

Improving Indoor Air Quality in University Buildings in Thailand

Wannawit Taemthong* and Watchara Sirikulyanon

King Mongkut's University of Technology North Bangkok, Bangsue, Bangkok - 10800, Thailand;
wannawit@gmail.com, watchara.sirikulyanon@gmail.com

Abstract

Nowadays, people spend most of their times in buildings, which makes us aware of indoor air quality and our health. This research was conducted by installing four air ventilation systems in a class room with air conditioning systems in order to study air quality. The study is to determine the most suitable system in terms of air quality and operating cost. Air quality in a classroom depends on six factors which are ventilation rate, carbon dioxide level, dust concentration, air speed, temperature, and humidity. The recommended ventilation system creates better air quality while uses minimal energy from air conditioning and ventilation system. The recommended system composed of a fresh air intake by fans pass through three layers of filters without installing any exhaust fan in a room. The system can reduce carbon dioxide levels, which is a primary factor, from 1000 ppm to 760 ppm within 40 minutes and can control other air quality factors within generally accepted indoor air standards.

Keywords: Air Quality, Carbon Dioxide, Classroom , Ventilation System

1. Introduction

City people, nowadays, are staying inside building most of the day. Indoor air quality is a critical issue for engineers to design and control during operation of a building. A green building rating system which is well known in the world is the Leadership in Energy and Environmental Design⁹. Design certification means healthier, more productive places, reduced stress on the environment by encouraging energy and resource-efficient buildings, and savings from increased building value, higher lease rates and decreased utility costs⁹. Green building has many aspects such as location and transportation, sustainable sites, water efficiency, energy and atmosphere, materials and resources, and indoor environmental quality. Our research aims at the indoor environmental quality. The indoor environmental quality generally concerns in six factors which are a ventilation rate, a carbon dioxide level, a concentration of dust, air speed, temperature, and humidity. These factors can be controlled within limits by using an air conditioning system and a filtered ventilation

system. But how to control them within acceptable standards and at minimum operation costs is not known. Researches shows that poor Indoor Air Quality (IAQ) in school buildings can cause a reduction in students performance assessed by short-term computer-based tests; whereas good air quality in classrooms can enhance children's concentration and also teachers productivity³. High levels of CO₂ have been shown to cause a negative influence on pupils learning ability⁶. Levels of carbon dioxide can be increased to 4800 ppm during the first two lessons for a classroom of 25 students of a not well ventilated classroom⁸. The mechanical ventilation system was able to ensure the highest outdoor air supply rates in the classroom, independently of the season⁵. Not only does more and more ventilation result in less and less dilution, but high ventilation rates can have huge impacts on energy costs and comfort. Therefore many indoor air pollutant sources are best controlled with methods other than basic dilution with outside air¹¹. Therefore, an objective of this research is to determine a ventilation system which can control the six factors in an indoor classroom within

*Author for correspondence

generally accepted standards with yielding minimum operating costs.

2. Standards Related to the Six Factors

Six primary factors are used in this research. They are shown in Table 1. A ventilation rate according to ⁹ recommends using an additional 30% above minimum ventilation rate specified in ASHRAE 62.1–2010 standard or using a local equivalent, whichever is more stringent. In this case, the lowest ventilation rate for a lecture classroom is at 8 cfm/person according to American Society of Heating, Refrigerating, and Air-Conditioning Engineers². Therefore, a minimum ventilation rate required is 10.4 cfm/person. Meanwhile, a local standard for a classroom in Thailand is at 15 cfm/person⁴.

For a carbon dioxide level, ASHRAE does not specify an exact value as a limit to this factor. Occupational Safety and Health Administration¹⁰ specifies limit of carbon dioxide level for general industry workplace as 5,000 ppm for time weighted average¹⁰. A generally accepted CO₂ limits for indoor air is 1,000 to 1,500 ppm. Therefore, the level of CO₂ of 1,000 ppm is used as limit in this research.

