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Indoor Air Quality of Schools: A Case Study Approach

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Abstract

This study aims to investigate the level of indoor air pollutants in selected schools for different types of classrooms and level of activities in Singapore. Indoor air quality (IAQ) parameters in five tertiary school buildings were measured during the period between year 2013 and 2014.

The results show that elevated levels of carbon dioxide and bacteria were found in lecture theatres when it is occupied. This could be due to the high occupancy with insufficient ventilation. Introduction of more fresh air and better air circulation can help to alleviate the problem. The OT results at several locations were found to be lower than the recommended range of between 24-26°C. Generally, in a well maintained building, it would be reasonable to maintain the operative temperature at around 24°and 26°C. The goal should be to maintain the temperature that will satisfy at least 80% of the occupants. Air movement in a few indoor locations was found to be lower than the recommended range. This may not have direct influence over occupant's perception in indoor environment as compared to temperature and humidity. However, it is synergistically related to the thermal comfort and the overall performance of the ventilation system. Too high or low air movement will affect the thermal comfort of individuals. Total bacterial counts at many indoor locations exceeded the recommended threshold limit of 500CFU/m3. Human occupants themselves are normal reservoirs of bacteria; the level of airborne viable bacteria is based on the number of occupants and their activity at the site. Bacterial impurities found in the indoor environment should normally be removed through the ventilation systems and cleaning procedures. Improving the ventilation system and routine cleaning or regular housekeeping should lead to lower level of airborne bacteria.

Keywords - IAQ; Air Quality in Schools; Thermal Comfort; Indoor Air Pollutants

1. Introduction

1.1. Background

Indoor air quality (IAQ) refers to the quality of air inside an air-conditioned environment. It is of a concern because most people spend the majority of their time indoors. Good indoor air quality is an important component of a healthy indoor environment, which contributes to productivity, comfort, and a sense of health and well being at the work place. Health complaints related to indoor air are common in many schools, and are often worse in humid climates such as Singapore.

If the health and comfort of occupants are recognized as being crucial in ensuring a productive workforce, it is necessary to adopt an integrated IAQ and energy analysis to gain more insights into the provision and sustenance of acceptable quality of the built environment. This would form the basis for exploration and development of methods and procedures for establishing and achieving acceptable target levels of indoor air quality and energy consumption.

Schools, office buildings, and other non-industrial buildings might develop poor indoor air quality, moisture and dampness issues from roof and window leaks, high indoor humidity and other things. Research studies have revealed consistent association between the poor indoor air quality, dampness and mould in buildings and respiratory systems in building occupants. Exposures in poor indoor air quality buildings are complicated and vary from buildings to buildings and at various locations within a building. In Singapore's high humidity environment, moisture ingression in buildings could contribute to increased indoor microbial growth on building materials and other surfaces. Building occupants might be exposed to structural components of microbes (e.g. fungal fragments and spores) and to exact substances the microorganisms might produce; the potential contaminants will vary subject to the species that exists and on environmental condition.

1.2. Research Problem

This study aims to investigate indoor air pollutants concentration in selected tertiary and secondary schools with different surrounding human activities in Singapore. Failure to identify and establish indoor air pollution status could increase the chance of long-term and short-term health problems for these students and staff; reduction in productivity of teachers; and degrade the students learning environment and comfort. Indoor air quality (IAQ) parameters in five schools were conducted during 2013-14 for the purposes of assessing ventilation rates, levels of respirable particulate matter and air quality differences between schools. In each classroom, carbon monoxide (CO), carbon dioxide (CO_2), formaldehyde, total volatile organic compounds, air velocity, relative humidity, operative temperature, total viable bacteria count and total viable fungal count were performed during working hours and a walkthrough survey was completed.

1.3. Objectives

Determination of an Indoor Air Quality (IAQ)

The determination of an indoor air quality (IAQ) target aimed at establishing sustainable levels of various indoor air pollutants – chemical, biological and physical parameters. The first objective was aimed at obtaining an extensive database of concentration levels of various indoor air pollutants for typical School buildings, which employs various air conditioning designs. The main objective was to translate the prevailing IAQ conditions in various schools buildings into target levels of concentration for different types of indoor pollutants. IAQ testing was performed in accordance to "Singapore Standard SS554:2009; Code of Practice for Indoor Air Quality for Air-Conditioned Buildings" and has been presented in an test results attached separately to this IAQ report, the summary of the results is presented later in this report for further discussion. In assessing the acceptability of IAQ, the subjective responses obtained through a detailed IAQ questionnaire have been subjected to rigorous modelling techniques to identify the most appropriate method of modelling IAQ perceptions of school buildings in Singapore.

Provide Improvement and Recommendations

In order to provide improvement and recommendations based on the data collection and onsite assessment, the second objective is intended to suggest remediation, corrective actions and enhanced abatement approaches following the test results and findings during the IAQ audit.

CHAPTER 2: LITERATURE REVIEW

A review of local and international studies offers an insight on the past, current and future progress of research on IAQ. These studies contain international conference papers, international journals, newspaper articles, and past dissertations.

2.1. Local Research

Similar to the rest of South East Asia, Singapore has an increase in the quantity of research papers on IAQ ever since the government focused additional attention to IAQ in air-conditioned buildings and Green Mark scheme. Another factor is the deteriorating air quality levels due to the transboundary haze and environmental changes. The majority of these research papers focus on the importance and impact of indoor air quality on human health and productivity. It also includes the measurement of contaminants.

SPRING Singapore issued the code of practice in 2009, Singapore Standard 553:2009 (SS553:2009) for air-conditioning and mechanical ventilation in buildings and Singapore Standard 554:2009 (SS554:2009) for IAQ for the air-conditioned buildings. The Singapore Standard describes satisfactory IAQ as air in an occupied space where a significant majority (80%) of occupants prompt no dissatisfaction, and there are no likely contaminants at concentration contributing to exposures that establish a significant health risk.

In Teo's dissertation (2011) on Indoor Environment Quality (IEQ), the audit was completed on two building spaces, one which has achieved BCA Green Mark Platinum and one without Green Mark certification. The results indicate little differences between the parameters of both offices. This is due to the absence of points distributed to the IEQ component of the Green Mark Scheme, hence contributing the Green Mark Platinum building to display little or no improvement of IEQ as compared to the non-Green Mark building.

Study completed by Moey (2011) on the effects of room air temperature on concentration in performance of healthy and asthmatic office workers in the tropics through physiological, psychological & perceptual responses. The study results indicated that room air temperature increases concentration ability in healthy subjects by 5% under moderate cold temperature while the results for asthmatic subjects were inconclusive. The high level of observed thermal comfort is correlated to better concentration performance. While poor perceptions of environment and presence of SBS symptoms may decrease concentration as in the situation for asthmatic subjects, who experience more SBS symptoms than healthy subjects.

In dissertation conducted by Loo (2011) on achievements of green mark using plants, the survey results showed that 31% of the occupants are not satisfied with the indoor air quality of Zero Energy Building (ZEB) and symptoms such as irritation were experienced. Controlled experiments conducted revealed that big-leaf plants are more capable of reducing carbon dioxide and formaldehyde than small-leaf plants due to its larger surface area and greater stomatal openings for more gaseous exchange. Actual implementation of using larger surface area leaf plants in ZEB further proves the effectiveness of plants in improving the indoor air quality in real-life situation though it is limited by cost, time and space constraints. Hence, the study highlighted that plants are recommended to be implemented in the achievement of Green Mark to improve the indoor air quality.

In study by Hong (2011) on single coil twin fan system on various air distribution methods such as personalised ventilation system, displacement ventilation, Ceiling Supply Mixing Ventilation System as well as Underfloor Air Distribution System and its effect on differences between the thermal comfort and indoor air quality of the spaces served by these air distribution methods in zero energy building (BCA). The study found have shown that the SCTF system has capability of achieving more savings in energy consumption through significant reduction in cooling energy required and yet still being able to meet the needs of the occupants in the targeted zones through the principle of ‘demand ventilation’ and ‘demand cooling’.

In another undergraduate dissertation by Lee (2011) on a comparative study of window air conditioner and split air conditioner in residential bedrooms study seek to assess the air change rates and IAQ status in bedrooms served by window air conditioner with ventilation damper opened (VDO); window air conditioner with ventilation damper closed (VDC); and split air conditioner. The study showed that readings for PM10 kept fluctuating in both types of air conditioners but did not significantly reduce its level to below threshold. Bacteria and fungi counts increased after the use of both types of air conditioners and exceeded the limit in most cases. It was recommended although a higher ACH i.e. more outdoor air into the bedroom could help to dilute and reduce the indoor contaminants level, the rate of dilution is dependent on many factors as well.

Another two separate undergraduate dissertation was prepared by Muhammad (2012) and Quah (2012) on the office indoor air quality in an educational institution and assessment of indoor environmental quality of the seminar rooms in SDE buildings. Muhammad (2012) discovered that IAQ issues have strong connection to the occupants' health and comfort levels. It was discovered that high CO2 and air temperature levels result in the occupants having SBS symptoms and make them to feel discomfort respectively through the IAQ assessment conducted. Although the research results by Quah (2012) discovered that the respondents' perception on the overall satisfactory level for the indoor air quality, lighting, thermal comfort and sound level of the seminar rooms, it was revealed that majority of the respondents were contented with the IEQ in the seminar rooms. At least 80% of the occupants have voted satisfactory for those IEQ aspects.

Another dissertation by Swee (2012) on indoor air quality study of Republic Polytechnic facilitation room, the study considered 24 randomly selected facilitation rooms to study the impact of indoor air quality on students where classes are conducted. The study analysed increased carbon dioxide concentration during class due to lack of exhaust grills in the facilitation rooms and a tightly sealed environment. The study concludes that only indoor air contaminates would affect the student's health when staying in the facilitation rooms throughout the academic hour with minimal break. Furthermore, the lack of ventilation caused an increase to several indoor air contaminants and thermal comfort parameters.

In two separate undergraduate dissertations prepared by Ng (2012) and Chan (2012) on a comparative study of thermal comfort and IAQ in NV/MV and air-conditioned classrooms in secondary schools. The comparative study is also on IAQ in split and central air conditioning units in office buildings displayed the importance of good Indoor Air Quality on the performance of students and office employees. Ng (2012) discovered that the results indicated that the overall IAQ in a natural ventilated classroom is better. However, the thermal comfort and biological parameter could not meet the recommended level. In summary, the indoor air quality and thermal comfort level in the air-conditioned classroom is better than the natural ventilated classroom, mainly the students' perception and its temperature and relative humidity level. The consolidation of carbon dioxide in the air-conditioned classroom is above the recommended level. However, the study results on IAQ in split and central air conditioning units in office experiments indicated that the central air conditioning system offers a better IAQ as compared to the split air conditioning system based on a more controlled environment. IAQ of offices with split air conditioning were affected more by social environments and office characteristics.

Low (2012) conducted a study on evaluation of indoor air quality on of a childcare centre in Naturally-Ventilated and air-conditioned areas. Findings from this study showed that the Child Care Centre did not perform as expected in terms of the Indoor Air Quality and Thermal Comfort as some of the parameters did not meet the acceptable limits specified by the standards. Nevertheless, some of the parameters experimented showed that the results were better in the Naturally Ventilated area compared to the air-conditioned areas.

In undergraduate dissertation by Tan (2012) on comparative evaluation of Indoor air quality of an indoor cafe and atrium cafe, Objective measurement showed that during peak occupancy period, the indoor café had 5 parameters – operative temperature, respirable particulate matter 10, air velocity and total viable bacteria count that did not meet the threshold stated in SS554: 2009. On the other hand, the results for atrium café showed that it had fulfilled the stipulated threshold stated in the standard. Maintenance policy for ACMV system is recommended to ensure cleaner and better air quality. Dilution is also recommended to purge contaminants out of the space in door cafe, to ensure that the IAQ is conducive for the occupants' health and thermal comfort.

