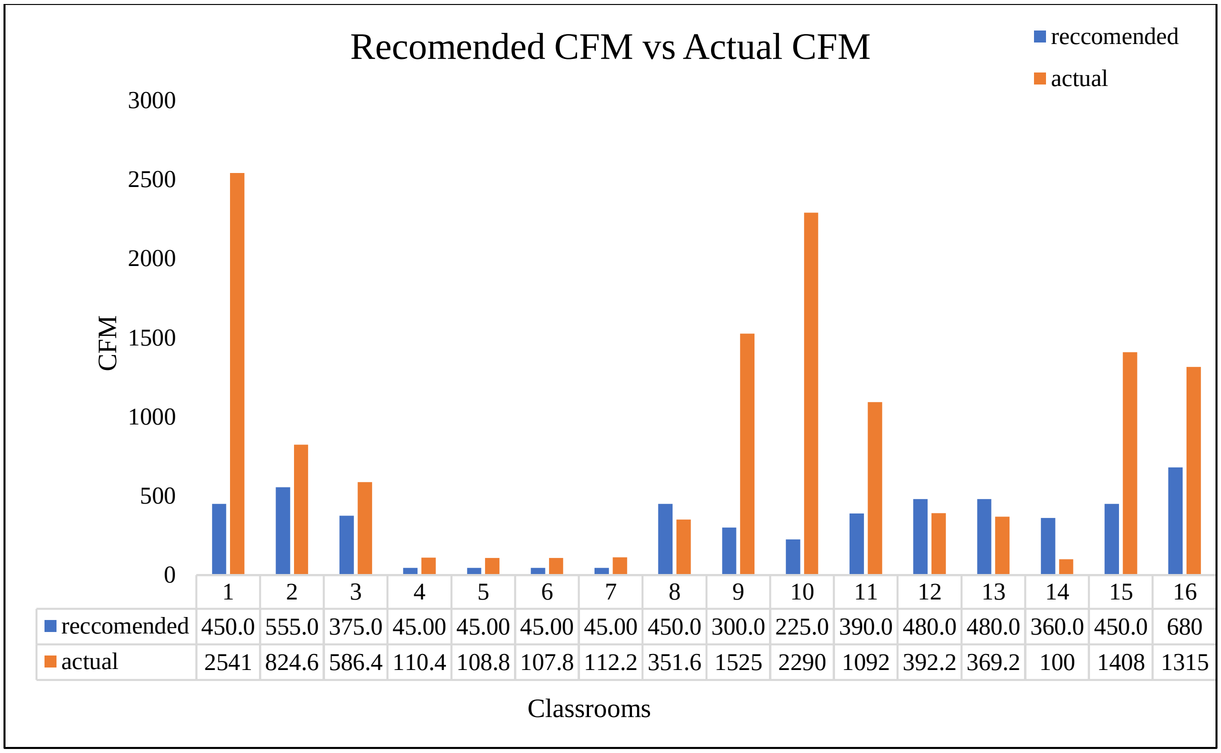
The General VOC08 device was placed near the center of the room to measure the VOC levels inside the room. In addition to VOC08, the EXTECH CO240 was used to measure CO_2 inside the room as a mixed level. This device also measures dew point and wet bulb temperatures, supply and return ducts to measure the amount of CO_2 entering the classrooms.

The electrical device was designed and built using two different microcontrollers, sensors from MQ family, Xbee Pro 900HP which is a radio frequency module used for transmitting the data, Arduino Mega 2560 used as primary processor for different nodes (Figure 2), Arduino MKR1000 which is used to connect the Hub to Wi-Fi connection and for all hub data processing. This device is used to measure temperature, humidity, carbon monoxide, carbon dioxide levels, methane, total volatile organic components (TVOC's) in different schools.

Figure 2: Node 1

Results and Discussion:

The indoor air quality samples were taken at 4 different locations in the Saginaw Michigan area. The air quality was tested in 14 rooms in the Building A. These rooms were supplying nearly 1/3 more air per person than a normal classroom setting. These rooms did have some rise in VOC levels which could be due to lack of filtration or poor exhaust in the rooms. As per the data shown in Figure 1, Classrooms 1 to 11 in Building A met the ASHRAE 62.1 standards when classroom occupancy is up to half capacity. Students in any classroom with full occupancy rates in building A had high carbon dioxide levels. These elevated CO_2 levels were ranging between 1000-2000 ppm in a full class room. The dew point temperatures maintained in building A were between 36º F and 42º F and wet bulb temperatures were maintained between 54º F and 60º F. In most classrooms, the air exchange rates were maintained at 4 per hour in building A. For overall building IAQ improvement, schools should increase filtration and possibly update the HVAC system to match with daily activity.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
reccomended	450.0	555.0	375.0	45.00	45.00	45.00	45.00	450.0	300.0	225.0	390.0	480.0	480.0	360.0	450.0	680
actual	2541	824.6	586.4	110.4	108.8	107.8	112.2	351.6	1525	2290	1092	392.2	369.2	100	1408	1315

Figure 3: A Theoretical Experimental comparison of recommended air flow in relation to actual air flow.