For a concentration of dust, if the particles are less than 3.0 µm, it is considered respirable. If it is less than 10 µm, it is considered inhalable². According to the National Ambient Air Quality Standards (NAAQS), the concentration of dust within 24 hour average should be less than 15 µg/m³ and 50 µg/m³ for particles less than 2.5 µm and 10 µm, respectively. Therefore, in this research these values are used but changing the unit from µg/m³ to mg/m³. Thermal comfort are related to six factors. They are metabolic rate, clothing insulation, air speed, radiant temperature, air temperature, and humidity¹. In this research,

Table 1. Generally accepted values for indoor air quality and used in this research

Factors	Values used in This Research
Ventilation Rate	15 cfm./person or 25 m ³ /hr/person
CO ₂	1,000 ppm
Dust	
– Particles <2.5 µm	0.015 mg/m ³
– Particles <10 µm	0.05 mg/m ³
Air Speed	0.2 m/s
Temperature	Approx. 22.5°C to 26°C or See Fig. 1
Relative Humidity	Approx. 30% to 70% or See Fig. 1

we focus on certain factors which can improve people comfort through a mechanically ventilated system. They are air speed, air temperature, and humidity. Air speeds should be less than 0.2 m/s to be in environmentally comfort zone in conjunction with Figure 1¹.

In Thailand, an average humidity for outside air all year round is approximately 73%¹². Indoor humidity should be in moderate. Relative humidity between 40% and 70% does not have a major impact on thermal comfort⁷. In this research, a comfort temperature and humidity use the values¹ as shown in Figure 1. For example, if room relative humidity is 50%, an operative temperature should be in between 24°C – 27.2°C, based on 0.5 Clo. of clothing insulation to give a thermal comfort room.

3. Four Experiments

A class room size of 5.00 x 7.00 meters is used as an experiment room as shown in Figure 2. A floor to ceiling height is 2.60 meters. It was equipped with two air conditioning units. An air conditioning unit one has 18,000 Btu/hr in capacity and is attached at ceiling level. Meanwhile, an air conditioning unit two has 22,000 Btu/hr in capacity and is attached at floor level. A fresh air supply fan is labeled as IN in Figure 1. It has a capacity of 181 cfm. or 308 m³/hr.

The fresh air intake is pressurized by fans and passed through three layers of filters. They are pre-filter, medium filter, and High-Efficiency Particulate Arrestance or HEPA filter. The pre-filter is a class G3 or equivalence to MERV5. It has less than 20% of filter efficiency. The medium filter is a F8 class or equivalence to MERV 14-15. It has filter efficiency about 90-95 %. The HEPA filter is U13-U15 class, and has filter efficiency about 99.97-99.99 %. The air then was filtered and removed all particles which

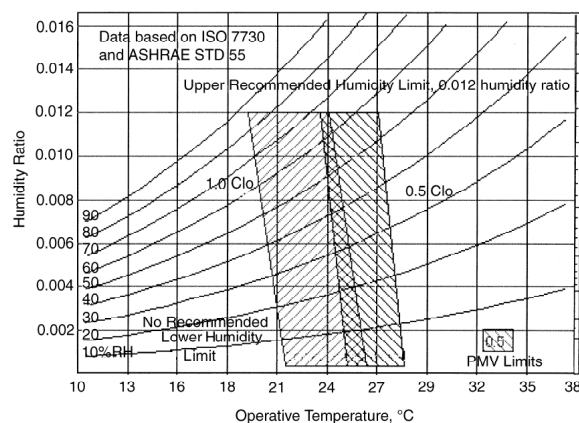


Figure 1. A Comfort envelope¹.