In a study by Liu (2012) on a case study approach in understanding the relationship between CO_2 and TVOCs in the extent of affecting building occupant's productivity level found that CO_2 level had exceeded the acceptable indoor threshold in the office but no significant effect was observed for occupant's alert level. The concentration of TVOCs was kept within the limit but showed a rising trend at areas with photocopiers and use of cleaning agents. Although the objective result indicated acceptable TVOCs level, the perceived IAQ by occupants was considerably unsatisfactory. Inadequate ventilation in the office could lead to poor IAQ and thus creating an environment that lower worker's productivity. Recommendations have been provided to improve the overall indoor air quality performance in the office.

In undergraduate dissertation by Goh (2013) Green schools and environmental education in Singapore: A comparative analysis of green and non-green schools, found out that certification of green schools could affect the quality of Environmental Education where there was greater presence of students' led initiatives in green activities. This could suggest that green schools could have greater potential of encouraging and inspiring students to protect their environment. The push for green schools throughout the entire island would allow the regulation and control of standards of Environmental Education.

Undergraduate research completed by Guo (2014) on indoor air quality of zero energy building's multipurpose classroom which study the new air-conditioning system known as the Single Coil Twin Fan (SCTF) system which is based on cooling and ventilation on demand is invented to provide a better the indoor environmental condition without incurring huge energy costs. The study found out that based on the subjective and objective assessment IAQ parameters are within threshold limits with the exception of biological contaminants. The air velocity in the classroom is also found to be inadequate and subjective assessment results showed the occupants perceived air flow to be still and there were dissatisfaction with the existence of odour. The study highlighted in recommendation to install ceiling fan to operate simultaneously with the air-conditioning system have been proposed to improve the indoor air quality of the classroom.

2.2 International Research

Chuah *et al.* (1997) is concerned with the indoor air quality in an office building situated in Taipei, Taiwan. The authors examined the IAQ of that building by evaluating the concentration levels of carbon dioxide (CO_2), carbon monoxide (CO), formaldehyde and total hydrocarbons. This includes conducting ventilation rate measurements using tracer gas decay technique. It was discovered that the concentration levels of formaldehyde and overall hydrocarbon were found to peak at midnight and specified that they were not produced by human activity. Furthermore, with the partial opening of windows in the building, the air quality improved and met the required health standards. This dissertation pursues to improve on these results by reviewing the occupants' comfort in relative to the ventilation rate. A reference is prepared for a ventilation mechanism that delivers a maximum supply of fresh air to maintain good IAQ standards.

Wargocki et al. (2002) conducted the study on the air quality in a simulated office environment intending of decreasing pollution sources and increasing ventilation. It is detected that the perceived air quality was subsequently enhanced by eliminating the sources of the pollutants or by increasing outdoor air supply rate. However, the technique of increasing outdoor air supply rate was verified to be not as effective as eliminating the sources of the indoor pollutants. The study also established that the systematic use of low-polluting building materials will contribute to improved air quality.

In research conducted by Lee et. al., (2002), on investigation of indoor air quality at residential homes in Hong Kong indicated that the 8-h average concentrations of CO_2 and PM_{10} in the domestic kitchens investigated were 14% and 67% higher than those measured in the living rooms. The indoor air pollution caused by PM_{10} was more serious in domestic kitchens than in living rooms as almost all of the kitchens investigated had higher indoor levels of PM_{10}.

Chou (2013) recent study on characterization of Indoor Air Quality in Public Area of Taiwan found high carbon monoxide (CO) and PM10 concentration may be ascribed to emissions from vehicle exhaust resulting on high-traffic locations at shopping mall and hospital. The high levels of total volatile organic compounds (TVOCs) appear at post office that may be caused by mail machine and vehicle exhaust from outdoor air. Bacteria and fungi may be caused by outdoor pollutants and air conditioning systems. In addition, CO_2 concentrations above

1,000ppm indicate poor ventilation of the indoor environment and can be remedied by improving ventilation.

Another research by Hsu et .al., (2012) investigated indoor air quality (IAQ) at 39 public sites in southern Taiwan including hospitals, schools, office buildings, hypermarkets, libraries, railway stations and theatres.

Total Bacterial count (TBC) and Total fungal count (TFC) concentrations were weakly linked to particulate matters due to the low percentages of bioaerosols in indoor air. Particulate matters might contribute more to TFC than TBC. This is ascribed to the fact that most TFC originates
outdoors. TBC concentration was moderately correlated with CO_2 level, and thus TBC concentrations can be potentially affected by the intensity of indoor human activity and ventilation rate.

Another study conducted by Tang et. al., (2013) on Air Quality Monitoring of the post-operative recovery room and locations surrounding operating theatres in a medical centre in Taiwan. This study assessed air quality in the post-operative recovery room, locations surrounding the operating theater area, and operating theatres in a medical centre. Measurement results reveal clear differences in air quality in different operating theatre areas. The post-operative recovery room had significantly higher CO_2 and bacterial concentrations than other locations. In conclusion, air quality in the post-operative recovery room and operating theatres warrants attention, and merits long-term surveillance to protect both surgical patients and healthcare workers.

CHAPTER 3: RESEARCH METHODOLOGY

Below is the flowchart of my research methodology.

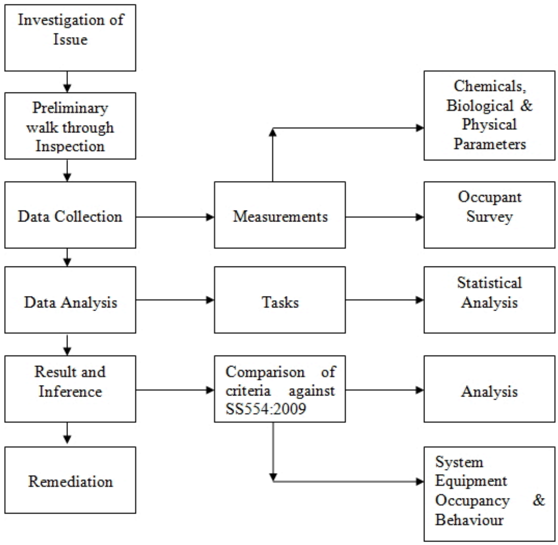

Figure 3-1 Indoor Air Quality Methodology

An integrated IAQ-energy audit methodology is adopted for this project, details of which are presented later in this report. The scope of work in this study includes investigation of the characteristics of various buildings in terms of their current status on IAQ and energy issues. A total of 5 buildings varying in age, height and building characteristics were studied. The data, which are accumulated, formed the basis of a rigorous analysis spanning the following.

3.1. Objective Measurement

Briefly, the integrated IAQ and energy auditing procedures involve the following:

- Preliminary walk-through assessment of the building to identify intricate details of actual field measurements.
- Measurement and identification of chemical pollutants in the occupied space.
- Measurement of particulate level in air-conditioning occupied space.
- Measurement and identification of biological contaminants in air-conditioning occupied spaces.

- Measurement of thermal comfort parameters at the occupant level in the building.

In the case of objective measurements, the results are a summary of all the different setups of measurements in each building. The prevailing pollutant levels are compared against recommended IAQ guidelines, “Singapore Standard SS554:2009; Code of Practice for Indoor Air Quality for Air-Conditioned Buildings”.

3.2. Subjective Measurement

- Use and Occupancy Type
- Each building study included a brief survey on the type of activities performed such as classroom, laboratory, study rooms and recreation rooms
- Number of people
- Number of student/people present or occupancy was observed and noted at each sampling location
- Occupant survey to determine human response to the indoor environment.

Occupant survey was taken to get the feedback on the indoor air environment to get a better understanding on the health or comfort issues they might have experienced.

3.3. Building Remedial Action

The corrective action and improvement recommendation on the basis of air sampling and data analysis results.

3.4. Singapore Legislative Framework

The enabling Provision under the Building Control Act - Section 49 (a)(2)(e)(viii), “Environmental sustainability approaches that improves the total quality of life and minimise adverse effects to the environment for both now and in the future.” (Building control (Amendment) Bill was passed by Parliament on 20th September 2007). To establish a minimum environmental sustainability standard in the planning, design, construction and operation of building projects, to mitigate the environmental impacts of building structures. A minimum environmental sustainability standard that yields about 10% - 15% energy saving over our revised Energy Efficiency Standard SS 530 and other green requirements which enhance water efficiency, environmental protection, indoor air quality etc.

The 3 guiding principles that underpin the new Occupational Safety & Health framework are:

- Decreasing risk at source by requiring all stakeholders to eliminate or minimise the risk they create
- Instilling greater ownership of safety and health outcomes by industry
- Preventing accidents through higher penalties for poor safety management.

For all the IAQ testing conducted a Risk assessment analysis was conducted and provided to the building management before the IAQ testing.

3.7. Frequency of Indoor Air Quality (IAQ) Audit

- Recommended for existing building once every 3 years (Risk assessment requirements under WSH Regulations)
- After fitting out works and before occupancy for new buildings and newly renovated premises.

3.8. Additional Consideration

In addition to the number of potential pollutants, another complicating factor is that indoor air pollutant concentration levels could vary by time and location within the school building, or even a single classroom.

- Pollutants could be emitted from a variety of sources including:
- Point sources (such as from science storerooms);
- Area sources (such as newly painted surfaces); and
- Mobile sources (such as cars, buses, and power equipment).
- Pollutants could also vary with time since some activities take place over a short period of time (such as stripping floors) or occur continuously (such as mold growing in the HVAC system).

CHAPTER 4: EXPERIMENTAL SETUP

4.1. Objective Measurement

The following section describes the equipment applied during the testing that was carried out. The full test report, which presents detailed information about the results of the air parameters tested at individual locations and the exact time that each test was carried out.

10 parameters testing were carried out in randomly selected locations performed in and around the indoor premises, inside classrooms and common areas using "Singapore Standard SS554:2009; Code of Practice for Indoor Air Quality for Air-Conditioned Buildings". One outdoor baseline sample was taken for comparison purposes.

4.2. Sampling Procedures

4.2.1. Sampling Height

The sampling height should be between 75 and 120 cm from the floor at the centre of the room or an occupied zone.

4.2.2. Minimum Number of Sampling Points

At least one sample should be taken from each floor or from each area serviced by separate air handling unit. For large floor spaces, the minimum required numbers of sampling points are as follows:

Area of building (m^2)	Minimum number of sampling points
3,000 - < 5,000	8
5,000 - < 10,000	12
10,000 - < 15,000	15
15,000 - < 20,000	18
20,000 - < 30,000	21
30,000 or more	25

Table 4-1 Minimum Numbers of Sampling Points

For a multi-storey building, the percentage of floors to be sampled randomly is as follows:

Number of occupied floors in a building	**Percentage of randomly selected floors to be sampled (%)***
<5	80% of floors*
5-10	70% of floors*
11-20	60% of floors*
21-30	12 floors or 50% of floors* whichever higher
31-40	15 floors or 40% of floors* whichever higher
41-50	16 floors or 35% of floors* whichever higher
>50	18 floors or 30% of floors* whichever higher

*round up to whole number

Table 4-2 Percentage of Floors to be Sampled Randomly

The recommended or required sample size will ensure with 90% confidence that at least 1 floor from the 10% floors with the highest IAQ levels is included or contained in the sample.One sample from outside location for reference value should be taken at the entrance of the building or at the centralised fresh air intake. Record the level of occupants and movement of people at the time of sampling.

4.3. Equipment and Method Description

The following section describes the equipment and methods applied during the testing that was carried out.

Figure 4-1 IAQ Equipment used during the Audit

4.4. Bio Aerosol (Total Bacterial and Fungal Count)

4.4.1. Equipment Description

Bio Aerosols testing was performed with a MAS-100 NT Air Sampler loaded with Malt Extract Agar (MEA) plates for fungal retrievals and Tryptone Soy Agar (TSA) for bacterial retrievals. The MAS-100 NT Air Sampler is a widely used and accepted device, which is calibrated to draw 100 litres of air per minute and trap the organisms onto the plate. Results are customarily reported as Colony Forming Units (CFU) per cubic meter of air. Active airborne microbial sampling with impactor is based on inertia impact principle.

