Methodology for IEQ Standard Implementation in Different Types of Buildings

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Abstract

In recent times Indoor Environmental Quality (IEQ) and its impact on occupant satisfaction are a significant area of research. The present study focuses on IEQ investigations at selected locations viz commercial, office, residential and institutional buildings in Chennai city, India. The monitoring campaign was carried out for three seasons (summer, monsoon and winter) to characterize the IAQ and thermal comfort using air quality monitor, potable gas monitor, multi gas detector, thermal environment meter, indoor air quality meter, noise level meter, lux meter, surface temperature and bio sampler. Results showed that only office buildings were within the compliance zone for operative temperature during summer and winter seasons. The RH was found to be the highest in monsoon season (66%) with 50% of the sampling locations lying outside the compliance zone. The level of non-compliance was 33% and 36% in winter and summer, respectively. The floor surface temperature also (36% of locations) fell out of the compliance zone (17-31°C), being the highest in residential buildings located in the city centre. It was seen that the illuminance and circadian light design in office buildings were higher than other locations and acoustic discomfort was observed in all the locations. Higher CO_2 concentration was observed in the air conditioned buildings and offices and the lowest in residential buildings, where the number of occupants is less. The measured $PM_{2.5}$, PM_{10}, SO_2, NO_2 and CO concentrations at all the locations were within the threshold range. The presence of thick vegetation cover inside IITM campus resulted in increased indoor TMC. The overall IEQ satisfaction expressed by the occupants in different types of buildings varied between 81-88%. The results show that majority of the IEQ parameters in all locations have been found to be meeting the minimum threshold limit.

Keywords

Indoor Air Quality, IEQ Standard, Human Comfort, Instrumentation, Monitoring

1. Introduction

Indoor Environmental Quality is the quality of a building's environment in relation to health and well being. Healthy and comfortable indoor environment is the primary requirement of the occupants as they spend most of their time indoors. IEQ is affected by building location, orientation, climatic conditions, occupant behaviour and building systems and typology. There has been a clear association between IEQ and the sense of well-being, health and productivity. Indoor air quality (IAQ) has gained much interest in recent years as it can result in a variety of adverse health outcomes ranging from headache and allergies to respiratory illness and even cancer. Furthermore, temperature and humidity at too high or low level, excessively bright or dim and deficient lighting system and high noise level lead to increase in mental and physical stress level in the human body, which causes health problems such as concentration impairment, memory loss, digestive problems and sleep disorder. Indoor environments are highly complex and building occupants may be exposed to a variety of contaminants from the surroundings.

Indoor environmental conditions that affect human comfort are thermal, visual, acoustic and air quality. Standards define thermal environment as a function of air temperature, mean radiant temperature, relative air velocity and air humidity. Visual comfort is obtained through parameters like luminance, distribution, illuminance and its uniformity, glare, colour of light, colour rendering, flicker rate and amount of day light. The quality of acoustic environment is linked with physical property of sound and physical property of room. It is affected by sound insulation, absorption and reverberation time (Monica et al., 2011). In indoor environment, a number of physical and chemical parameters have been considered to obtain comfort of building occupants. Indoor environment quality standards have been developed to define the acceptable ranges of parameters (Tiberin e.al, 2011).

Many countries and national organizations have specified certain standards and guideline values that coincide with Indoor Air Quality Management. These standards and guidelines are executed with general consensus of limiting exposure to human beings. Air quality guidelines are designed to offer guidance to reduce adverse health impacts of air pollution based on scientific evidence. Guidelines and standards were developed for industrial settings and non industrial settings. International agencies that establish air quality guide lines and standards are National Health and Medical Research Council, Australia (NHMRC), National Occupational Health and Safety Commission, Australia (NOHSC), State Environment Protection Agency, China (SEPA), American society of Heating, Refrigerating and Air Conditioning Engineers, USA (ASHRAE), National Ambient Air Quality Standards, USA (NAAQS), World Health Organization (WHO), Occupational Safety and Health Administration (OSHA), etc. NAAQS, developed by US EPA, are applicable for outdoor and indoor environment. WHO's air quality guidelines are applicable for non occupational environment.

According to ASHRAE (Standard 62-1989), an acceptable IAQ can be defined as the air in which there are no known contaminants at harmful concentrations and the air with which a substantial majority of the people exposed do not express dissatisfaction. IAQ is recognized to cause chronic and acute effects on occupant health. It is directly related to the concentration of pollutants and ventilation rates, which, in turn, cause Sick Building Syndrome (SBS) symptoms. Indoor air pollutants mainly consist of particulate pollutants ($PM_{2.5}$, PM_{10}), gaseous pollutants (CO_2, CO, volatile organic compounds, formaldehyde, SO_2, NO_2, O_3, etc.) and biological pollutants (bacteria, fungi, mould, pollen, animal dander, mites, virus, etc.). Lighting comfort directly affects the occupant's work productivity and efficiency. It is a subjective measure and directly dependent on factors like illumination, risk of glare, luminous spectrum, brightness and luminance (CEN, 2012). A proper visual environment condition causes increment in the productivity and well-being of building occupants (Serghides et al., 2015). Acoustic comfort can be defined as absence of any uncomfortable noise within the indoor environment. Comfortable sound levels and speech privacy are considered as main requirements for occupants' satisfaction in work-places because it directly affects the work productivity and well-being (Jensen et al., 2005).