IAQ data in Building B data was relatable to building A. While testing in building B the classrooms (12-13 in Figure 3) were never at full capacity. Air samples were taken by high school girls from different schools as part of the project. 16 girls were selected from different schools to conduct IAQ tests in Building B. When taking an air sample, the results showed normal carbon dioxide levels around 600 ppm in the classrooms. The outdoor air concentration seemed low and the air exchange rates per hour in the classrooms were ranging from 2.4 to 2.84. According to ASHRAE standards, each room is supplying minimum required outdoor airflow and there were no VOCs in Building B. The dew point and wet bulb temperatures were in normal range similar to what was found in Building A. However, the air supplied per person was low in comparison to building A. The air supplied per person was between 11-12 cfm. Whereas, in building A the air supplied per person was near 40 cfm. The present study recommends increase in air flow per person and filtration to improve the IAQ for Building B.

Building C results had some nonocclusive data because some classrooms only provided radiant heat from a boiling system without any exhaust or return ventilation. These classrooms (14-15 in Figure 3) have 40 middle school students and they displayed high VOC levels reaching 6.74 ppm. Building C displayed normal levels of dew point and wet bulb temperature in comparison to Buildings A and B. The percentage of outdoor air was unobtainable in these specific classrooms because there was not any supply air or return air entering the room. The classrooms with a proper HVAC system showed high cfm values nearing 1400 and high air exchange rates at about 10.16 per hour. This means that Building C's HVAC systems in these classrooms are always running when the classrooms are in use. This creates a positive pressurized classroom room which sends all toxins into hallways and to any other air escaping sources. If the classroom is a lab this creates health issues because the chemicals or toxins can be easily moved around the building because the classroom is pushing the bad air into hallways and to other classrooms. The present study recommends renovation or fully update the HVAC system for Building C. Students in this environment can feel discomfort and become distracted from learning.

In Building D, the IAQ tests were recorded in a singular classroom (Classroom 16 in Figure 3) with 17 computers and a large volume. These air samples taken displayed that the classroom had normal levels of outdoor air entering the classroom and no VOC's. Dew point and wet bulb temperatures were normal in comparison to all the other buildings tested. Carbon dioxide levels were slightly over the recommended ASHRAE standards at 1019 ppm with a full classroom and each occupant having a fully operating computer. The air exchange rates for this setting were below the required value by 1.5 air exchanges per hour. The present study recommends increase in cfm per person, increase air exchange rates and increase outdoor air for Building D.

Figure 4 (a-b) below shows that increase in CFM rates has low Carbon dioxide and VOC levels in Building A. The approach used in the present study is cfm-based approach that relies on ventilation performances in buildings. Ventilation and CO_2 deficiencies can remain undetected if there is supply air leakage or lack of proper air distribution with respect to building occupancy rates. Monitoring the IAQ data provides feedback to building owners and help them maintain efficient IAQ.