4.4.2. Sampling Handling and Laboratory Reporting of Bio Aerosols

After exposure, retrieval plates are closed and transported to the laboratory. Then the TSA plates were incubated at 35˚C for 48 hours and MEA plates were incubated at 25 ˚C for 5 days to allow viable organisms that have been retrieved to grow (or colonize) and then these are able to be counted.

4.4.3. Physical Check

Take the instrument out from the carrying case in a clean, dry environment and check for any dirt / blocked holes of the perforated lid. Care must be taken to ensure that fluid or dust is not drawn into the sampling head holes.

4.4.4. Quality Check

The MAS-100 NT® is a high-performance instrument that is based on the principle of the Andersen air sampler, which aspirates air through a perforated plate. The resultant airflow is directed onto a standard agar poured plate. After the collection cycle, the Petri dish is incubated and the colony forming units (CFU) are counted. The MAS-100 NT® operates with a high-performance suction device, and the aspirated volume is continuously monitored. The system measures the inflow of air and regulates the aspirated volume to a constant value of 100 liters per minute.

4.4.5. Measurement Method

The Petri dishes containing approximately 20ml of Tryptone Soya Agar (TSA) for bacteria and Malt Extract Agar (MEA) for fungal growth should be used for the sampling. The following procedures should be followed. Place the MAS-100 on a firm support. Open the perforated lid (with attached dust cover) by rotating counter clock wise. Place a closed standard Petri dish filled with agar on top of the dish support. Take the lid off the Petri dish. Close the MAS-100 perforated lid. Press "yes" to switch on the MAS-100. At the end of the sampling the total volume sampled is displayed and the time shows 0:00 and the red (stop) LED is on. Open the sampling head, cover the Petri dish with the lid and remove the Petri dish from the dish support. Secure the lid of the petridish by wrapping it with parafilm. Label the petri dish with essential information such as date, site number & site description prior to moving to the next sampling site. Proceed to submit collected air samples to laboratory for incubation. Bacterial sample should be incubated at 35°C for 48 hours and fungal plates at 25°C for 5 days.

4.4.6. Sealing and Labelling (Sample)

Seal the agar plate around the circumference with tape or Parafilm to prevent contamination due to the top and bottom of the plate separating. Label the top of the agar plate with all pertinent sampling information (sample identification, date, initials, etc.) and ship to the laboratory.

4.4.7. Shipping

Place the agar plates in a sturdy box to prevent crushing and ship to the laboratory.

Note: Do not pack with ice or freezer block as this practice results in excess moisture condensing inside the plate and rendering it uncountable.

4.4.8. Sterilization

In the field, parts could be swabbed with 70% isopropyl alcohol on a sterile gauze pad and air dried. For complete sterilizing in the event of cross contamination, autoclave the perforated lid and dust cover at 121°C for 20minutes or immerse in ethanol/isopropanol solution and air dry.

4.4.9. Cleaning

The external surface of the air sampler should be cleaned with 70% ethanol or isopropanol solution. All cleaning / disinfectant solution should be removed / wiped dry properly before using the air sampler.

4.4.10. Incubation Condition

Sample should be incubated and examined in a timely manner so that microbial overgrowth or under growth does not occur. Incubate the Bacterial plates at 35°C +/- 2°C for 24 to 48 hours in order to get good recovery of bacteria. Incubation start and end time should be included in secondary container and results analysis work sheet.

4.4.11. Counting of Colonies

Examine the plates as soon as they are removed from the incubators. If this is not possible, then Technical Manager should arrange a staff to store at 4°C for no longer than 24 hours.
Count the colonies present in or on plates.

Spreading colonies could interfere with counts. A chain of colonies that appears to be formed by the disintegration of a clump of organisms, a spreading growth developing as a growth on the bottom of the Petri dish or a colony that forms in a film of water at the edge or on the surface of the Petri dish should be regarded as single colonies.

4.4.12. Calculation of Results

Count all Colony Forming Units (CFUs) that occur at impaction sites and correct these counts for positive-hole coincidence.

Calculate the colony forming unit as follows:

$$\text{CFU/m}^3 \text{ of Air} = \frac{\text{Number of corrected colonies}}{\text{Volume of air sampled}} \times 1000$$

4.4.13. Speciation

Speciation is to be performed when single species dominate from the culture plate.

4.5. Measurement of Air Velocity

4.5.1. Equipment Description

TSI Velocicalc 9515 was used to measure the air velocity. Straight Air Velocicalc 9515 measures the air velocity, temperature and relative humidity. It gives the best-in-class air velocity accuracy and accommodates up to two K-alloy thermocouples. Hot wire method based on heat transfer measurement principle. Typical characteristic include accuracy in low velocity region and accuracy across a wide dynamic range.

4.5.2. Measurement Method

Place the probe on the stable platform at the measuring location in order to minimise the error in reading due to fluctuation and hand movement. Extend the probe so that the air flows through the window. This will minimise the time required for the temperature/velocity readings to stabilize. Turn on the VelociCalc 9515 instrument using the ON/OFF switch. The VelociCalc 9515 will begin to display velocity in meters per second (m/s). Note down the reading on the Measurement Report Datasheet with the location and point. Retract the probe by holding the handle in one hand while gently pushing on the probe tip with the other hand. Switch OFF the instrument by using the ON/OFF switch.

4.6. Measurement of Respirable Suspended Particulate Count

4.6.1. Equipment Description

TSI Dustrak 8533 with light-scattering laser photometers that give real-time aerosol mass readings was used to measure the respirable suspended particles presence in the air. It provides real-time optical scattering based on photometric measurement principle.

4.6.2. Measurement Method

Place the instrument on a stable platform at the measuring location. Turn on the power switch which is located on the side of the unit. When the instrument is on, press the green Start button. The counter is set at 'Manual Mode' with 5 second log interval for 1 minute. The average of the 12 logged data's will be displayed on the main screen. The mass fraction region shows the size segregated mass measurement (PM1, PM2.5, Resp. PM10 and Total). The highlighted channel displayed in the larger font on the left could be changed by touching on the screen the measurement of most interest on the right hand side of the screen. Note down the reading on the Measurement Report Datasheet with the current location and point.

4.7. Measurement of Formaldehyde

4.7.1. Equipment Description

PPM Technology htV-m Formaldemeter with electrochemical sensor with a capacity of measuring low levels of formaldehyde in the air was used to detect the presence of formaldehyde. E PPM Technology htV-m Formaldemeter works on the principle of electrochemical sensor.

4.7.2. Measurement Method

Hold the instrument in the atmosphere to be analysed. Press the ON-OFF button once to activate the instrument. Press and release the SAMPLE button once. Switch the instrument off by pressing the ON-OFF.

4.8. Measurement of Relative Humidity, Carbon Dioxide, Carbon Monoxide

4.8.1. Equipment Description

TSI VelociCalc Multi-Function Ventilation Meter 9565 was used to measure carbon dioxide, carbon monoxide, relative humidity. Carbon Dioxide: Non-dispersive IR, Intensity of light reaching detector is proportional to CO2 concentration. Carbon Monoxide: Electrochemical, reacting with gas of interest and producing a signal proportional to the gas concentration. Relative Humidity: Thin film capacitive, as humidity changes; it changes the capacity of the sensor.

4.8.2. Measurement Method

Attach the probe and switch on the TSI equipment. The unit will display live readings from the probe in real time. Record down the stabilized readings.

4.9. Total Volatile Organic Compound (TVOC)

4.9.1. Equipment Description

MiniRae 3000 was used to measure the Total Volatile Organic Compound (TVOC). The photo-ionization detector (PID), with a detection limit in parts per million (ppm), was utilized to detect the volatile organic compounds. Real time photo-ionisation detector, the electric current produced by the positively charged TVOC is proportional to a concentration.

4.9.2. Measurement Method

Place the instrument on a stable platform at the measuring location. Turn on the yellow power switch which is located in the centre of the unit. Switch the instrument off by pressing the ON-OFF.

4.10. Measurement of Operative Temperature

4.10.1. Equipment Description

QUESTemp 44 was used to measure the operative temperature. QUESTemp 44 is used to evaluate indoor and outdoor environmental conditions for the potential to cause heat stress or heat-related injuries. The QUESTemp 44 incorporates a Waterless Wet Bulb sensor, which provides traditional heat stress monitoring without the aggravation of wet bulb maintenance. Air Temperature: Thermistor, which is thermally sensitive semiconductors whose resistance varies with temperature. Globe Temperature: Globe thermometer, a hollow globe coated on the outside with the matt black paint absorbs the radiant heat from surrounding object. The temperature at the centre of the globe is the measure of radiant heat, and not of the surrounding air.

4.10.2. Measurement Method

Turn the unit on. Allow 10 minutes for the sensors to stabilize to the environment before taking readings. Use the UP and DOWN arrow keys to select the display to the desired item.

4.10.3. Calculation of operative temperature

Operative temperature is the average of the air temperature and the mean radiant temperature.

To - Operative temperature °C: $To = (Ta + Tr)/2$
Ta – Air temperature °C
Tg – Globe Temperature °C
V – Air velocity m/s
Tr – Mean Radiant Temperature °C:
$Tr = Tg + 2.44 \times V0.5\ (Tg - Ta)$

Note down the air temperature, globe temperature and air velocity reading on the Measurement Report data sheet and calculate the operative temperature by applying the above mentioned formula. The unit turns off by holding the I/0 key while a countdown of 3-2-1 occurs in the lower right corner of the display.

4.11. Subjective Measurement

4.11.1. Design

IAQ in a building is the result of several factors, not just ventilation rates and ventilation characteristics. Consideration should be given to the environment, ambient air quality, source and control of indoor air contaminants, ventilation characteristics, nature and use of the building.

A building design, including its ventilation and air conditioning should be designed to provide acceptable IAQ under normal operation condition.

Tabulation of prevailing Wind Direction & Speed obtained from NEA over a period of 18 years.

Wind Direction	Mean Speed(m/s)
North	2.0
North-East	2.9
South	2.8
South-East	3.2

Table 4-3 Prevailing Wind Direction & Speed

The prescribed wind direction and relevant wind speeds for Green mark version 4.1.

4.11.2. Use or Occupancy Type

Use and occupancy type was studies for each 5 educational institutes since contamination level I a building are directly influenced by the kind of activities that take place within the building. For instance IAQ in school buildings are affected by the emission from new furniture and equipment such as copiers and printers. Similarly IAQ in school cafeterias are affected by the humidity fumes odour generated by cooking and environmental tobacco smoke from outside into other parts of the building.

4.11.3. Number of People

The number of people in the given area, occupant density was also studies at the time of sampling. Variable occupancy should be given adequate consideration in determining ventilation rates and the capacity to vary them during the day in each zone of the building.

4.11.4. Occupant Survey

For occupant perception, their evaluation of the physical environment and physiological responses are solicited through a detailed survey questionnaire. The form can be referenced in the Appendix section.

CHAPTER 5: RESULT AND DISCUSSION

5.1. CASE STUDY 1 – BUILDING A

5.1.1. Introduction

Indoor Air Quality testing was conducted at Building A located at the West of Singapore. The purpose of the IAQ testing was to compare the air quality to the existing Code of Practice for Indoor Air Quality for Air-Conditioned Buildings in Singapore and identify issues.

The air quality parameters that were sampled are carbon dioxide, carbon monoxide, operative temperature, relative humidity, respirable suspended particulates, total volatile organic compounds (TVOC), formaldehyde, air velocity, total bacterial count and total fungal count.

5.1.2. Design

Building A is a 6 storey building comprising of various seminar rooms, office areas and meeting rooms located in each floor of the building. Each floor consist of multiple zones that are served by a dedicated Air Handling Unit (AHU) with no cross mixing of air between AHUs on any floor and thus the building might be considered to be served by floor–by–floor AHU. A Constant Air Volume (CAV) system is used and the conditioned air is supplied through the supply diffuser mounted on the ceiling while the returns air is through the ceiling plenum. The work involves mainly lectures, seminars, and documentation and in few zones heavy human traffic occurs.