In the year 2016, ISHRAE released India's first IEQ Standard. In this standard, thermal comfort, indoor air quality, acoustic comfort and lighting comfort are defined as elements of IEQ and they have been further divided into parameters. The threshold values of parameters have been defined as three levels such as Class A (Aspirational), Class B (Acceptable) and Class C (Marginally Acceptable). Class A level is comparable with the worldwide accepted international standard (ISHRAE 2016). The scope of the present study was to understand the implementation of India's IEQ standard in different types of buildings, and analysis of preliminary findings from a pilot study to evaluate implementation methodology. This study also reviews the availability of instruments in the Indian and international markets.

2. Materials and Methods

2.1 Study Area

The present measurements were carried out in Chennai metropolitan area located at 13.067439°N and 80.237617°E along the south-eastern coastline of Indian continent. The region experiences a tropical climate zone. Indian meteorological department has categorized the months of January and February as winter season, March to May as summer season, June to September as south west monsoon and October to December as northeast monsoon. Most part of the investigation was carried out within academic campus, which is a lush green area located in the heart of Chennai city. All the buildings located inside campus were away from road traffic. In order to compare the effect of outdoor traffic on IEQ, a few outside locations adjacent to heavy traffic were also selected. Experimental investigation of IEQ parameters is being carried out at eight buildings (12 locations) located in warm and humid climatic zone (*Table 1*). Measurements were carried out for winter, summer and monsoon seasons. The sampling locations I1 and I2 was at a newly built building and during the summer season, construction work was progressing, which might have an impact on the measurement values.

2.2 Monitoring Campaign

Following the ISHRAE IEQ Standard, measurements were carried out once in a month and thrice a day (10:00, 14:00 and 16:30 hrs) to assess all climate changes during different seasons (summer, monsoon, and winter). In thermal comfort measurements, the mean radiant temperature, room air temperature, air velocity and relative humidity were recorded at 0.6 m for seating position. IAQ parameters such as concentrations of CO_2, CO, Particulate matter ($PM_{2.5}$, PM_{10}), total volatile organic compounds,

Table: 1 Description of the selected buildings for IEQ measurements in Chennai

Building Type	Building Code	Location
Commercial building	C1: Computational Room C2: Departmental Stores	IITM campus IITM campus
Institutional building	I1& I2: Research Scholar Room I3: Laboratory	IITM campus IITM campus
Office building	O1: Office in Background Site O2: Research Park O3 & O4: Conference Hall	IITM campus Taramani IITM campus
Residential building	R1: Residential Building 1 R2: Residential Building 2 R3: Residential Building 3	IITM campus Thiruvanmiyur Anna Nagar

formaldehyde, SO_2, NO_2 and O_3 were measured at different occupant locations and also at possible fresh air inlet of the rooms. Lighting comfort parameters like illuminance, circadian lighting design, uniformity of illuminance and ratio of illuminance of task area to immediately adjacent surroundings were monitored at different potential occupant locations. Acoustic comfort in terms of overall sound level was also observed at different locations. Subjective method was carried out to record the responses from occupants using a 7 point subjective scale for the given environment as specified in ISHRAE IEQ standard.

2.3 Instrumentation

Indoor and outdoor SPM concentrations were measured using AQM (Y09-PM, applied Technosystem) with a flow rate of 2.83 litre/min. Handy samplers were used for measuring particulates and gaseous pollutants in sampling sites. Thermal comfort meter (Delta Ohm Srl, HD 32.3) was used to measure indoor and outdoor temperature, relative humidity and velocity of air. For measuring acoustic comfort, noise level meter (SLM 100, Envirotech) was used. For measuring the light comfort, lux meter (LX101, work zone) was used. Surface temperature was measured with the help of surface temperature instrument (905-T2, Testo). For finding TMC, the monitoring was done with the help of bio sampler (MAS100). A TSI IAQ- CALC model was used to measure the indoor, outdoor temperature, relative humidity, CO, CO_2 concentrations. The instruments were placed in the in the workplace with the inlet approximately 0.6m for seating position. The measurements were carried out once in a month, thrice a day to assess all climatic changes during different seasons.

2.4 Quality Assurance and Quality Control

The project plan describes all work and quality control activities associated with the project. Accurate standard operating procedures were adopted for monitoring. All laboratory deliverables received with an independent review that includes quality assurance and technical component. Fixing the sampling area, choice of adequate specimen, materials, statistical sampling design and standard operating procedures were adopted for monitoring. All relevant attributes of the data, weather conditions, population of sampling and results were documented. It was ensured that the data are in compliance with the procedures, completed and technically good. Precautions were taken at every step for monitoring and collection of sample to prevent contamination.

3. Results and Discussions

3.1 Thermal Comfort

Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment. The six primary factors that must be addressed for thermal comfort are metabolic rate, clothing insulation, air temperature, radiant temperature, air speed and humidity (ASHRAE 2013).