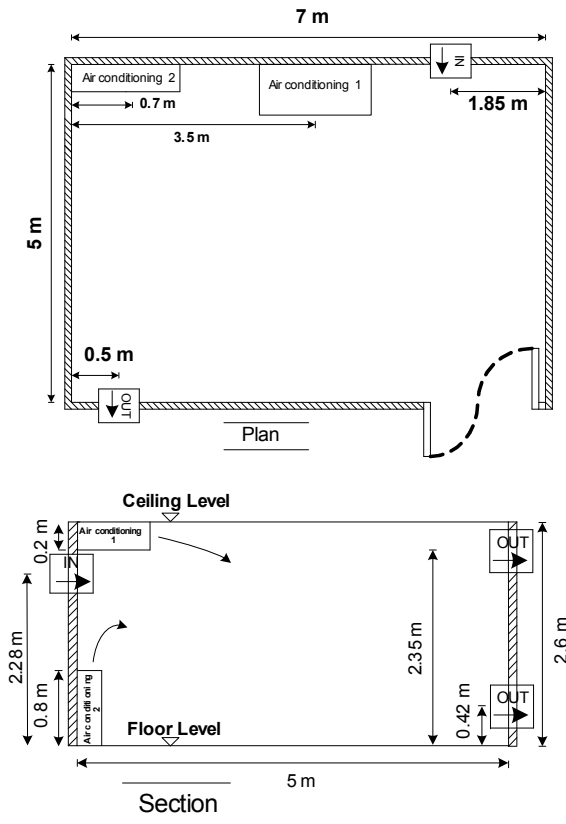


Figure 2. Plan and section of an experiment classroom.

have size over $0.3 \mu\text{m}$. The fresh air fan is turned on in every experiment to provide fresh air. Two exhaust fans are installed at two positions as shown in the Figure 2 and labeled as OUT. Each exhaust fan has a capacity of 141 cfm. or $240 \text{ m}^3/\text{hr}$.

Four experiments are set up for eight occupants. Experiments start with pre-cooling the room and allow eight students to sit in the room and monitoring CO_2 level until it passes above 1000 ppm. Then, the ventilation system is turned on in four experiments. The first experiment is to take fresh air into the room pass through the filters only without using exhaust fans. The second experiment is to take fresh air into the room pass through the filters and exhaust the air out with a top fan. The third experiment is to take fresh air into the room pass through the filters and exhaust the air out with a bottom fan. And the last experiment is to take fresh air into the room pass through the filters and exhaust the air out with both top and bottom fans. Classroom sections for the four experiments are shown in Figure 3. They are labeled as FA or Fresh Air intake only, FA/TE for Fresh Air with Top Exhaust fan, FA/BE for Fresh Air with Bottom Exhaust fan, and FA/