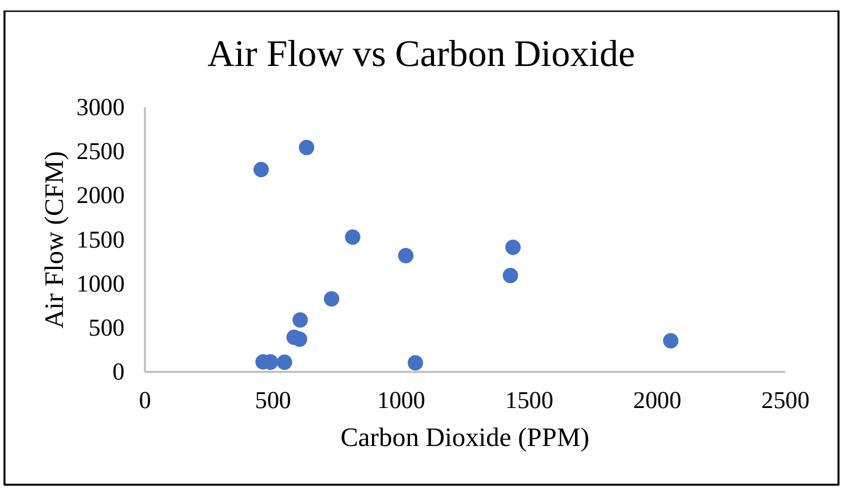


Figure 4 (a): Comparison of air flow with Carbon Dioxide in Building A

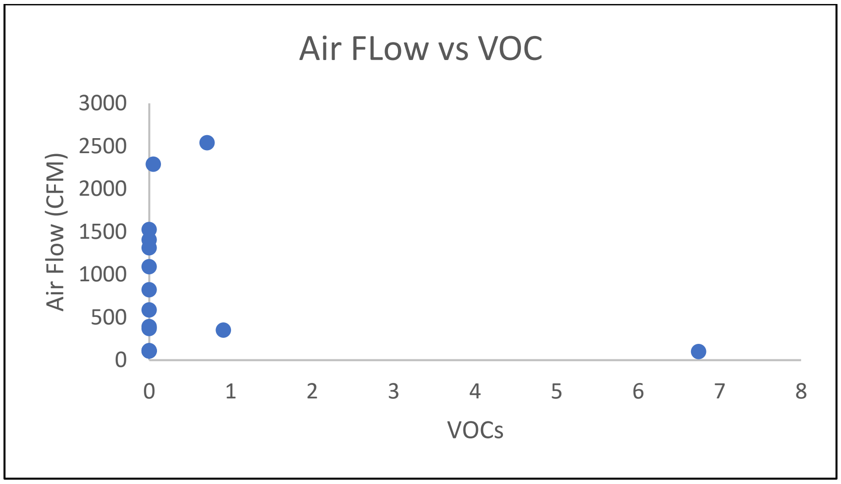


Figure 4 (b): Comparison of air flow with VOC in Building A

Table 1 below shows that high levels of VOC's and carbon dioxide were observed in classrooms with high occupancy rates and in classrooms with improper Heat Ventilation & air conditioning systems. Table 2 below provides the air exchange rates, air supplied in each room, air flow rate per person in Building A, B, C and D at peak occupancies. The fan flow rates at peak occupancies are more than the recommended air flow rates which indicates better air quality. However, low air flow rates indicate elevated levels of CO_2 and VOC's.

The electrical device was used to test the air quality data in Building E at a high school where they had 40 students in the classroom. The carbon dioxide, carbon monoxide, methane and TVOC levels were in the acceptable range (Table 3). The device also collected temperatures and relative humidity's in the classroom during the class time. For high school students this research project provides Science Technology Engineering and Math (STEM) learning experience.

Student Impact:

Students from all the schools showed interest in this topic. Most of the STEM activities middle and high school students are familiar with are Robotics, Science Fair, Math Counts, etc. They haven't done any STEM projects related to Indoor Air Quality. These activities increased their interest in this topic and many students had questions related to job opportunities and salaries in this sector. Some of them realized that poor air quality can cause illness in students who are exposed to that environment. Couple of students were confused in choosing their major: mechanical, electrical or computer engineering. During the activity sessions, students were able to interact with the research team and the team could explain them the difference between different programs, part time and full-time job opportunities, estimated number of years to receive their bachelor's degree, etc. Overall, some of the participants showed interest in STEM field.

Table 1: Indoor Air Quality in Building A, B, C and D at Peak Occupancies

Classroom	Peak Occupancy	VOC (ppm)	Dew point (F)	Wet Bulb (F)	Carbon dioxide (PPM)	Observations from ASHRAE 62.1
1	30	0.71	38.2	54.6	631	Minimal air quality complaints
2	37	0	36.2	54.8	729	Minimal air quality complaints
3	25	0	36.5	57.6	607	Minimal air quality complaints
4	3	0	39.38	54	490	Acceptable
5	3	0	38	57.5	545	Acceptable
6	3	0	38.3	57.4	490	Acceptable
7	3	0	37.4	57.3	462	Acceptable
8	30	0.91	54.2	60	2053	Long term health effects
9	20	0	42	57.4	812	Human discomfort begins
10	15	0.05	41	58.3	454	Acceptable
11	26	0	46.5	59.7	1427	Long term health effects
12	32	0	47	58	583	Acceptable
13	32	0	46.8	57.8	604	Minimal air quality complaints
14	24	6.74	36.6	55.2	1056	Long term health effects
15	30	0	37.9	56.7	1438	Long term health effects
16	34	0	36.5	56.8	1019	Long term health effects
Average	21.69	0.53	40.78	57.07	837.5	