3.1.1 Operative Temperature and Air Velocity

Comfort zone is a range of operative temperatures that provide acceptable thermal environmental conditions. Operative temperature represents the combined effects of room air temperature, mean radiant temperature and air velocity recorded for the specified potential occupant location. It measures the effects of heat transfer by radiation and convection in the actual non-uniform indoor climate. It was seen that operative temperature in air conditioned buildings where there is occupant control over the room temperature were within the comfort range, and some locations with higher air velocity were found to have lower operative temperature (*Figure 1*). As per ISHRAE standard, in summer season C1, O1, O3 and O4 are within the compliance zone. There is no limit for monsoon season mentioned in the standard. The average air velocity in Chennai for summer, monsoon and winter season is 0.25m/s, 0.30m/s and 0.04m/s, respectively, being the highest in monsoon and lowest in winter season (*Figure 2*).

3.1.2 Relative Humidity

The average relative humidity in Chennai in summer, monsoon and winter season is 49%, 66% and 57%, respectively. The recorded RH values were found to be the highest in monsoon season with 50% of the sampling locations lying outside the compliance zone. The level of non-compliance was 33% in winter season and 36% in summer respectively (*Figure 3*).

3.1.3 Floor Surface Temperature

An occupant may feel uncomfortable due to contact with floor surfaces that are too warm or too cold. The temperature of the floor rather than the material of

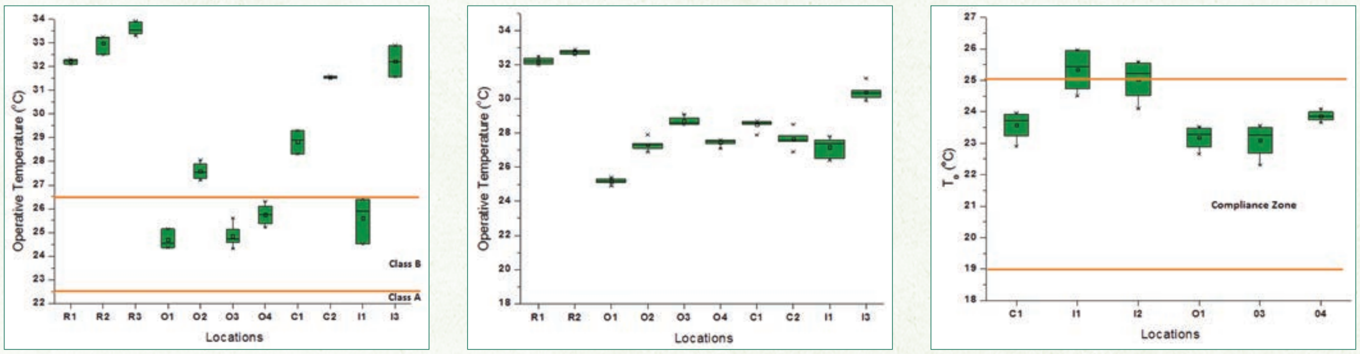

Figure 1: Location-wise variations in operative temperature for summer, monsoon and winter

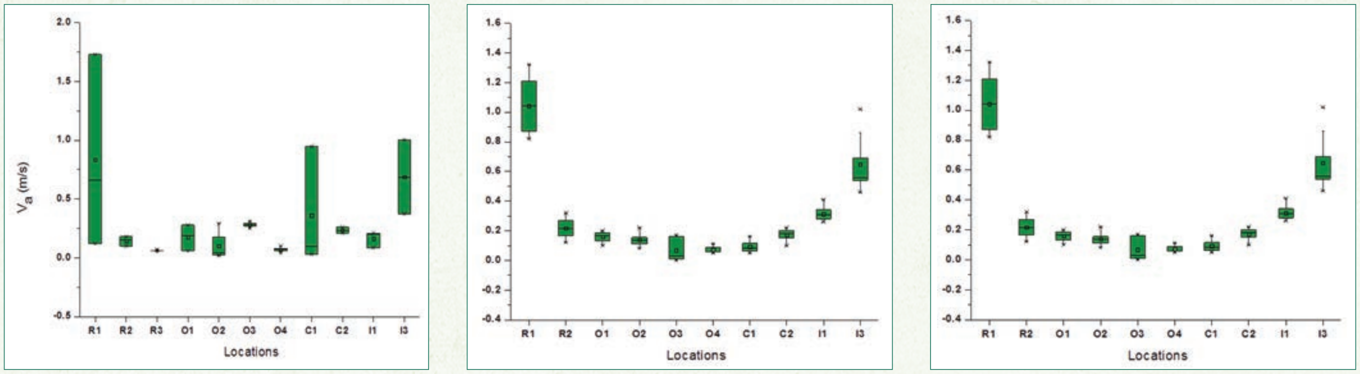

Figure 2: Location-wise variations in air velocity for summer, monsoon and winter