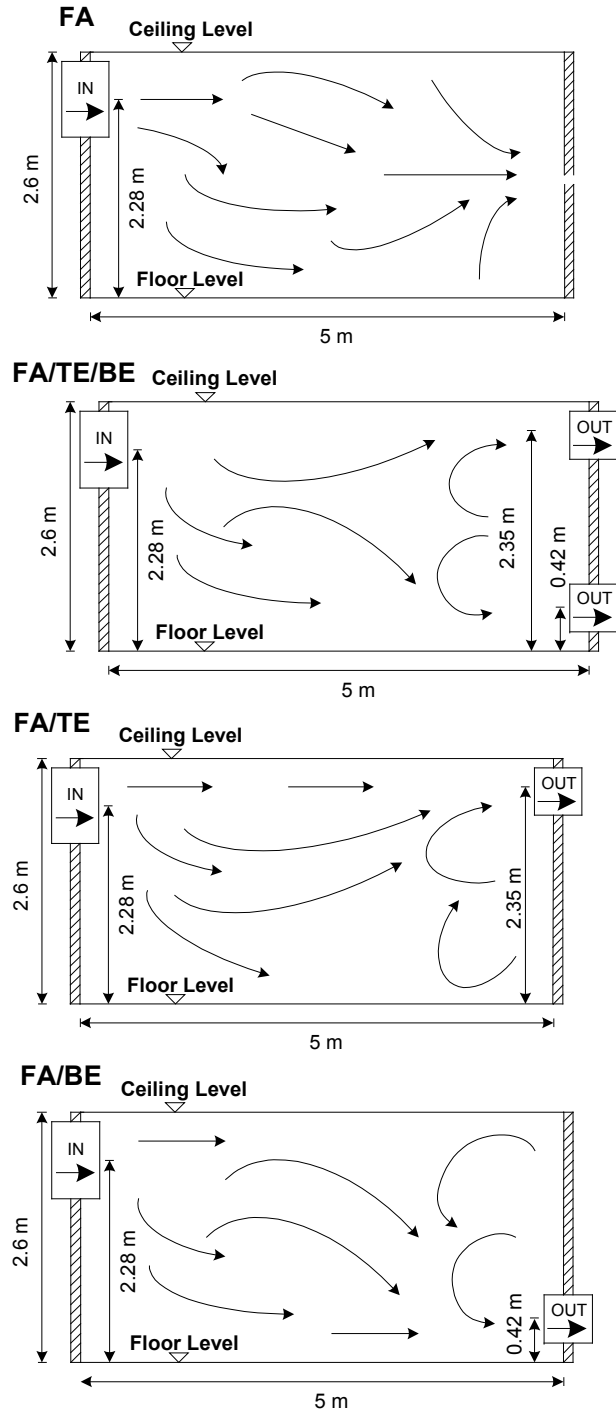


Figure 3. Room sections of four experiments.

TE/BE for Fresh Air with Both Exhaust fans. All experiments are ended approximately 40 minutes after turning the ventilation system on.

Three instruments are used to monitor and record CO_2 level, dust concentration, air velocity, relative humidity, and temperature. They are installed at the middle of room and at 1.10 meters from the floor, which is a breathing

level of students, as shown in Figure 4. An air quality AQ200 can measure the CO₂ concentration up to 5000 ppm. A personal aerosol monitor kit AM510 can measure dust concentration in air for particle sizes smaller than 10 µm or 2.5 µm. An air velocity meter 9545 TSI can measure air speed from 0 to 30 m/s, relative humidity from 0 to 95%, and temperature from -10°C to 60°C. All instruments record data every minute from start to the end of experiment, except for the AM510. The AM 510 can record data for dust concentration smaller than 2.5 µm every minute. But for dust concentration smaller than 10 µm, it can record only at the beginning and ending of the experiment due to the limitation of the instrument. Another factor which was recorded in every experiment is energy consumption. This factor were considering as an operating cost since some experiments may consume energy more than another. Therefore, energy consumption information is recorded in order to deciding which ventilation system is the most appropriate system for using in classroom in term of operating cost.

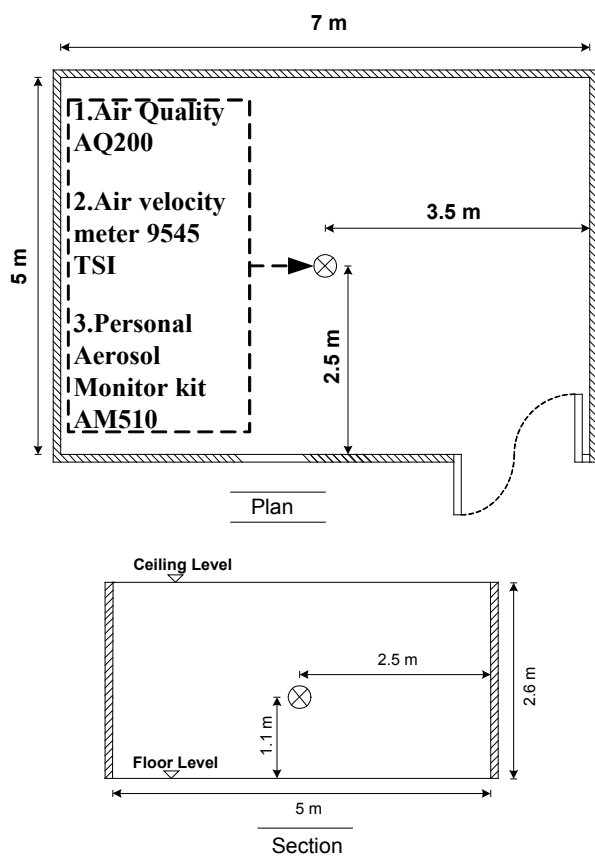


Figure 4. Three measuring devices are installed in the middle of a classroom.