5.1.3. Building Details and Summary

Description	**Specification**
Gross Floor Area	10,063 sq. m
Teaching Room Seating Capacity	1,628
No. of Lecture Theatres	8
No. of Classrooms	11
No. of Computer/Science Laboratories	2
Library	1
Others	The Lounge, Administration

Table 5-1 Building A - Details and Summary

A total of 30 indoor points and 1 outdoor point were tested. The air sampling results indicated that out of the 30 indoor locations tested, an amount of air parameters failed, which are not in accordance with the relevant standards.

Summary of failed parameters in 30 indoor locations tested

Parameters Tested	Threshold limit	Number of Failed Locations	Failed Locations in %
Carbon Dioxide	<1139 ppm (700ppm above Outdoor)	0	0
Carbon Monoxide	<9ppm	0	0
Formaldehyde	<0.1ppm	0	0
TVOC	<3000ppb	0	0
Respirable Suspended Particulates	<50µg/m^3	4	13
Operative Temperature	24 - 26°C	19	61
Relative Humidity	<70%	0	0
Air Velocity	0.1 – 0.3 m/s	5	16
Total Bacteria Count	< 500 CFU/m^3	4	13
Total Mould Count	< 500 CFU/m^3	0	0

Table 5-2 Building A - Details and Summary

5.1.4. Background Information

An Indoor Air Quality (IAQ) audit was conducted at Building A located at the West of Singapore in accordance to “Singapore Standard SS554:2009; Code of Practice for Indoor Air Quality for Air-Conditioned Buildings”. The purpose of the IAQ testing was to identify any general issues associated with indoor air quality and compare to the “Singapore Standard SS554:2009; Code of Practice for Indoor Air Quality for Air-Conditioned Buildings”.

There are total of 30 indoor sample was taken and 1 outdoor sample was taken for baseline comparison purposes. Field measurements were taken to generally assess the indoor air quality parameters such as Carbon Dioxide (CO_2), Carbon Monoxide (CO), Formaldehyde, Total Volatile Organic Compounds (TVOC), Respirable Suspended Particulates (RSP), Operative Temperature, Relative Humidity (RH), Air Velocity, Total Bacterial Count, and Total Fungal Count.

5.1.5. Results and Discussion

This section focuses on providing further detail on the most important and significant areas of the IAQ audit which have been interpreted from both the IAQ test results and analysis of the samples. This section also goes on to highlight some of the potential health effects and the comparison of test results with the Singapore Standard for IAQ in air conditioned buildings (SS554:2009) as a baseline reference to the failed test results.

5.1.5.1. Respirable Suspended Particulates (RSP)

Particulate count at 4 indoor locations were exceeded the recommended threshold limit of 50µg/m3.

RSP refers to a range of substances that remain suspended in the air and which comprise of a mixture of organic and inorganic substances. Several irritant effects are associated with exposure to RSP, which could further result in airway constriction and respiratory illnesses. Excessive levels of particulates could cause allergic reactions, such as dry eyes; nose, throat, and skin irritation; coughing; sneezing; and respiratory difficulties.

5.1.5.2. Operative Temperature (OT)

The OT reading at 19 indoor Locations had exceeded the "Singapore Standard SS554:2009; Code of Practice for Indoor Air Quality for Air-Conditioned Buildings" recommended range of between 24°C–26°C. Generally, in a well maintained, air tight building, it would be reasonable to keep the operative temperature of around 24°C–26°C.

5.1.5.3. Air Velocity (AV)

The air velocity results at 5 indoor locations were not within the recommended range of 0.10-0.30 m/s. Air velocity might not have a direct influence over the occupants' perception of the indoor environment as compared to temperature and humidity. However, it is synergistically related to the thermal comfort and the overall performance of the ventilation system. Very high or very low air movement will affect the comfort level of different individuals.

5.1.5.4. Total Bacterial Count (TBC)

Total bacterial counts at 4 indoor locations exceeded the recommended threshold limit of 500CFU/m3. Bacteria found in indoors air are generally shed from the skin by the occupants and usually harmless for the majority of people (healthy) as they drop off with dead skin and dust and could become airborne in less ventilated indoor environments and with a lot of activity to stir up the surface dusts into the air. A build-up of air borne bacterial concentration is generally due to insufficient fresh air exchanges, overcrowding and poor housekeeping.

5.1.5.5. Subjective Assessment

A total of 40 people were surveyed based on their perception, their evaluation of the physical environment and physiological responses for IAQ Assessment. Out of the 40 questionnaires respondent 27 were male and 13 were female. 75% of the respondent confirmed that they had to put on extra clothing for comfort during lectures, which can be explained, by lower operative temperature than the limits in 19 locations in classroom and lecture theatres.

5.1.6. Improvement Recommendations

An indoor environment must contribute to the well-being of the occupants and be a safe environment; the poor indoor air quality found at certain locations could have a significant impact on occupants, especially those who have chronic illnesses or existing allergies and sensitivities.

5.1.6.1. Respirable Suspended Particulate

Respirable suspended particulates could be addressed by replacing the filters of the air-conditioning system. Good housekeeping practices will also help decreases the particle level in the air and on surfaces.

5.1.6.2. Operative Temperature

The majority of building occupants perceive indoor air quality problems to be associated with comfort, such as with regards to temperature, relative humidity, and air flow, when these are found to be too low or high in the indoor environment. Generally, in a well-maintained and airtight building, it would be reasonable to keep the operative temperature at around 24 °C – 26 °C. However, thermal comfort is often subject to the individual's preference, so it is suggested to maintain the operative temperature for which a maximum number of the occupants will be expected to find the indoor temperature acceptable.

5.1.6.3. Air Velocity

Airflow throughout the premises should be addressed concurrently with the temperature control settings. Some level of air balancing or adjustment should be reviewed to achieve equilibrium between the variations in occupancy and kind of activities in the office premises. Air velocity data logging could also be considered to ascertain if there are any imbalances in the distribution system.

5.1.6.4. Total Bacterial Count

Bacterial impurities found in the indoor air should normally be removed through the ventilation systems and cleaning procedures. Increasing the air changes at the lobby area and the space has a lot of people will not only help to decrease the bacterial pollutants; it would also help to decrease the build-up of carbon dioxide and other internally generated pollutants. Enhanced housekeeping practices will also assist to decrease the bacterial load in the air and surfaces, in which the species present, are sourced from skin cells and general dust.

5.2. CASE STUDY 2 – BUILDING B

5.2.1. Executive Summary

Indoor Air Quality testing was conducted at Building B located at the West of Singapore. The premises are served by a mixture of Air Handling Units (AHU) and Fan Coil Units (FCUs). The kind of testing consisted of physical, chemical, and bio aerosol sampling. Purpose of the testing was to conduct standard IAQ sampling as per the requirements listed in the BCA Green Mark Certification scheme.

5.2.2. Design

The Building B is located in the West of Singapore, situated besides a busy road leading up to an expressway. Each floor of the building has a separate air handling unit (AHU) supplying various zones with individual thermostatic temperature controls for each zone. The intake air is filtered, cooled and dehumidified within the AHUs. Filters in the AHU consist of double stage air filters consist of primary air filter having a Minimum Efficiency Reporting Value (MERV) of rating 6 and secondary filter having a MERV rating of 13 to protect building occupants from airborne particulate matter (PM 2.5). The air distribution is by means of a variable air volume (VAV) system (Figure 5-1 to 5-6). Return is air is drawn from individual offices by way of grilles suspended on the ceiling. Air is returned to the AHU via the ceiling void which serves as return air plenum.

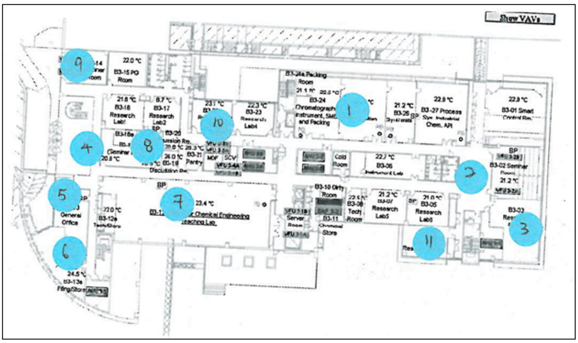

Figure 5-1 Building B's Floor Plan – 1

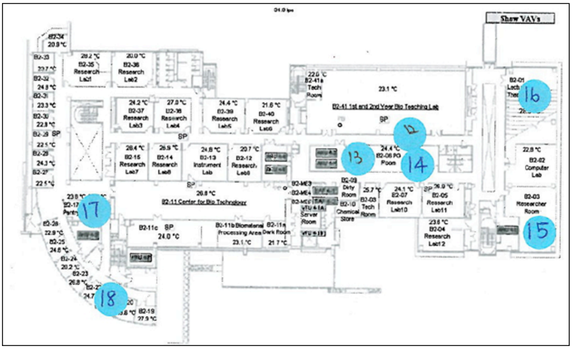

Figure 5-2 Building B's Floor Plan – 2

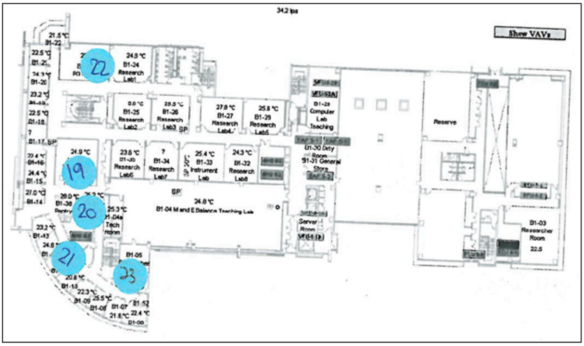

Figure 5-3 Building B's Floor Plan – 3

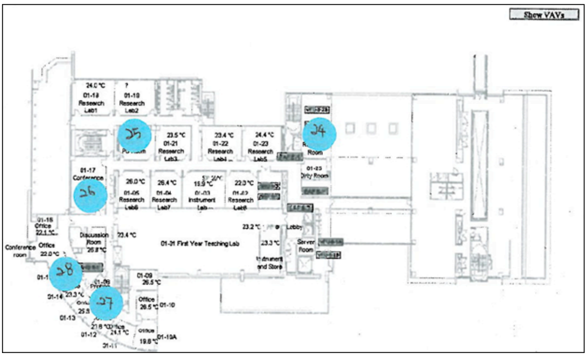

Figure 5-4 Building B's Floor Plan – 4

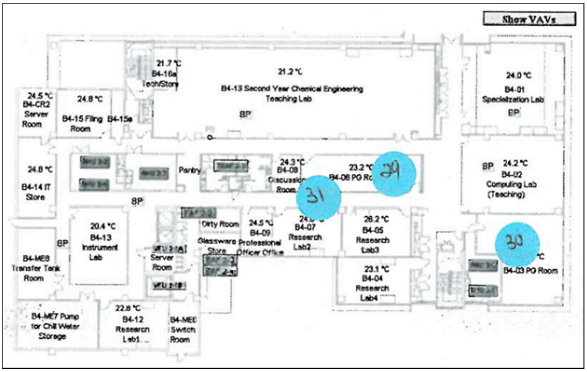

Figure 5-5 Building B's Floor Plan – 5

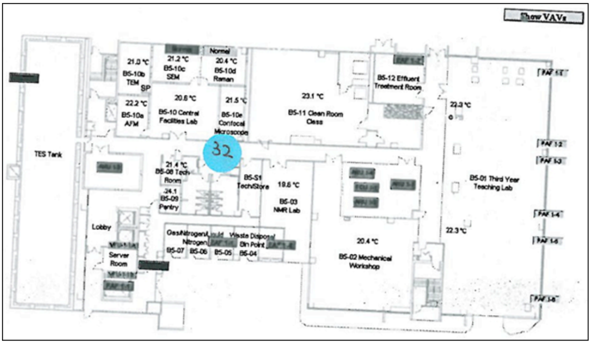

Figure 5-6 Building B's Floor Plan – 6

5.2.3. Building Details and Summary

Description	Specification
Gross Floor Area	10,063 sq. m
Teaching Room Seating Capacity	1,534
No. of Lecture Theatres	7
No. of Classrooms	3
No. of Research Rooms/Research Laboratories	6
Library	1
Others	Common Corridors Study Area

Table 5-3 Building B - Details and Summary

A total of 32 indoor samples and 1 outdoor sample were taken for baseline comparison purposes. Field measurements of general indoor air quality parameters such as Carbon Dioxide (CO_2), Carbon Monoxide (CO), Formaldehyde, Total Volatile Organic Compounds (TVOC), Respirable Suspended Particulates (RSP), Operative Temperature, Relative Humidity (RH), Air Velocity, Total Bacterial Count, and Total Mould Count were tested. IAQ measurements indicated generally acceptable indoor air levels for all the tested parameters except for comfort parameters such as operative temperature in 3 locations and air velocity in 10 locations which are not in accordance with the "Singapore Standard SS554:2009; Code of Practice for Indoor Air Quality for Air-Conditioned Buildings".