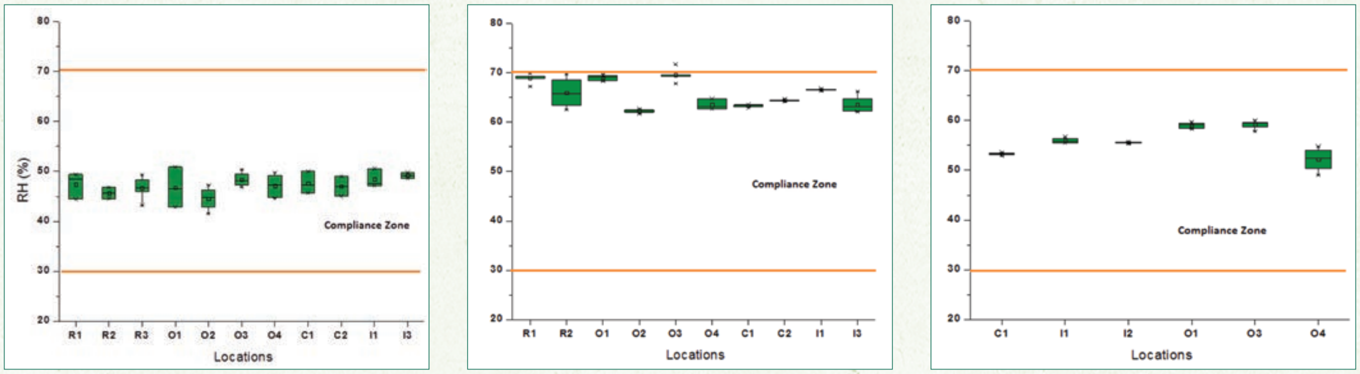

Figure 3: Location wise variations in relative humidity for summer, monsoon and winter

the floor covering is the most important factor for foot thermal comfort for people wearing shoes (ASHRAE 2013). Local thermal discomfort is a function of vertical temperature gradient, uniformity of radiant temperature and local convective heat transfer via hot and cold floor surface. Following ISHRAE IEQ standard, the floor surface temperature for the occupants having feet contact with floor shall be 17-31ºC within the occupant zone. In the present study, the floor surface temperature in 36% of locations fell out of the compliance zone due to higher ambient temperatures reaching 37°C during the day. Floor surface temperature was found to be the highest in residential buildings located in the city centre with less vegetation cover and probably higher outdoor temperature (*Figure 4*). The mean floor surface temperature for summer, monsoon and winter was 29.3°C, 27.4°C and 24.5°C respectively.

3.2 Indoor Air Quality

3.2.1 CO_2 Concentration

Two major elements influencing CO_2 concentrations are observed to be fresh air intake and occupancy. High concentration of CO_2 is recorded in classrooms (high occupancy) and in rooms conditioned by split air conditioners due to less availability of fresh air. However, lower concentrations are recorded in naturally ventilated rooms and evaporative cooler rooms, where fresh air intake is high. The increasing ventilation rates for fresh air may mitigate indoor air pollution (Cheng et al., 2017). It is observed that in summer season, R1, R2, R3, C2 and I3 are in class A, O1 in class B, and O2, O3 and O4 in class C. In winter season, R1, R2, O1 and C2 are

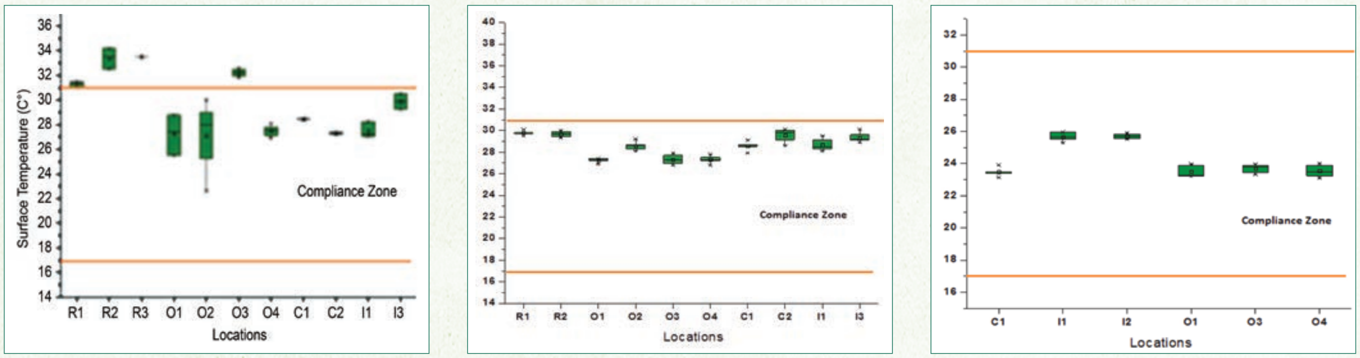

Figure 4: Location-wise variations in floor surface temperature for summer, monsoon and winter