4. Results

Actual ventilation rate of all experiments are the same at 17.6 cfm/person or 30 m³/hr/person based on eight occupants and specification of the fresh air supply fan installed. CO₂ concentrations in the air are presented in two parts, which are before and after turning the ventilation system on. Data are presented from 900 ppm to 1000 ppm to show the rising rate of CO₂ in the air as shown in Figure 5 (a). The CO₂ rises at the rate 5.5 to 10 ppm per minute under the same room condition and number of occupants. The results are slightly different due to two reasons. First, people are not the same person in every experiment. Since, the experiments were performed on different days. The people that we recruited are different. The second reason depends on activity that they did before entering experiment room. Running, walking, and working could contribute to an amount of CO₂ emission

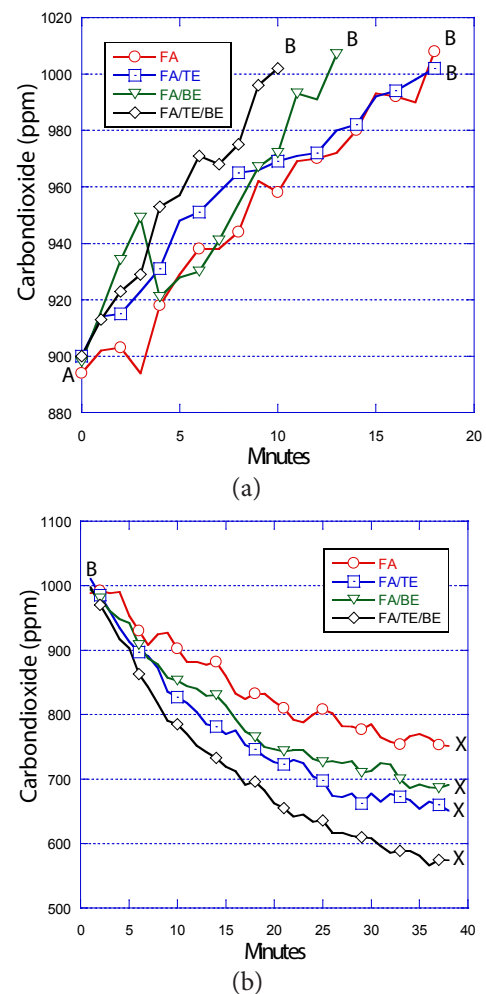


Figure 5. CO₂ level in ppm (a) Before turn the ventilation system on, and (b) after turn the ventilation system on.

during experiment. The experiment started at this point forward in order to test which ventilation system is appropriate for maintaining good air quality. Figure 5 (b) shows CO₂ concentration in the air from 1000 ppm to the end of the experiment. All experiments can reduce CO₂ concentration in the air. The quickest method is FA/TE/BE or to use both top and bottom exhaust fans in reducing the CO₂ concentration. It could reduce from 1,000 ppm to 580 ppm within 40 minutes or at the rate of 10.5 ppm per minute. The using of FA or fresh air supply fan only is offering the slowest way in reducing CO₂ level in the air. It can reduce from 1,000 to 760 ppm within 40 minutes or 6 ppm per minute. An average of dust concentration for particle that is smaller than 2.5 μm before and after turning the ventilation system on for all experiments are shown in Figure 6. Before turning the ventilation systems on, dust concentration is over 0.015 mg/m³ in every experiment except the FA/TE/BE. After turning the ventilation systems on,

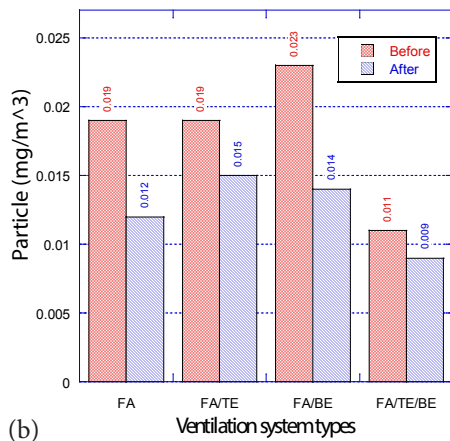
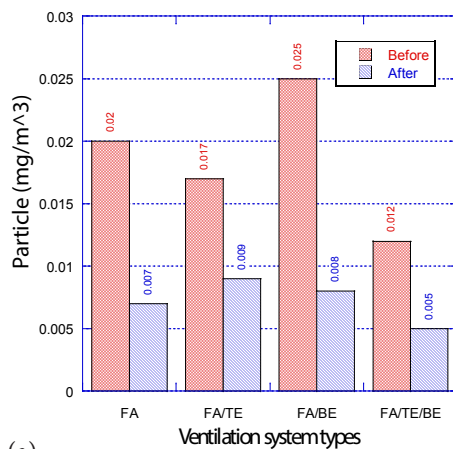