Summary of failed parameters in 32 indoor locations tested

Parameters Tested	**Threshold limit**	**Number of Failed Locations**	**Failed Locations in %**
Carbon Dioxide	(700ppm above Outdoor)	0	0
Carbon Monoxide	<9ppm	0	0
Formaldehyde	<0.1ppm	0	0
TVOC	<3000ppb	0	0
Respirable Suspended Particulates	$<50\mu g/m^3$	0	0
Operative Temperature	24 - 26°C	3	9
Relative Humidity	<70%	0	0
Air Velocity	0.1 – 0.3 m/s	10	31
Total Bacteria Count	< 500 CFU/m^3	0	0
Total Mould Count	< 500 CFU/m^3	0	0

Table 5-4 Building B - Summary of failed parameters in 32 indoor locations

5.2.4. Background Information

A total of 32 indoor samples and 1 outdoor sample were taken for baseline comparison purposes. IAQ equipment was deployed as close to the sampling area as possible. The sampling height was taken to be an average 'breathing zone'. The air conditioning was in operation at the time that the air testing was conducted. IAQ testing was performed in accordance to "Singapore Standard SS554:2009; Code of

Practice for Indoor Air Quality for Air-Conditioned Buildings" and has been presented in an accredited test results report, issued separately to this IAQ report.

5.2.5. Result and Discussion

This section focuses on providing further detail on the most important and significant areas of the IAQ audit which have been interpreted from both the IAQ test results and the consultant's professional opinion. This section also goes on to highlight some of the potential health effects and the comparison of test results with the Singapore Standard for IAQ in air conditioned buildings (SS554:2009) as a baseline reference to the failed test results.

5.2.5.1. Operative Temperature (OT)

The OT results at 3 indoor locations were found to be lower than the recommended range of between 24-26°C.

Majority of the occupants perceive indoor air quality problems to often comfort problems, such as temperature, relative humidity, and air flow in the indoor environment being too low or high. Generally, in a well maintained building, it would be reasonable to keep the operative temperature of around 24°C–26°C. However, thermal comfort is often subjected to individual's preference, so it is suggested maintain the operative temperature where a maximum number of the occupants could be expected to feel the indoor temperature acceptable.

5.2.5.2. Air Velocity (AV)

The air velocity results at 10 locations located inside the premises were below the lower recommended limit of 0.10-0.30m/s. Air velocity might not have direct influence over occupant's perception in indoor environment as compared to temperature and humidity; but it is synergistically related to the thermal comfort and the overall performance of the ventilation system. Either very high or low air movement will affect perceived comfort level felt from different individuals and might encourage complaints regarding temperature and humidity, when in fact the issue is the air flow.

5.2.5.3. Total Mould Count (TMC)

The total mould counts at all the tested locations were within the recommended limits of 500 CFU/m_3. However, the level retrieved at location 21 (490CFU/m3) was near to the threshold limits. Generally mould count indoors should be lower than outdoor counts and the types of mould found indoors should be similar to outdoors. Excessive concentrations of mould retrieved at the location could be due to inadequate maintenance and housekeeping. Moulds produce allergens, irritants, and in some cases, toxins that could cause reactions in humans. The health effects and severity of the symptoms depend, in part, on the species of mould present, the concentration of contamination and the extent of an individual's exposure (time spent in the affected environment). People who have existing sensitivities or allergies are worst affected, as well as the elderly and immune-compromised individuals.

5.2.5.4 Subjective Assessment

A total of 40 people were surveyed based on their perception, their evaluation of the physical environment and physiological responses for IAQ Assessment. Out of the 40 questionnaire respondent 30 were male and 10 were female. 75% of the respondent confirmed that their classroom / lecture theatre felt stuffy and some strong odour due to low air flow inside those locations. The lower air velocity has been observed in 10 locations between 0.01 to 0.03m/s in 10 locations.

5.2.6. Improvement Recommendations

This section provides suggestions for remediation and corrective actions and enhanced abatement approaches following the test results and findings during the IAQ audit.

5.2.6.1. Operative Temperature (OT)

Generally, in a well maintained building, it would be reasonable to keep the operative temperature of around 24°C–26°C. However, thermal comfort is often subjected to individual's preference; ideally, operative temperature in an office should be kept at a range that most people find comfortable. The goal should be to maintain an office temperature that will satisfy at least 80% of the occupants.

If zone control is not available, it is recommended to maintain the temperature range to between 24°C–26°C to keep the majority of occupants satisfied, additionally this does not encourage the unpleasant effects of extreme temperature fluctuations caused by independent control adjustments. It is recommended that if temperature control issues persist that a detailed temperature IAQ study is conducted.

5.2.6.2. Air Velocity (AV)

Air flow throughout the areas around the premises should be addressed concurrently with the temperature control settings. Some level of air balancing or adjustment should be reviewed to achieve the equilibrium between the variations in occupancy and kind of activities in the office premises. Review of the delivered air flow compared to the design air flow is recommended to test if there are any air loses in the duct work that might be decreasing the airflow.

5.2.6.3. Total Mould Count (TMC)

Although no visible surface mould was found at location 21 during the time of testing, it is suggested to conduct a thorough check of the surfaces and materials within the space to identify possible hidden mould growth. If no mould stains are found. It is strongly recommended to decrease levels of airborne mould spores in the internal environment of location 21 (Seminar Room). Thorough surface wipe down and bio fogging using biocide should be considered. Dust and dirt accumulated on the supply diffusers should also be included in the professional decontamination, as this might become a breeding ground for mould and other microorganisms. Re-testing is recommended after any biological decontamination treatment to ensure that the mould levels are decreased.

5.3. CASE STUDY 3 – BUILDING C

5.3.1. Executive Summary

Indoor Air Quality testing was conducted at Building C located at the West of Singapore. The premise is served by Fan Coil Unit (FCU) in Lecture theatre rooms and Air Handling Unit (AHU) in certain office and corridor areas. Kind of testing consisted of physical, chemical, and bio aerosol sampling.

Purpose of the testing was to conduct standard IAQ sampling of specific areas for their annual internal audit.

5.3.2. Design

Building C is located at the west of Singapore. The 6 storey building has open plan space concept, carpeted floor and glass windows. The premise is served by Fan Coil Unit (FCU) in Lecture theatre rooms and Air Handling Unit (AHU) in certain office and corridor areas. VAV system is used as the ACMV system. Fresh air is from centralized fresh air duct with branch ducts to the individual AHUs at each floor. The conditioned air is supplied through the diffuser mounted on the ceiling while the exhaust air returns via ceiling plenum.

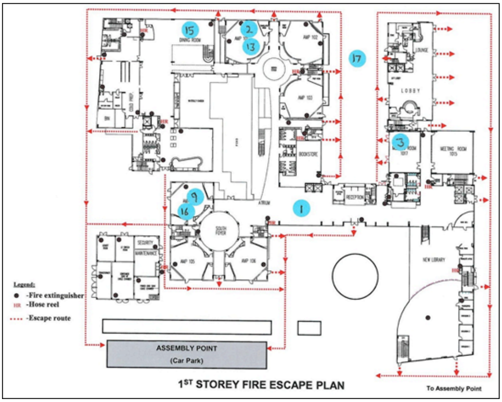

Figure 5-7 Building C's Floor Plan – 1

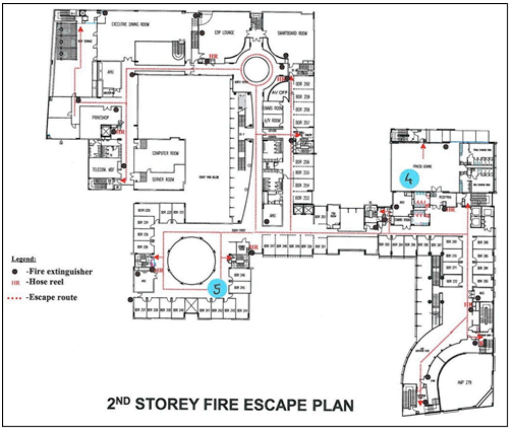

Figure 5-8 Building C’s Floor Plan – 2

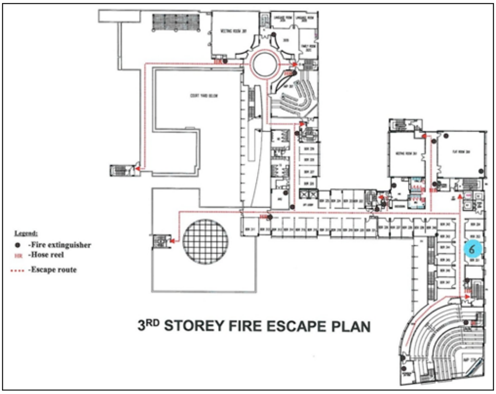

Figure 5-9 Building C’s Floor Plan – 3

Figure 5-10 Building C’s Floor Plan – 4

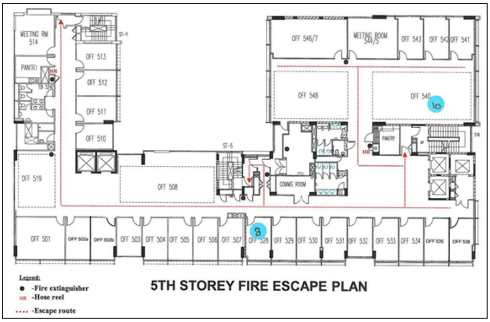

Figure 5-11 Building C's Floor Plan – 5

Figure 5-12 Building C's Floor Plan – 6

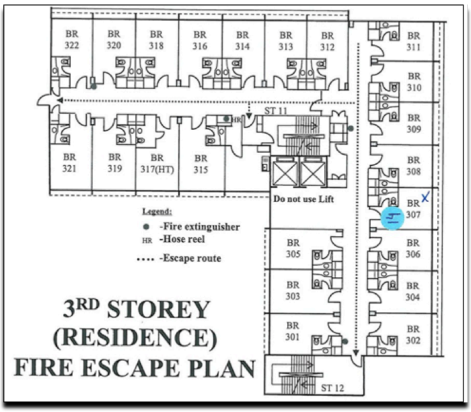

Figure 5-13 Building C's Floor Plan – 7

5.3.3. Building Details and Summary

Description	Specification
Gross Floor Area	14,300 sq. m
Teaching Room Seating Capacity	1200
No. Of Amphi Theatres	2
No. Of Office	5
No. of Computer/Science Laboratories	2
Library	1
Others	Fitness Centre Break Out Area

Table 5-5 Building C - Details and Summary

The air sampling results indicated that out of the 16 locations tested, an amount of air parameters failed. Those that failed included Carbon Dioxide in 2 locations, Operative Temperature in 1 location, Relative Humidity in 10 locations and Air Velocity in 9 locations, Total Viable Bacteria Count in 3 locations and Total Viable Mould Count in 1 location which are not in accordance with the "Singapore Standard SS554:2009; Code of Practice for Indoor Air Quality for Air-Conditioned Buildings". A summary of the test results for individual locations could be found further within this report.