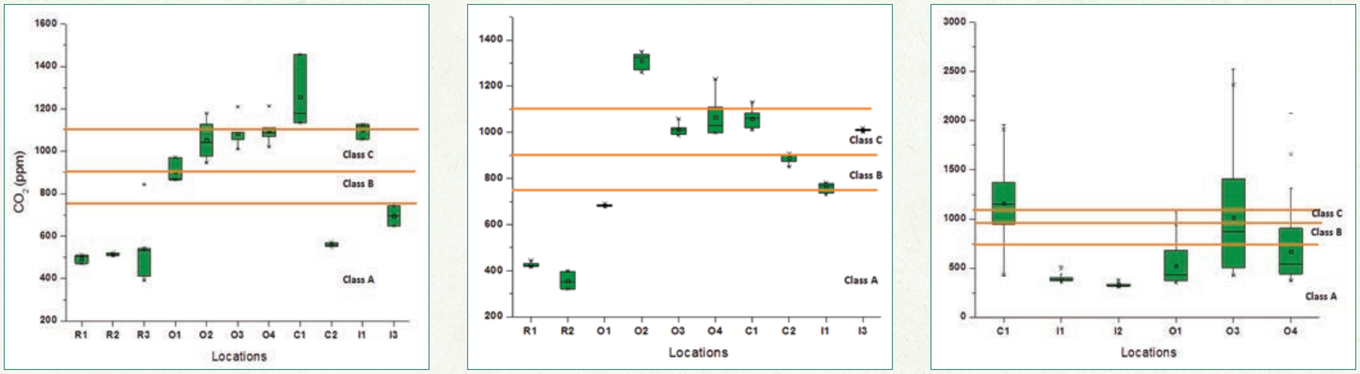

Figure 5: Location-wise variations in CO_2 for summer, monsoon and winter

in class A, C2 and I1 in class B, and O3, O4 and C1 in class C. In monsoon season, I1, I2, O1 and O4 are in class A, and O3 in class B (*Figure 5*).

3.2.2 RSPM Concentration

In the present study, $PM_{2.5}$ and PM_{10} concentrations were found to be well within the acceptable range for all air conditioned microenvironment. $PM_{2.5}$ concentrations in residential buildings were found to be above acceptable limit, whereas PM_{10} concentration was found to be within the acceptable limits. The average $PM_{2.5}$ concentrations in Chennai for summer, monsoon and winter season are 17, 12 and 27 μg/m^3, respectively. The average PM_{10} concentrations in Chennai for summer, monsoon and winter season are 32, 25 and 38 μg/m^3, respectively (*Figure 6*).

3.2.3 TVOC and CH_2O Concentrations

The TVOC and CH_2O concentrations in all locations were found to be within the compliance zone. The mean CH_2O concentration at residences R1 and R2 reached 50μg/m^3 during cooking activities. The CH_2O concentration in newly built locations was found to be high in all the seasons (*Figure 7* and *8*).

3.2.4 SO_2 and NO_2 Concentrations

SO_2 and NO_2 values in summer and monsoon seasons were within the compliance zone. It was seen that the SO_2 and NO_2 values in buildings located near road traffic were higher than buildings located inside the background site. The maximum mean SO_2 concentration occurred at residential building and lowest concentration occurred at office building. SO_2 and NO_2 values in summer were higher than in monsoon (*Figure 9*).

3.2.5 CO and O_3 Concentrations

CO concentration in buildings located near busy traffic roads are

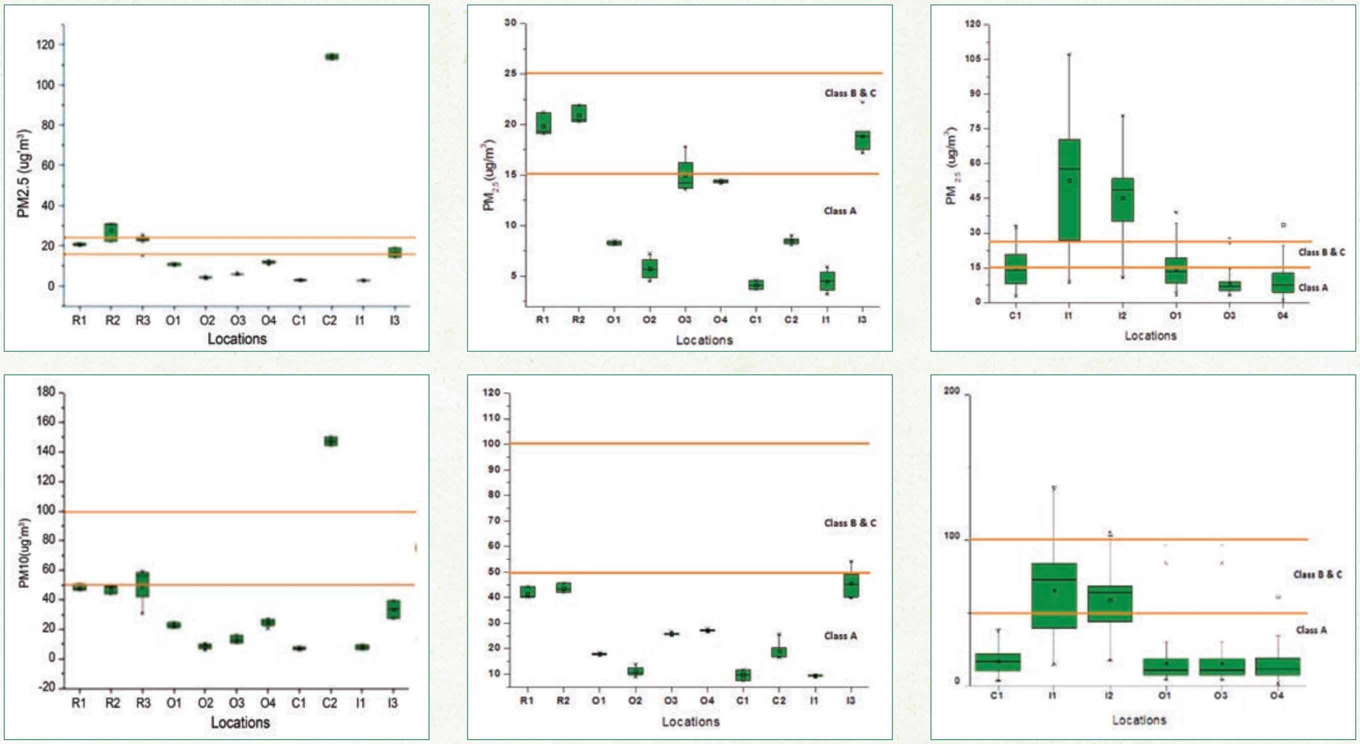

Figure 6: Location-wise variations in $PM_{2.5}$ and PM_{10} concentration for summer, monsoon and winter