Figure 6. (a) Particles smaller than 2.5 μm before and after turn the ventilation system on, and (b) Particles smaller than 10 μm before and after turn the ventilation system on.

dust concentration can be controlled within the standards at 0.015 mg/m³ for all experiments as shown in Figure 6 (a). The ventilation system can reduce particles which is less than 2.5 μm for 18% to 39% as shown in Table 2. Figure 6 (b) shows the reduction of particles which is less than 10 μm in the air after turn on the ventilation systems. Particles which are less than 10 μm in the air have not exceeded the recommend limit since the start of the experiment. However, the four ventilation systems still perform well. It can reduce particles in the air well below the standard value at 0.05 mg/m³. The ventilation system can reduce particles which is less than 10 μm for 47% to 68% as shown in Table 3. The air speed and temperature are within the standard values. Average air speeds for all experiments are shown in Figure 7. They are under 0.2 m/s for before and after turning the ventilation system on. Temperature can be well controlled in between 23.9°C to 24.3°C as shown in Figure 8. The air condition systems

Table 2. % Reduction of particles less than 2.5 μm (mg/m³) after turn on the ventilation system

	FA	FA/TE	FA/BE	FA/TE/BE
Average before	0.019	0.019	0.023	0.011
Average after	0.012	0.015	0.014	0.009
reduce for	0.007	0.004	0.009	0.002
% reduction	37%	21%	39%	18%

Table 3. Reduction of particles less than 10 μm (mg/m³) after turn on the ventilation system

	FA	FA/TE	FA/BE	FA/TE/BE
At before	0.02	0.017	0.025	0.012
At after	0.007	0.009	0.008	0.005
reduce for	0.013	0.008	0.017	0.007
% reduction	65%	47%	68%	58%

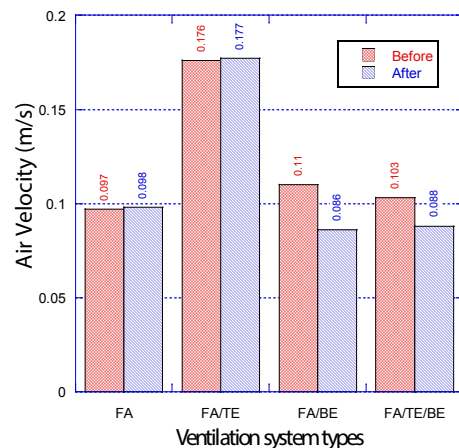


Figure 7. Average air speeds for all experiments.

are turned on to control room temperature before starting every experiment.

The relative humidity of all experiments are between 59% to 67.6% for before and after turning the ventilation system on as shown in Figure 9. FA system increases the lowest humidity to the room at 0.3%, which is another good aspect of FA system, as shown in Table 4. Meanwhile, the FA/TE increases the humidity to the room the highest at 7.5%, which is another deficit to the top exhaust ventilation system. Relative humidity value is quite high since Bangkok is in hot and humid climate. High humidity could easily bring the indoor air quality to an uncomfortable zone. This research recommends to add a dehumidifier appliance to the room to help control humidity levels in classrooms especially in rainy season, where the humidity are higher than the shown values in the experiments.

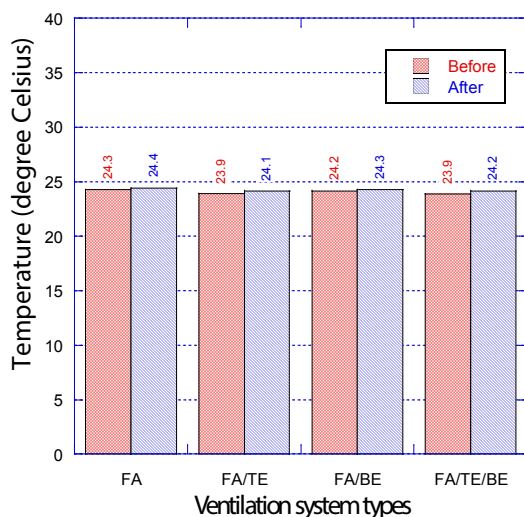


Figure 8. Average Temperature for all experiments.