Summary of failed parameters in 16 indoor locations tested

Parameters Tested	Threshold limit	Number of Failed Locations	Failed Locations in %
Carbon Dioxide	(700ppm above Outdoor)	2	13
Carbon Monoxide	<9ppm	0	0
Formaldehyde	<0.1ppm	0	0
TVOC	<3000ppb	0	0
Respirable Suspended Particulates	<50µg/m^3	0	0
Operative Temperature	24 - 26°C	1	6
Relative Humidity	<70%	10	62
Air Velocity	0.1 – 0.3 m/s	9	56

Total Bacteria Count	< 500 CFU/m^3	3	19
Total Mould Count	< 500 CFU/m^3	1	6

Table 5-6 Building C - Summary of failed parameters in 16 indoor locations

5.3.4. Background Information

A total of 16 indoor samples were taken and 1 outdoor sample was taken for baseline comparison purposes. IAQ equipment was deployed as close to the sampling area as possible. The sampling height was taken to be an average 'breathing zone'. The air conditioning was in operation at the time that the air testing was conducted. IAQ testing was performed in accordance to "Singapore Standard SS554:2009; Code of Practice for Indoor Air Quality for Air-Conditioned Buildings" and has been presented in an accredited test results report, issued separately to this IAQ report, the summary of the IAQ results is presented later in this report for further discussion.

5.3.5. Results and Discussion

This section focuses on providing further detail on the most important and significant areas of the IAQ audit which have been interpreted from both the IAQ test results and the consultant's professional opinion. This section also goes on to highlight some of the potential health effects and the comparison of test results with the Singapore Standard for IAQ in air conditioned buildings (SS554:2009) as a baseline reference to the failed test results.

5.3.1.1. Carbon Dioxide (CO_2)

Elevated levels of carbon dioxide were recorded at Lecture theatre rooms 101 and 104. Lecture theatre rooms 101 and 104 were occupied with staff and students over the course of the testing period. High levels of carbon dioxide in these class rooms are most likely due to the high occupancy and insufficient ventilation.

SS554:2009; Code of Practice for Indoor Air Quality for Air-Conditioned Buildings" recommends that carbon dioxide levels should not exceed 700ppm above outdoor (487ppm) which at the location tested is not recommended to be above 1187ppm.

Carbon dioxide is found naturally in the air and is not a toxic gas. Carbon dioxide is exhaled by the building occupants and is built up when the indoor air is not exchanged with adequate fresh air from the outdoor. It is primarily an indicator of how well the ventilation system is working. Some people might experience headaches and dizziness at concentrations above 1187ppm (700 ppm above outdoor). Complaints regarding stale air or stuffiness are more frequent when the CO_2 concentration reaches above recommended limit (1187ppm).

5.3.1.2. Operative Temperature (OT)

The OT result at Office 648 was found to be higher than the recommended range of between 24-26°C. Information provided during the time of the assessment was that the temperature settings have been adjusted to a warmer degree and air flow has also been adjusted on the request of the occupants using this room.

Majority of the indoor air quality problems perceived by occupants are often comfort problems, such as temperature, relative humidity, and air flow. In a well maintained building, it would be reasonable to set the operative temperature to between the ranges of 24°C–26°C. However, because thermal comfort is often subjected to each individual's preference, and other personal contributing factors, it is suggested maintain the operative temperature in the range of where the majority of the occupants feel the indoor temperature is acceptable.

5.3.1.3. Relative Humidity (RH)

The RH results at 10 locations were found to have exceeded the recommended SS554 threshold limits of below 70% for existing buildings.

RH is among the most common of indoor air environmental factors that affects occupant discomfort in air conditioned buildings. RH levels exceeding 70% could encourage the growth of mould and several other species of microorganism indoors. High levels of moisture indicate that the conditions are optimal for mould growth. Sustained high humidity leads to surface dampness and eventual saturation of building materials in Singapore and thus provides a suitable substrate (food source) on which the mould could grow.

Singapore Standard SS554-2009 is intended to provide a reference for acceptable thermal comfort for air conditioned buildings and baselines several indoor air parameters in order to a maintain balanced indoor environment. The relationship of how these specific air parameters are deployed by operational and engineering strategies inside of buildings that allow the building to optimise its design, which is to prevent mould growth and other air impurities which could cause occupant discomfort and risks to health. There is no documented relative humidity value as a threshold that indicates the imminent growth of mould on building materials and or surfaces. However, relative humidity levels directly correspond to dew point temperatures. The dew point effect could be minimised by closing the gap between low temperatures and high RH which in turn would minimise the likelihood of surface condensation effect and subsequent potential mould growth. Some building common building materials are prone to the effects of excess moisture damage and mould stains could appear in a short time frame on particularly porous materials such as ceiling boards, plaster walls, wall paper and leather or non-treated materials.

5.3.1.4. Air Velocity (AV)

The air velocity results at 9 locations within the building were below the lower recommended limit of 0.10-0.30m/s. Air velocity might not have direct influence over occupant's perception in indoor environment as compared to temperature and humidity; but it is synergistically related to the thermal comfort and the overall performance of the ventilation system. Either very high or low air movement will affect the perceived comfort levels felt from different individuals and might encourage complaints regarding temperature and humidity, when in fact the issue is the air flow.

5.3.1.5. Total Bacterial Count (TBC)

Total bacterial counts at 3 indoor locations exceeded the recommended threshold limit of 500CFU/m^3; ranging from 590CFU/m^3 - 3000CFU/m^3. Elevated levels of bacteria in the class rooms are most likely due to the high occupancy and insufficient ventilation. Human occupants themselves are normal reservoirs of bacteria; increased human activities combined with inadequate ventilation (shortage of outdoor/fresh air) could easily give rise to higher bacterial levels.

Bacteria found in indoor air are generally shed by building occupants. The high numbers in these locations indicate poor air quality. Bacteria such as *Bacillus* species found in indoor air amplify the risks of supportive infection when allowed to breed in high numbers. Other species such as *Micrococcus* and other gram-positive *coccus* are associated with human skin and are relatively harmless even if high counts are present. It is generally advised to get the speciation done to identify the source and health risk associated with the kind of bacteria present in the environment.

5.3.1.6. Total Mould Count (TMC)

Total mould counts at Lecture theatre 101 (during class) have exceeded the Singapore Standard SS554:2009 recommended threshold limit of 500CFU/m^3, measuring at 1670CFU/m^3. In general, mould levels below 200CFU/m^3 are considered good and acceptable for most individuals. Levels ranging from 200 to 500CFU/m^3 are marginal for hypersensitive individuals and levels above 500CFU/m^3 are expected to cause allergic problems, and could lead to an increase in airborne infections for a significant number of individuals with lower immunity levels.

Mould such as *Aspergillus* species give off mycotoxins, microbial volatile organic compounds (MVOC gases), and other by-products that could be highly toxigenic to susceptible individuals. Respiratory and asthmatic symptoms are more common to individuals exposed to *Aspergillus* spores. Other species such as *Mucor* is a ubiquitous fungus, which is often found in soil, plants house dust, and in moist building materials. It is an opportunistic pathogen and might cause infections in the lung, nasal sinus, brain and eye.

5.3.1.7. Subjective assessment

A total of 40 people were surveyed based on their perception, their evaluation of the physical environment and physiological responses for IAQ Assessment. Out of the 40 questionnaires respondent 22 were male and 18 were female. 85% of the respondent confirmed that their classroom / lecture theatre felt stuffy and suffered symptoms of lethargy during the class. The survey coincides with the air quality findings of high carbon dioxide during class and low air velocity in almost 10 various locations throughout the building.

5.3.6. Improvement Recommendations

This section provides suggestions for remediation and corrective actions and enhanced abatement approaches following the test results and findings during the IAQ audit.

5.3.6.1. Carbon Dioxide (CO_2)

Elevated levels of carbon dioxide indicate poor ventilation at Lecture theatre rooms 101 and 104 during class hours. High CO_2 levels are frequently reflective of overcrowding or inadequate ventilation exchanges at the location.

Review of the air conditioning systems in these areas is recommended to assess whether the equipment is able to still perform effectively and efficiency during full load periods.
Further introduction of fresh air and better air circulation could be increased in class rooms 101 and 104 in order decrease the build-up of these two indoor air impurities. Additional fresh air duct connected to existing FCU would be able to bring down the internal generated impurities.

5.3.6.2. Operative Temperature (OT)

Generally, in a well-maintained building, it would be reasonable to keep the operative temperature of around 24°C–26°C. However, thermal comfort is often subjected to individual's preference; ideally, operative temperature in an office should be kept at a range that most people find comfortable. The goal should be to maintain an office temperature that will satisfy at least 80% of the occupants.

If zone control is not available it recommended to maintain the temperature range to between 24°C–26°C to keep the majority of occupants satisfied, additionally this does not encourage the unpleasant effects of extreme temperature fluctuations caused by independent control adjustments. It is recommended that if temperature control issues persist that a detailed temperature IAQ study is conducted.

5.3.6.3. Relative Humidity (RH)

The relative humidity should be maintained at <65 % indoor all time. This could be achieved by deploying engineering control at the air-handling unit.

If RH issues persist, it is recommended that an IAQ investigation is conducted to identify the source of moisture ingression. The RH should be addressed concurrently with the temperature control strategy of the air conditioning system to rule out equipment malfunction or maintenance issues.

5.3.6.4. Air Velocity (AV)

Airflow throughout the areas around the premises should be addressed concurrently with the temperature control settings. Some level of air balancing or adjustment should be reviewed to achieve the equilibrium between the variations in occupancy and kind of activities in the office premises. Review of the delivered air flow compared to the design air flow is recommended to test if there are any air loses in the duct work that might be decreasing the airflow.

5.3.6.5. Total Bacterial Count (TBC)

Human occupants themselves are normal reservoirs of bacteria; the level of airborne viable bacteria is based on the number of occupants and their activity at the site. These contaminants are normally removed through the ventilation system and good cleaning procedures. Good housekeeping practices will also help to decrease the bacterial load build up in the air and surfaces.

It is most likely that the cause of raised bacteria levels is from the volume of human traffic and density of human occupancy in these areas. Additionally food handling and consumption which was observed in and out of these areas would likely cause an increase in air borne bacterial microorganisms, as well as fibre particulates from clothing and skin cells to be present at the majority of the time.

It is advised that, if an air borne bacterium is still found to be high, after re- testing, that an inspection of the cleanliness of the air conditioning system is reviewed for its ability to remove airborne biological contaminates, and that these areas are thoroughly decontaminated using a biological cleaning company with thorough knowledge of biological cleaning protocols. Re- testing is recommended after any biological decontamination treatment to ensure that the bacteria levels are returned to the healthy range.

5.3.6.6. Total Mould Count (TMC)

Although no visible surface mould was found in the Lecture theatre room 101 during the time of testing, it is suggested to conduct a thorough check of the surfaces and materials within the space to identify possible hidden mould growth appearing on surfaces. If no mould stain is found, then it is recommended that a surface wipe down and bio fogging using biocide is strongly recommended to decrease levels of airborne mould spores in the internal environment. Dust and dirt accumulated on the supply diffuser should also be included in professional decontamination as this might become a breeding ground for mould and other microorganisms. Re-testing is recommended after any biological decontamination treatment to ensure that the mould levels are returned to the healthy range.

5.4. CASE STUDY 4 – BUILDING D

5.4.1. Executive Summary

Indoor Air Quality testing was conducted at Building D located at the West of Singapore. The purpose of the IAQ testing was to identify any issues associated with indoor air quality and compare to the SS554: 2009 Code of Practice for Indoor Air Quality for Air-Conditioned Buildings.

The air sampling results indicated that the Carbon Dioxide in 7 locations, Operative Temperature in 33 locations, Relative

Humidity in 14 locations, Air Velocity in 18 locations, and Total Bacteria Count in 3 locations were not in accordance with the "Singapore Standard SS554:2009; Code of Practice for Indoor Air Quality for Air-Conditioned Buildings".

5.4.2. Design

The building D is 6 storey building served by Air Handling Units (AHUs) at the common areas and ceiling mounted Fan Coil Units (FCUs) with no additional FA intake at all training rooms and office premises. From the AHU, the main air supply ducts split into various branches to the various parts of the floor space via ceiling mounted air diffusers. The air distribution is by means of a variable air volume (VAV) system.