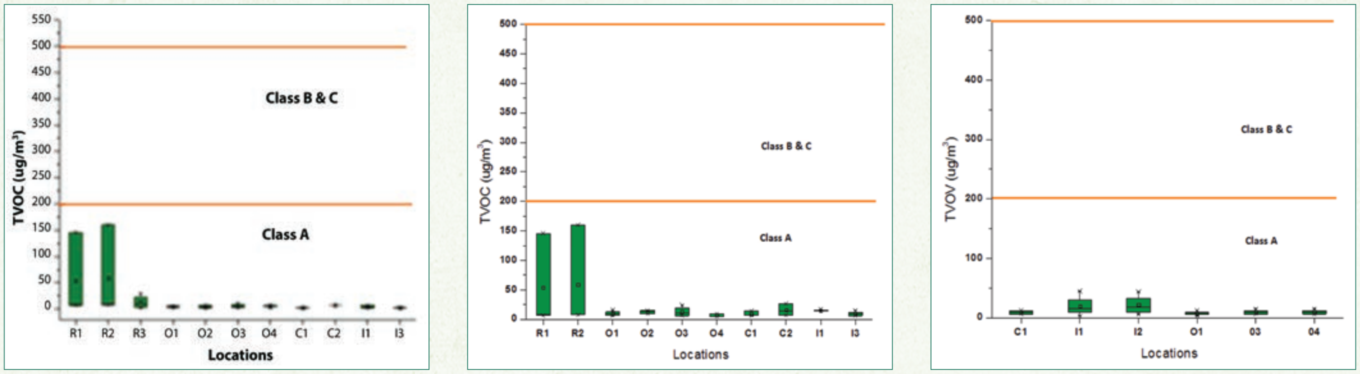

Figure 7: Location-wise variations in TVOC concentration for summer, monsoon and winter

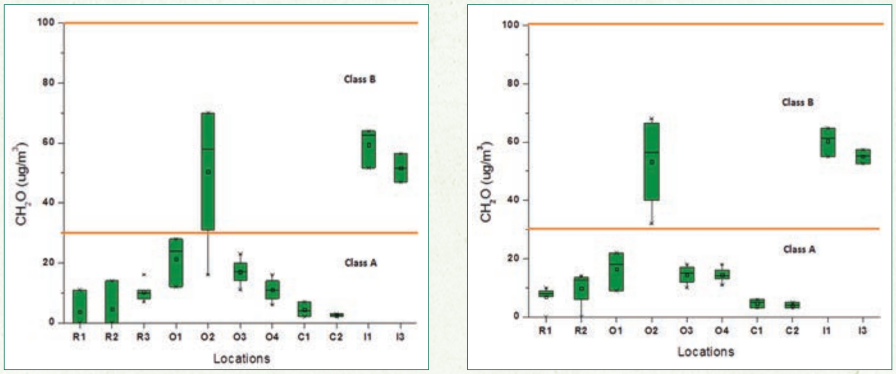

Figure 8: Location-wise variations in CH_2O concentration for summer and monsoon

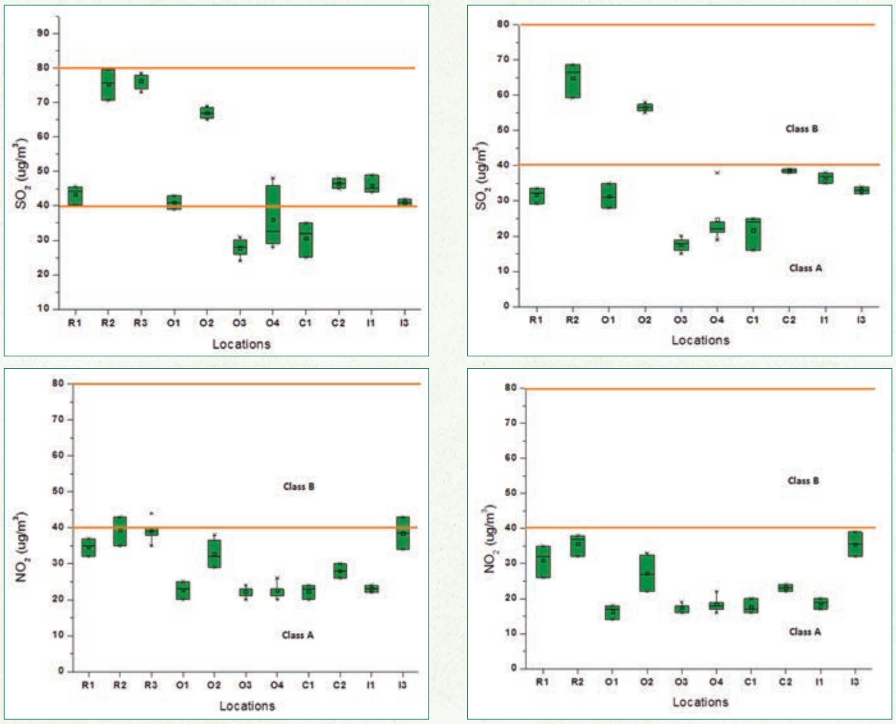

Figure 9: Location-wise variations in SO_2 and NO_2 concentrations for summer and monsoon