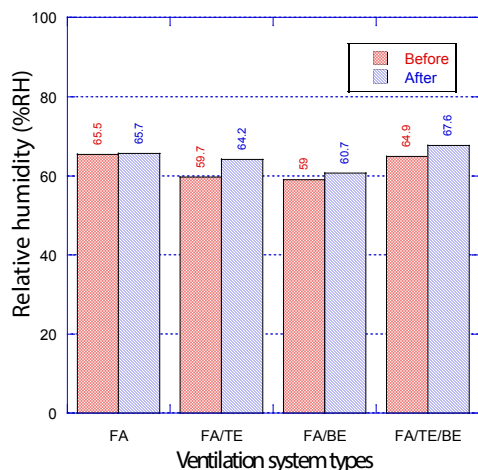


Figure 9. Average humidity for all experiments.

And energy Consumption in kilo Watt hour (kWh) are compared for all experiment and shown in Figure 10. They are average values before and after turning the ventilation system on. From Figure 10, energy is consumed differently before experiments started. They are 2.25, 2.22, 2.00, and 2.40 kWh due to outside temperature are a little bit different in each day. Therefore, an additional energy consuming due to operating ventilation system in kWh are calculated from Figure 10 and shown in Table 5 in order to consider the impact of ventilation system on operating costs. The additional energy consumption in percentage for different ventilation systems are calculated in order to decide which ventilation system gives better air quality and uses minimum energy and shown in column 3 of Table 5.

5. Analysis

From Figure 9, averaged humidity values after turning the ventilation system on are higher than before turning the system on. In our experiments, a humidity controller is not used. Therefore, the rising of humidity occurs from sweat or other factors from occupants during experiments, since there are no rainfalls during experiments. Temperature and humidity for both before and after turning the ventilation system on are in comfort zone as shown in Figure 11. The energy is consumed more due to hot air

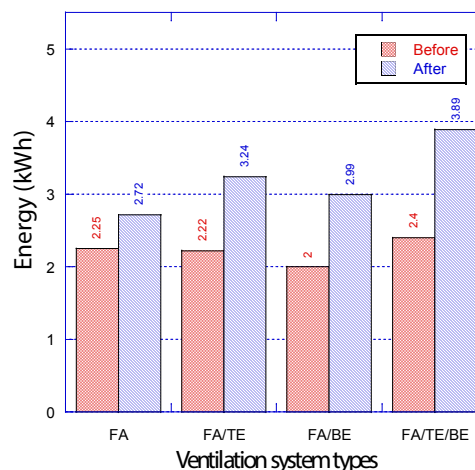


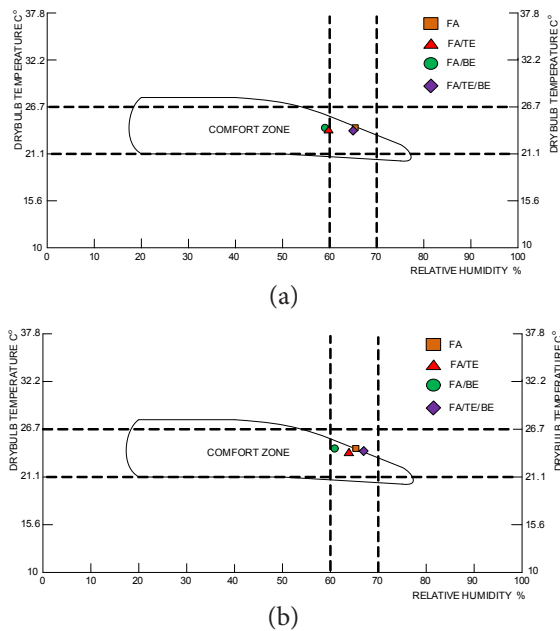
Figure 10. Energy consumption for all experiments.