5.4.3. Building Details and Summary

Description	Specification
Gross Floor Area	14,088 sq. m
Teaching Room Seating Capacity	1,328
No. of Teaching Rooms (TR)	12
No. of Seminar Room/Auditorium	7
No. of Computer/Science Laboratories	2
Staff Lounge	1
Others	Server Room Function Room

Table 5-7 Building D - Details and Summary

The air sampling results indicated that out of the 48 locations tested, an amount of air parameters failed. Those that failed included Carbon Dioxide in 7 locations, Operative Temperature in 33 locations, Relative Humidity in 14 locations and Air Velocity in 18 locations and Total Viable Bacteria Count in 3 locations which are not in accordance with the "Singapore Standard SS554:2009; Code of Practice for Indoor Air Quality for Air-Conditioned Buildings". A summary of the test results for individual locations could be found further within this report.

Summary of failed parameters in 48 indoor locations tested

Parameters Tested	Threshold limit	Number of Failed Locations	Failed Locations in %
Carbon Dioxide	(700ppm above Outdoor)	7	15
Carbon Monoxide	<9ppm	0	0
Formaldehyde	<0.1ppm	0	0
TVOC	<3000ppb	0	0
Respirable Suspended Particulates	<50µg/m^3	0	0
Operative Temperature	24 - 26°C	33	69
Relative Humidity	<70%	14	29
Air Velocity	0.1 – 0.3 m/s	18	38
Total Bacteria Count	< 500 CFU/m^3	3	6
Total Mould Count	< 500 CFU/m^3	0	0

Table 5-8 Building D - Summary of failed parameters in 48 indoor locations

5.4.4. Background Information

Indoor Air Quality testing was conducted at Building D located at the West of Singapore. The building is served by Air Handling Units (AHUs) at common areas and ceiling mounted Fan Coil Units (FCUs) at all training rooms and office premises. Type of testing consisted of physical, chemical, and bio aerosol sampling. The purpose of the assessment was to provide client with information regarding the indoor air quality of building premises for their internal audit.

A total of 48 indoor locations and 2 outdoor baseline sample was taken at the site. IAQ equipment was deployed as close to the sampling area as possible. The sampling height was taken to be an average ‘breathing zone’. IAQ testing was performed in accordance to “Singapore Standard SS554:2009; Code of Practice for Indoor Air Quality for Air-Conditioned Buildings”.

5.4.5. Results and Discussion

This section focuses on providing further detail on the most important and significant areas of the IAQ audit, which have been interpreted from both IAQ test results and the consultant's professional opinion. This section also highlight some of the potential health effects and the comparison of test results with the Singapore Standard for IAQ in air conditioned buildings (SS554:2009) as a baseline reference to the failed test results. Eight sampling locations were conducted at the car park areas. These are No 1-8 on the summary of IAQ test results below. Failed air parameters should not be considered as an indicator of poor IAQ in these premises.

5.4.5.1. Carbon Dioxide (CO_2)

Elevated levels of carbon dioxide have been detected at 7 indoor locations, ranging from 1153ppm – 1849ppm and outdoor was 441ppm. Singapore Standard SS554:2009; Code of Practice for Indoor Air Quality for Air-Conditioned Buildings recommends that carbon dioxide levels should not exceed 700 ppm above outdoor (441 ppm) which at the location tested is not recommended to be above 1141ppm. At the time of site testing it was observed that majority of the Training Rooms were packed with people and the fan coil units were in operation without any fresh air intake.

Carbon dioxide is found naturally in the air. CO_2 is exhaled by the building occupants and is built up when the indoor air is not exchanged with fresh air from the outdoor. Elevated levels of carbon dioxide thus indicate inadequate ventilation in the occupied area. The CO_2 level builds up throughout the day and peaks in the late afternoon especially in areas with too many people in a poorly ventilated area.

CO_2 is not a toxic gas. It is primarily an indicator of how well the ventilation system is working. Some people might experience headache and dizziness at concentrations above 1141 (700 ppm above outdoor) because of poor air circulation. Complaints regarding stale air or stuffiness are more frequent when CO2 concentration reaches above recommended limit (1141ppm). These symptoms normally go away when the person leaves the building.

5.4.5.2. Formaldehyde

Low formaldehyde levels were detected at all the indoor locations and were within the SS554:2009 recommended threshold limit of 0.10ppm. Elevated level of formaldehyde at Basement 2, Location 1 car park has been recorded, is most likely from the automobile exhaust.

5.4.5.3. Operative Temperature (OT)

The OT results at 33 indoor locations were found to be lower and at 1 indoor location were found to be higher than the recommended range of between 24-26°C. Majority of the occupant perceived poor indoor air quality to comfort problems, such as temperature, relative humidity, and air flow in the indoor environment being too low or high.

Thermal comfort means that a person feels comfortable – they are neither too cold nor too warm. It could be achieved when the air temperature, relative humidity and air velocity are within the specified range often referred to as the comfort zone. Even with ideal conditions cold or warm walls and floors could cause air temperature differences that might cause discomfort. Drafts caused by excessive air movement within the occupied space might also be a factor.

In a room that is too warm, occupants might feel tired quickly. A room that is too cold causes occupants to feel restless and easily distracted. Even minor deviation from the comfort might be stressful and affect the occupant's performance. People's age, activity level, health conditions and clothing vary widely and so do personal temperature preferences.

5.4.5.4. Relative Humidity (RH)

The relative humidity at 14 indoor locations were found to have exceeded the SS554 recommended threshold limit of <70%. Elevated levels of relative humidity encourage the growth of mould and other microorganisms in the indoor environment that might cause health problems.

5.4.5.5. Air Velocity (AV)

The air velocity results at 18 indoor locations were below the lower recommended limit of 0.10-0.30m/s.

Air velocity might not have direct influence over occupant's perception in indoor environment as compared to temperature and humidity; but it is synergistically related to the thermal comfort and the overall performance of the ventilation system. Either very high or low air movement will affect the comfort level of different individuals.

5.4.5.6. Total Bacterial Count (TBC)

Total bacterial counts at 3 indoor locations have exceeded the recommended threshold limit of 500CFU/m^3. Human occupants themselves are normal reservoirs of bacteria; increased human activities combined with inadequate ventilation (shortage of outdoor/fresh air) normally give rise to higher bacterial levels.

Bacteria found in indoor air are generally shed by building occupants. Although, the speciation for these locations have not been conducted and it is generally advised to get the speciation done to identify the source and health risk associated with the Type of bacteria present in the environment. The high numbers in these locations indicate poor air quality. Bacteria found in indoor air amplify the risks of developing bacterial infections in humans or lower immunity levels when they are allowed to breed in high numbers and are given the right environment to multiply.

5.4.5.7. Subjective assessment

A total of 40 people were surveyed based on their perception, their evaluation of the physical environment and physiological responses for IAQ Assessment. Out of the 40 questionnaires respondent 20 were male and 20 were female. 80% of the respondent confirmed that their classroom / lecture theatre felt stuffy and suffered symptoms of lethargy during the class. The survey coincides with the air quality findings of high carbon dioxide during class and low air velocity in almost various locations throughout the building. In addition the operative temperature at 33 locations was above the range of 24-26 degree Celsius.

5.4.6. Improvement Recommendations

An indoor environment must contribute to the well-being of the occupants and be a safe environment; the poor indoor air quality found at certain locations could have a significant impact on occupants, especially those who have chronic illnesses or existing allergies and sensitivities.

5.4.6.1. Carbon Dioxide (CO2)

An elevated level of carbon dioxide indicates poor ventilation when classes are on-going at the training rooms. High CO2 levels are frequently reflective of overcrowding or inadequate ventilation rates supplied at those locations. The high carbon dioxide level could be address by providing outdoor air with damper control connected to the existing air condition system, to the room throughout the duration when courses are conducted or when the classes are fully occupied.

5.4.6.2. Comfort Parameter - Operative Temperature (OT)

Generally, in a well-maintained building, it would be reasonable to keep the operative temperature of around 24°C–26°C. However, thermal comfort is often subjected to individual's preference; ideally, operative temperature in an office should be kept at a range that most people find comfortable. The goal should be to maintain an office temperature that will satisfy at least 80% of the occupants.

5.4.6.3. Relative Humidity (RH)

Relative Humidity in the occupied spaces should be maintained below 65% to minimise the growth of mould and other allergenic organisms. The combination of high RH and decreased air movement in the conditioned space, significantly increase the risk of mould contamination. Further investigation is required to ascertain the cause of high RH in the indoor environment.

5.4.6.4. Air Velocity (AV)

Airflow throughout the premises should be addressed simultaneously with the temperature control settings. Some level of air balancing or adjustment should be reviewed to achieve the equilibrium between the differences in occupancy and activity types in the office premises.

5.4.6.5. Total Bacterial Count (TBC)

High bacteria count could be address by airing the room during break time by opening the windows and doors, and turn of the air conditioning to save energy consumption. Good housekeeping in general will help maintain indoor air quality by controlling particulates and bacteria within the occupied space.

5.5. CASE STUDY 5 – BUILDING E

5.5.1. Executive Summary

Indoor Air Quality testing was conducted at Building E located at the West of Singapore. The purpose of the IAQ testing was to identify any issues associated with indoor air quality and compare to the SS554: 2009 Code of Practice for Indoor Air Quality for Air-Conditioned Buildings.

5.5.2. Building Details and Summary

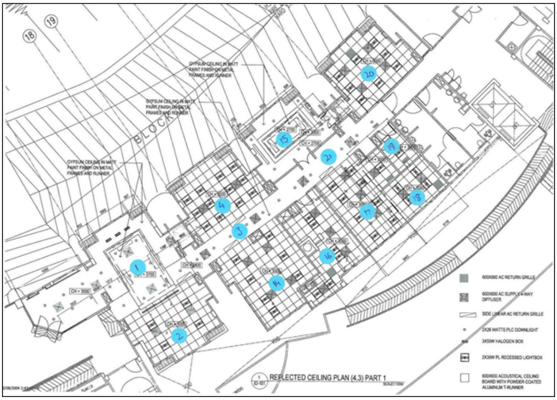

Figure 5-14 Building D's Floor Plan

The air sampling results indicated that out of the 23 locations tested, an amount of air parameters failed. Those that failed included Formaldehyde in 1 locations, Operative Temperature in 3 locations, Relative Humidity in 1 locations, Air Velocity in 8 locations and Total Viable Bacteria Count in 2 locations which are not in accordance with the "Singapore Standard

SS554:2009; Code of Practice for Indoor Air Quality for Air-Conditioned Buildings”.

Description	Specification
Gross Floor Area	11,322 sq. m
Teaching Room Seating Capacity	1,500
No. of Auditorium	2
No. of Function Room	5
No. of Offices Area	8
Quiet Room	1
Others	Gymnasium Pantry

Table 5-9 Building E - Details and Summary

Summary of failed parameters in 23 indoor locations tested

Parameters Tested	Threshold limit	Number of Failed Locations	Failed Locations in %
Carbon Dioxide	(700ppm above Outdoor)	0	0
Carbon Monoxide	<9ppm	0	0
Formaldehyde	<0.1ppm	1	4
TVOC	<3000ppb	0	0
Respirable Suspended Particulates	$<50\mu g/m^3$	0	0
Operative Temperature	24 - 26°C	3	13
Relative Humidity	<70%	1	4
Air Velocity	0.1 – 0.3 m/s	8	35
Total Bacteria Count	< 500 CFU/m^3	2	9
Total Mould Count	< 500 CFU/m^3	0	0

Table 5-10 Building E - Summary of failed parameters in 23 indoor locations

5.5.3. Background Information

Indoor Air Quality testing was conducted at Building E located at the West of Singapore at Student Services Office, Function Rooms, Auditorium Areas. The premises are served by Fan Coil Units. Type of testing consisted of physical, chemical, and bio aerosol sampling. The purpose of the assessment was to provide the Client with information regarding the indoor air quality of the building premises.

A total of 23 indoor locations were tested. The locations and time of sampling at each site were determined by consultation with the site contact, and were based on convenience and availability. The indoor air quality test was conducted without causing any inconvenience to the staff.