Table 2: Ventilation Rates in Building A, B, C and D at Peak Occupancy

Class room	Peak Occupancy	Recommended Minimum Outdoor Air Flow (CFM)	Additional Outdoor Air %	% of Outside Air	Total Air Supplied to Zone/Room (CFM)	Total Air Supplied Per Person	Air Exchange Rates/HR	Fan Flow Rate (CFM)	Outdoor Air Flow Rate Per Person
1.0	30.0	450.0	1.1	1.2	2540.8	84.7	14.9	635.0	1.0
2.0	37.0	555.0	6.4	1.5	824.6	22.3	4.3	824.6	1.5
3.0	25.0	375.0	1.4	24.9	586.4	23.5	3.4	586.4	1.0
4.0	3.0	45.0	1.4	72.9	110.4	36.8	4.4	110.4	0.1
5.0	3.0	45.0	1.9	74.5	108.8	36.3	4.4	108.8	0.1
6.0	3.0	45.0	1.0	63.0	107.8	35.9	4.8	107.8	0.1
7.0	3.0	45.0	0.5	35.5	112.2	37.4	4.6	112.2	0.1
8.0	30.0	450.0	0.4	11.2	351.6	11.7	1.0	351.6	1.2
9.0	20.0	300.0	1.3	67.9	1525.2	76.3	2.6	1525.2	1.0
10.0	15.0	225.0	0.7	62.9	2290.4	152.7	5.7	2290.4	0.6
11.0	26.0	390.0	4.8	25.3	1092.0	42.0	5.5	1092.0	1.0
12.0	32.0	480.0	1.0	18.0	392.2	12.3	2.4	329.2	1.3
13.0	32.0	480.0	0.5	5.9	369.2	11.5	2.8	396.2	1.3
14.0	24.0	360.0	0.2	20.6	100.0	4.2	0.8	100.0	0.9
15.0	30.0	450.0	0.5	4.7	1408.4	46.9	10.2	1408.4	1.3
16.0	34.0	680.0	0.8	22.1	1315.0	38.7	3.8	1315.0	1.3
Average	21.7	335.9	1.5	32.0	827.2	42.1	4.7	705.8	0.9

Table 3: Indoor Air Quality using Electrical Device in Building E with change in time

Time (h)	Temperature (°C)	Humidity (%RH)	CO (ppm)	CO_2 (ppm)	CH_4 (ppm)	TVOC (ppm)
0.068886	27.5	18.4	0.02	565	13.91	25
0.080942	27.5	17.7	0.02	441	18.32	6
0.08295	27.5	17.7	0.05	460	18.71	9
0.088981	27.5	17.7	0.05	481	10.04	12
0.127167	27.4	18.3	0.34	460	10.58	9
0.129175	27.4	18.1	0.34	436	5.84	5
0.143239	27.4	17.7	0.34	452	3.83	7
0.145247	27.4	17.7	0.34	463	3.83	9
0.167344	27.4	17.8	0.02	462	10.94	9
0.169356	27.4	17.6	0.02	457	7.73	8
0.197683	27.6	17.5	0.1	480	22.56	12
0.199694	27.7	17.5	0.11	480	5.66	12
0.298131	27.4	17.4	0.01	480	11.78	12
0.300139	27.4	17.4	0.01	480	10.58	12
0.312189	27.3	17.3	0.01	480	9.33	12
0.314197	27.4	17.4	0.01	480	9.12	12
0.350369	27.5	17.3	0.42	480	15.49	12
0.352381	27.5	17.2	0.42	480	14.65	12
0.368447	27.6	17.1	0	480	23.75	12
0.370456	27.5	17	0	480	26.27	12
0.396583	27.8	17	0.04	480	14.39	12
0.436769	27.9	16.9	0.21	480	17.99	12
0.438781	27.9	16.9	0.21	480	17.99	12
0.472942	27.7	17.4	0.12	480	17.99	12
0.47495	27.7	17.4	0.12	480	21.67	12
0.661811	27.7	17.2	0	480	27.03	12
0.758247	27.8	16.5	0.02	480	17.99	12
0.760258	27.9	16.7	0.02	480	21.34	12
0.830561	27.9	17.1	0	480	32.08	12
0.832572	27.8	17	0.01	480	28.42	12
0.848644	27.7	17.2	0.01	480	25.85	12
0.850653	27.7	17.3	0.01	480	17.92	12
0.914939	27.8	17.5	0.02	480	36.73	12

Conclusion:

Indoor Air Quality in classrooms is an important study for health and safety. This research was conducted to analyze the indoor air quality in different schools and try to influence several students to choose STEM as their career path. The results from the Indoor air quality testing showed that nearly each room was supplied with at least the recommended amount of air flow. The analysis also shows that according to ASHRAE 62.1 standards, there are four classrooms with minimal air quality complaints, one classroom with human discomfort and five classrooms with long term health effects in Buildings A to D. Air flow higher than 1000 cfm often showed proper or adequate amounts of air exchange rates throughout the experiments. Wet bulb and dew point temperatures remained normal throughout the study. VOC's were found in class rooms without proper HVAC systems as well as in school laboratories. The present study found elevated carbon dioxide levels in full capacity classrooms where students felt discomfort and drowsiness. The recorded observations and recommendations were handed over to the building management department for further analysis. As part of the STEM collaboration, students measured the IAQ data in different buildings and learnt more about the difference between mechanical and electrical engineering applications. The present study noticed mixed response in students. Some of them showed a lot of interest in the STEM field while few of them understood the level of difficulty and expectations.

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