Table 4. Increasing of relative humidity (%) after turn on the ventilation system

	FA	FA/TE	FA/BE	FA/TE/BE
At before	65.5	59.7	59.0	64.9
At after	65.7	64.2	60.7	67.6
increase for	0.2	4.5	1.7	2.7
% increasing	0.3%	7.5%	2.9%	4.2%

Table 5. Additional energy consumptions for all experiments due to ventilation systems

Experiments	Additional Energy Consumption (kWh)	Consume Additional Energy (%)
FA	0.47	21%
FA/TE	1.02	46%
FA/BE	0.99	50%
FA/TE/BE	1.49	62%

**Figure 11.** Temperature and humidity (a) before and (b) after turning the ventilation system on.

intakes to alleviate the concentration of CO_2 indoor. The air conditioning system works harder to keep the room temperature in control at 24°C . And the air conditioning system performed very well in controlling the room temperatures as shown in Figure 8. The Fresh Air ventilation system (FA) has two best aspects which are consuming the least energy and increasing the least humidity to the experiment room. FA still performs well in controlling dust level, it comes in the second place when comparing to other systems. The top exhaust (FA/TE) is in the second place in term of energy, but it is not good in term of dusts. The top exhaust tends to initiate and encourage particles to fly free in the air. From Tables 2 and 3, top exhaust could not reduce particles in the air well enough when compared to the FA and FA/BE. The top exhaust (FA/TE) is better than bottom exhaust (FA/BE) in term of CO_2 reduction rate. However, the top exhaust system increases the humidity in the air the highest at 7.5%.

A room with bottom exhaust (FA/BE) is good in two aspects. It offers the lowest dust particles flying in the air

Table 6. Opinions from eight participants in four questions

	FA	FA/TE	FA/BE	FA/TE/BE
Question 1: How do you feel about room temperature				
cold	5	6	1	1
A little bit cold	1	1	2	4
Alright	2	1	5	3
Warm to Hot	0	0	0	0
Question 2: How do you feel about room ventilation				
Uncomfortable				
A little bit uncomfortable		1	2	
Alright	8	7	6	8
too much				
Question 3: How do you feel about dusts in the room				
Feel clean or no dusts	7	8	7	7
A little bit of dusts	1		1	1
More dusts				
A lot of dusts in the air				
Question 4: How do you feel about noise in room from ventilation system				
No noise	1	1		
A little bit of noise	7	7	8	4
More noise				4
Noisy				

as shown in Tables 2 and 3, since it encourages the dusts to fall down by gravity. The FA/BE also yields the lowest air speed as shown in Figure 7. Although the top and bottom exhaust (FA/TE/BE) is good in terms of the quickest CO_2 reduction rate, however it consumes the highest energy as shown in Table 5. The FA/TE/BE gives the best air quality in term of CO_2 level. It reduces CO_2 concentration from 1,000 ppm to 580 ppm within 40 minutes. The room air quality is almost like a fresh air outside. Table 6 shows opinion from eight participants in each experiment. From question one, if we compare two experiments between top exhaust and bottom exhaust. FA/TE is a little bit cooler than FA/BE from opinions of participants. Bottom exhaust drains cool air which is falling down out. Therefore, FA/BE are expected to consume more energy than room with top exhaust. The results also concurred with additional energy consumptions in Table 5. From question two and three, participants felt that rooms are in good ventilation and clean. The last question shows that

FA/TE/BE is the noisy ventilation system since two fans are operated at the same time.

6. Conclusion

A ventilation system that this research recommends to use in classroom is a Fresh Air system (FA). It consumes less energy compared to others, while yields good indoor air quality. It composes of fans and filters as shown in Figure 12. The fans should give the ventilation rate at least 15 cfm/person or 25 m³/hr/person. The three layers of filter, which are G3, F8, and HEPA filters, are in a wooden box. The recommended system provides good air quality with minimum energy consumption and conforming with generally accepted indoor air quality standards. Meanwhile, another finding in this research is to be careful using top and bottom exhaust. FA/TE could generate dust flying and increase air humidity slightly. While, FA/BE can consume more energy in hot and humid climate. Students and professors could have more concentration and positive learning ability based on air quality provided with the ventilation system recommended in this research.



(a)



(b)

Figure 12. Fresh air fan unit supply air to room (a) inside room (b) outside room.

7. Acknowledgements

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