5.5.4. Results and Discussion

The air sampling results show that the formaldehyde in 1 location, operative temperature in 3 locations, relative humidity in 1 location, air velocity in 8 locations and total bacteria count in 2 locations are not in accordance with the "Singapore Standard SS554:2009; Code of Practice for Indoor Air Quality for Air-Conditioned Buildings".

5.5.4.1. Operative Temperature (OT)

The operative temperature results at all the 3 locations were found to be lower than the recommended range of between 24-26°C.
Majority of occupants perceive indoor air quality problems to be associated with comfort problems, such as temperature, relative humidity, and air flow when these are found to be too low or high in the indoor environment. Generally, in a well maintained air tight building, it would be reasonable to keep the operative temperature between 24°C–26°C. However, thermal comfort is often subjected to individual's preference, so it is suggested to maintain the operative temperature where a maximum number of the occupants could be expected to feel the indoor temperature acceptable. Temperatures that are maintained too low within artificial environments have been linked in some cases to be one of the causes in lowering immunity levels in some individuals. Low body temperatures sustained over long periods of time is known to be a contributing factor to the development and spreading of flu and cold in closed environments, due to the affect temperature has on human immunity levels.

5.5.4.2. Air Velocity (AV)

The air velocity results in 8 locations were not within recommended range of 0.10-0.30m/s. Air velocity might not have direct influence over occupant's perception in indoor environment as compared to temperature and humidity; but it is synergistically related to the thermal comfort and the overall performance of the ventilation system. Either very high or low air movement will affect the comfort level of different individuals.

5.5.4.3. Relative Humidity (RH)

The relative humidity at Function Room 1 (Location 8) was found to have exceeded the recommended SS554 threshold limits of 70%.

RH is among the most common of indoor air environmental factors that affect occupant discomfort. RH levels exceeding 70% could encourage the growth of mould and several other species of microorganism indoors. High level of moisture indicates that the conditions are optimal for mould growth. The high humidity causes the surface dampness and thus provides a suitable substrate (food source) on which the mould could grow which enables colonization. Singapore Standard SS554-2009 is intended to provide acceptable thermal comfort for the occupants in the air conditioned building and to maintain conditions for preventing mould growth. There is no documented relative humidity value as a threshold that indicates the imminent growth of mould on building materials and or surfaces. However, relative humidity levels directly correspond to dew point temperatures. Increasing relative humidity values and lower temperature might elevate the likelihood of surface condensation and subsequent potential mould growth. Some building materials such as porous ceiling boards, concrete walls, and leather materials are prone to mould growth.

5.5.4.4. Formaldehyde

Elevated level of formaldehyde measured at Location 12, is most likely from the glues and varnish used during the renovation works being carried out around this location.
When formaldehyde is present in the air at levels exceeding 0.10ppm, some individuals might experience health effects such as watery eyes; burning sensations of the eyes, nose, and throat; coughing; wheezing; nausea; and skin irritation. The U.S. Environmental Protection Agency (EPA) classified formaldehyde as a human carcinogen under conditions of unusually high or prolonged exposure. SS554 recommends

maximum threshold limits for formaldehyde is not above 0.10ppm.

5.5.4.5. Total Bacterial Count

Total bacterial count at 2 indoor locations marginally exceeded the recommended threshold limit of 500CFU/m^3. Human occupants themselves are normal reservoirs of bacteria; increased human activities combined with inadequate ventilation (shortage of outdoor/fresh air) normally give rise to higher bacterial levels.

Bacteria found in indoor air are generally shed by building occupants. The main bacterial species present were all common indoor environmental bacteria. The dominant bacteria, Micrococus sp. found in indoor air are normally human associated; these organisms are an inhabitant of the skin and usually harmless for the majority. Elevated levels of bacteria found in the Auditorium Point 1 (Location 10) and Meeting Room (Location 15) indicates poor air quality. Although, the levels are found to be above the recommended threshold limit, the organisms identified are generally human associated and harmless.

5.5.4.6 Total Fungal Count

Results from the laboratory analysis indicated that total viable mould count at all the locations were within the recommended SS554 threshold limits of 500CFU/m^3.

All the locations tested were found to have low levels, and in a balanced environment of non-dominating species. Results also show that the concentration of mould spores in the indoor air is lower than that found outdoors and the mould types present is very similar to the outdoor mould types retrieved. A normal indoor environment will have some level of mould activity, as long as they are minimal and equally distributed, then the environment could be considered as balanced and in the healthy range for mould spore activity.

5.5.4.7. Subjective assessment

A total of 40 people were surveyed based on their perception, their evaluation of the physical environment and physiological responses for IAQ Assessment. Out of the 40 questionnaire respondent 25 were male and 15 were female. 70% of the respondent confirmed that their classroom / lecture theatre felt stuffy and suffered symptoms of lethargy during the class. The survey coincides with the air quality findings of high carbon dioxide during class and low air velocity in almost various locations throughout the building.

5.5.5. Improvement Recommendations

An indoor environment must contribute to the well-being of the occupants and be a safe environment; the poor indoor air quality found at certain locations could have a significant impact on occupants, especially those who are most vulnerable: pregnant women, the elderly, and those who have chronic illnesses or existing allergies and sensitivities.

5.5.5.1. Operative Temperature (OT)

Majority of the occupant perceived poor indoor air quality to comfort problems, such as temperature, relative humidity, and air flow in the indoor environment being too low or high. Generally, in a well maintained building, it would be reasonable to keep the operative temperature of around 24°C–26°C. However, thermal comfort is often subjected to individual's preference, so it is suggested to maintain the operative temperature where a maximum number of the occupants could be expected to feel the indoor temperature acceptable.

5.5.5.2. Air Velocity (AV)

In buildings with low air velocity dispersal, it could be an indication of some maintenance issues or imbalance of air distribution in the system. The causes of erratic airflows should be investigated and addressed concurrently with the temperature control settings.

5.5.5.3. Relative Humidity

The control of indoor RH levels and moisture migration is critical for human control as well as being a primary means of minimizing the microbial growth. Air conditioning in the facility must maintain the RH of the indoor environment below 65% consistently. RH should be addressed concurrently with the temperature control settings of the ACMV, to rule out equipment malfunction.

5.5.5.4. Formaldehyde

Elevated formaldehyde level at location 12 was due to the renovation works around the area. By increasing the ventilation rate in the affected space the concentration of formaldehyde will decrease.

5.5.5.5. Total Bacteria Count

Bacteria found in indoor air are generally shed by the building occupants. Good housekeeping practices, adequate ventilation and cleaning or replacing air-con filters would help to decrease bacteria build ups in the air and on surfaces.

5.5.5.6. Total Fungal Count

Some locations with water damaged ceiling boards and visible mould, could indicate that a condensation issue exists or a water leak from the plumbing system. All the ceiling boards that are visually mouldy should be replaced/removed from the building.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATION

6.1. Comparison Summary of the 5 Buildings

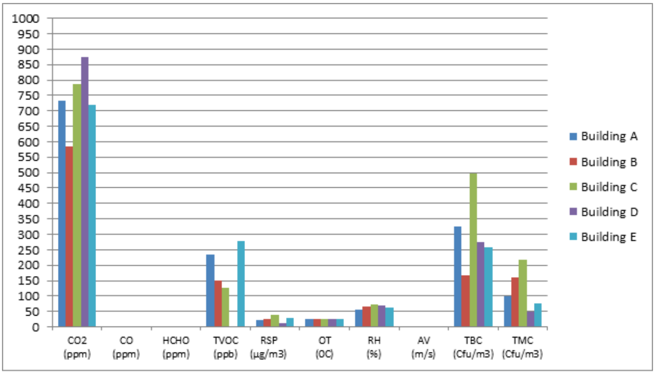

Figure 6-1 Comparison Summary of the 5 Buildings

The primary objective of this study was to determine the concentrations of selected IAQ parameters in the five school buildings. Through literature reviews, the importance of IAQ in relation to health, comfort and productivity in five school buildings has unveiled the importance of providing a satisfactory indoor environment to the occupants. This significance is further emphasized in the IAQ audit that was conducted in each of the five buildings from A to E. From the results and discussion, Carbon dioxide, Operative temperature, Relative Humidity, air velocity and bacteria counts were found to exceed the threshold level. Moreover, the correlation between the occupant density and contaminants concentration was demonstrated by the higher contaminants concentration during high occupancy when the lecture was in progress than in non-peak periods when the lecture theatres where unoccupied. Subsequently, methods were suggested to improve the overall IAQ. The solutions include source control, filtration, ventilation, maintenance, housekeeping and indoor plants. The recommendations show that in order to achieve excellent IAQ, good ACMV system design together with the roles of occupants and building management representatives must be ensured. Apart from particulate matter, I conclude my findings by confirming the important influence of surrounding human activities on indoor concentrations of pollutants in selected five school buildings in Singapore.

6.2. Limitation

The following limitations can be considered by future researchers:

1. The human resource and time constraints for the collection of quantitative data allow in each building based on the spot measurement compared to 8 hours time weighted average.

2. The lack of quantitative data from the IAQ audit which would enable to demonstrate the possible source of the SBS symptoms, but not with the extensive quantitative and qualitative data that characterises larger and more established research projects.

3. The evaluation of the visual and aural environment mentioned was based on subjective assessment. A more comprehensive understanding of the related SBS symptoms experienced by the occupants resulting from these parameters can be better obtained with objective measurements using instrumentations.

6.3. Enhanced Recommendations

The potential problems of exposure to low levels of multiple air pollutants are much less well understood and more difficult to tackle. This is due to the shortage of reliable data on the effects on human health; difficulties in accurately measuring air pollutants at low levels; potential interactions between pollutants; and wide variations in the degree to which building occupants are susceptible to air pollutants. There are also many external factors which might obscure the relationship between indoor air quality and its impact on the building occupants.

6.4. Decontamination and Anti-Microbial Protocol

Decontamination of the affected space is recommended when IAQ test results show that air pollution contaminants are above the recommended threshold levels. Decontamination protocol is recommended when mould and bacteria could be actually seen or smelled or when there is high level of dominant microorganisms concentration identified in speciation.

Specialist chemical based biocides or eco-friendly, 100% natural biocides are recommended in decontamination treatments. By working with a professional in this area will increases chances of successful decontamination and cleaning treatments needed for positive re- test and bringing IAQ back within the healthy range.

6.5. Identification of Microflora Species (Speciation)

Speciation is strongly recommended when the bacteria or fungi counts exceed the threshold limit of 500CFU/m^3. Our laboratories have been using advanced technological methods to provide the detailed identification of the source(s) of multiple microbial eruptions. This method allows a more precise analysis of diverse types airborne and surface dwelling pathogens. The benefits of enhanced identification methods used in laboratories greatly improve the specific corrective actions responses required to remediate indoor air quality levels in conditioned buildings. Results could provide the detailed information needed to control and remove high levels of potentially hazardous types of resident microorganisms and their associated health effects.

Speciation is also commonly used as an indicator for industrial hygiene schedules or performance contract reviews, and ACMV maintenance performance checks. Speciation provides valuable data on potential epidemics, and for preventive maintenance, standard checking and care and assurance, due diligence and for other building studies or diagnostics/fault finding for a host of multifactorial building related problems.

6.6. IAQ Retesting

Retesting is recommended when a sample location fails to meet the recommended threshold levels under SS554 guidelines. Retesting is required when the indoor areas have been remediated and the user wishes to determine the effectiveness of remediation and corrective actions taken.

6.7. Indoor Air Quality Management Planning (IAQMP)

To help the users maintain good indoor air quality over a continuous basis they should developed the Indoor Air Quality Management Plan (IAQMP). The system continuously monitors and maintains the indoor environment to ensure that excellent IAQ performance is maintained over the duration of the contract. The IAQMP has been designed to work with the OHSAS 18001:2007 and the ISO 14001 environmental management system (EMS) and enhances and compliments these standards. The IAQMP assesses the risks associated with poor IAQ and could determine the correct environmental control strategies to allow compliance with both the SS554 and other international environmental management standards.

6.8. Annual Indoor Air Quality Auditing

It is recommended that an annual Indoor Air Quality audit is conducted once per year to record the identified environmental parameters for conformance to SS554:2009 Code of practice for Air Conditioned Buildings.

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