higher than those located inside the background site. The concentration of CO at all the locations in class A is as per ISHRAE standard. It was seen that CO concentration in residential buildings is high compared to other buildings due to cooking activities, and in institutional buildings there is presence of CO due to electrical work. It was observed that the O_3 concentration was the highest in summer and lowest in winter season, which may be due to the high solar light intensity obtained in summer season (*Figure 10*).

3.2.6 Total Microbial Count

Higher values of TMC were observed in winter season and lowest in summer season irrespective of the sampling location. TMC depends on the number of occupants and the type of ventilation being used. The air conditioned office building with higher occupancy showed the highest TMC. The presence of thick vegetation cover inside IITM campus causes increased indoor TMC (*Figure 11*).

3.2.7 Variation in IAQ Parameters between Indoor and Air Intake

According to ISHRAE IEQ standard, the protocol for some of IAQ parameter measurement locations is: "shall be measured at possible fresh air intake in the room". In the present study, the team measured CO_2, CO, $PM_{2.5}$, PM_{10}, SO_2, NO_2 and O_3 concentrations at the possible fresh air intake in the room as well. The outdoor CO concentration was about 390±20 ppm throughout the monitoring period. The indoor CO_2 concentration in offices and institutional buildings was higher than the corresponding outdoor concentration, mainly due to the higher occupancy and dependence on air conditioning system for ventilation. Outdoor PM concentration was higher than the indoor levels in most of the cases. This signifies the impact of outdoor $PM_{2.5}$ concentration on the indoor

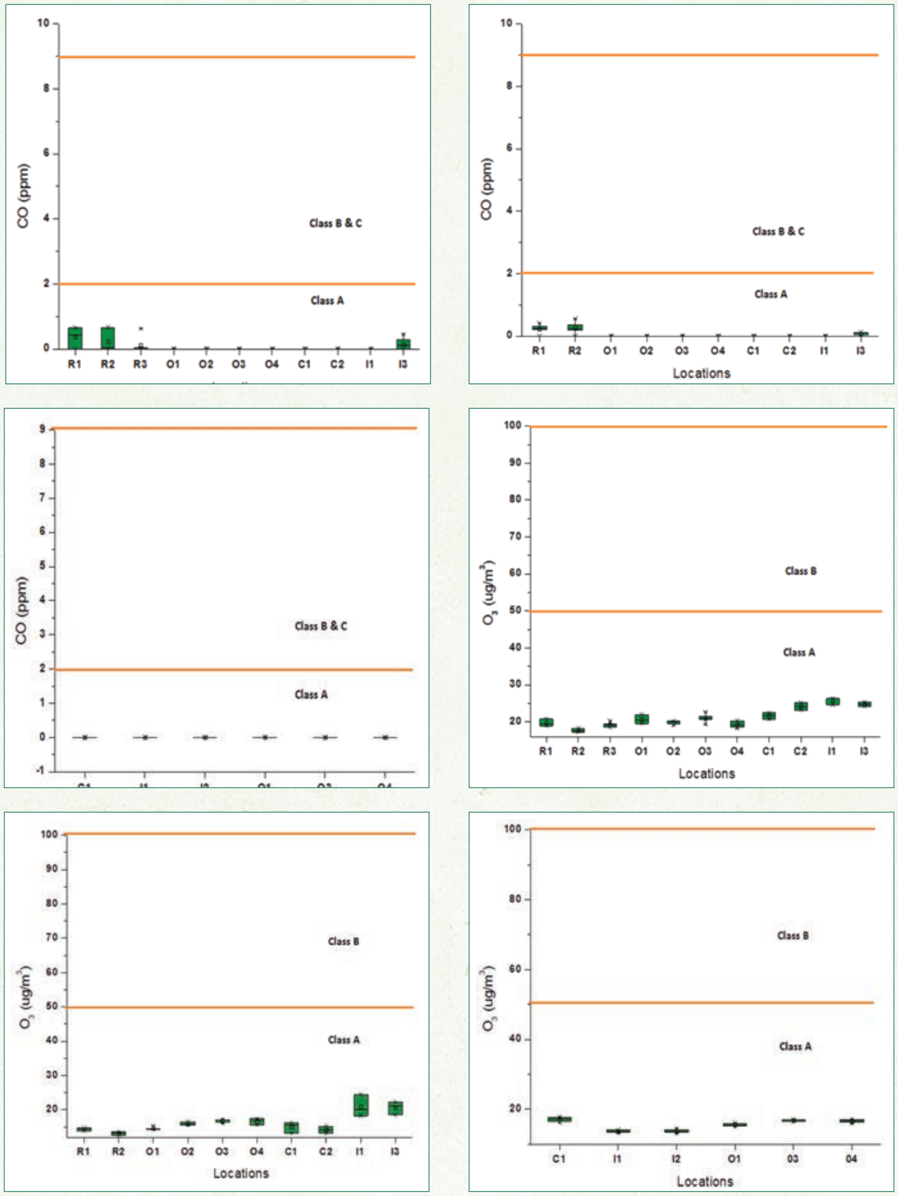

Figure 10: Location-wise variations in CO and O_3 concentrations for summer, monsoon and winter

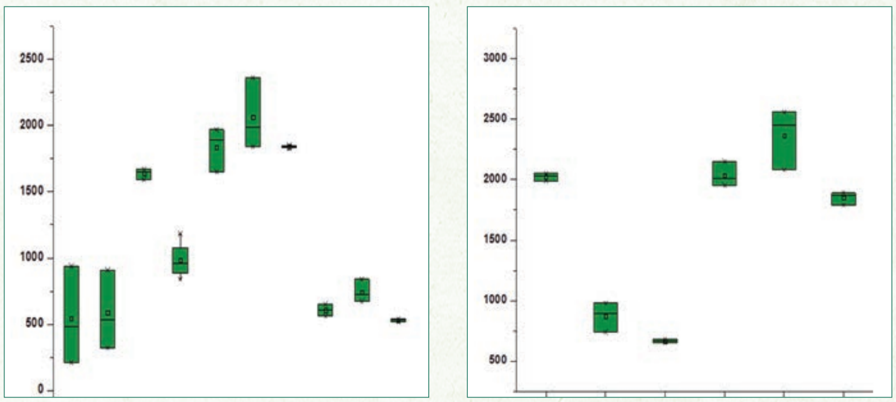

Figure 11: Location-wise variation in TBC for summer, monsoon and winter season

levels. PM concentration in I1 and I2 was high due to the construction activities that happened during the monitoring period. The outdoor SO_2 and NO_2 concentrations were higher than the indoor levels in all the locations. The high outdoor SO_2 and NO_2 concentration was due to higher vehicular traffic in the background site. In monitoring location I3, soldering activity was found to influence the indoor NO_2 concentration. It was seen that the outdoor CO and O_3 concentration was higher than the indoor levels at all the locations. CO is mainly produced from incomplete combustion activities, mainly cooking in residences and soldering activities in I3. O_3 levels in outdoor locations are high due to vegetated background and direct sunlight received by these areas. The outdoor total microbial concentration in background site was higher due to the thick vegetation cover present in this area. Indoor total microbial count was higher than outdoor levels in offices and institutional buildings with high occupancy. Location wise variations are presented in *Figure 12* to *19*.

3.3 Lighting Comfort

3.3.1 Illuminance and Circadian Lighting Design

Lighting is another contributing factor to IEQ, which influences many bodily functions like the nervous system, circadian rhythms, pituitary gland, endocrine system, pineal gland and alertness due to its different wavelengths. Lighting comfort is the function of various parameters such as illuminance, circadian lighting design, uniformity of illuminance within the task area and a ratio of illuminance of task area to immediately adjacent surroundings at different occupant locations. Location wise variation in illuminance and circadian light design for various seasons was measured in Chennai. It was seen that the illuminance and circadian light design was higher in C2 where natural day light was employed. The values of illuminance and circadian light design were the highest in summer and lowest in monsoon due to the overcast cloud cover during the later season (*Figure 20*).

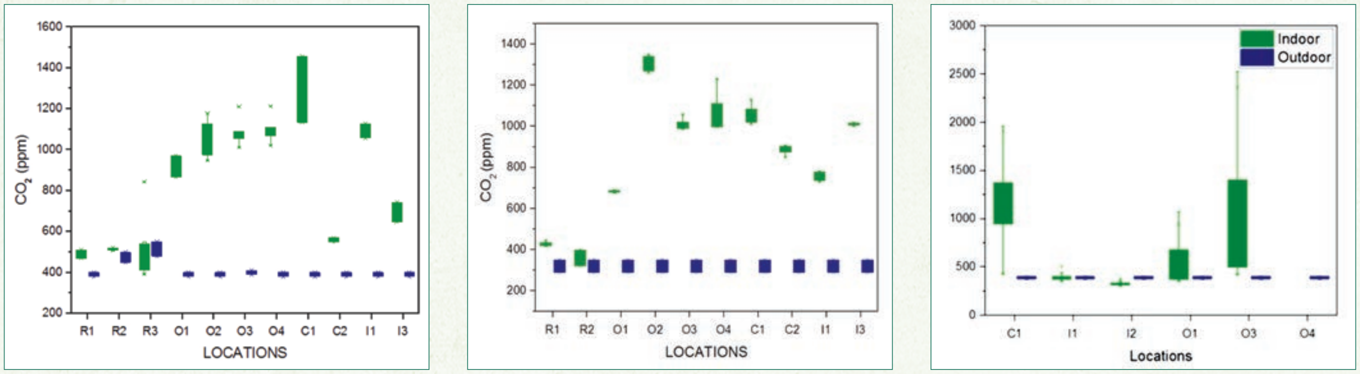

Figure 12: Location-wise variations in indoor and outdoor CO_2 concentration for summer, monsoon and winter

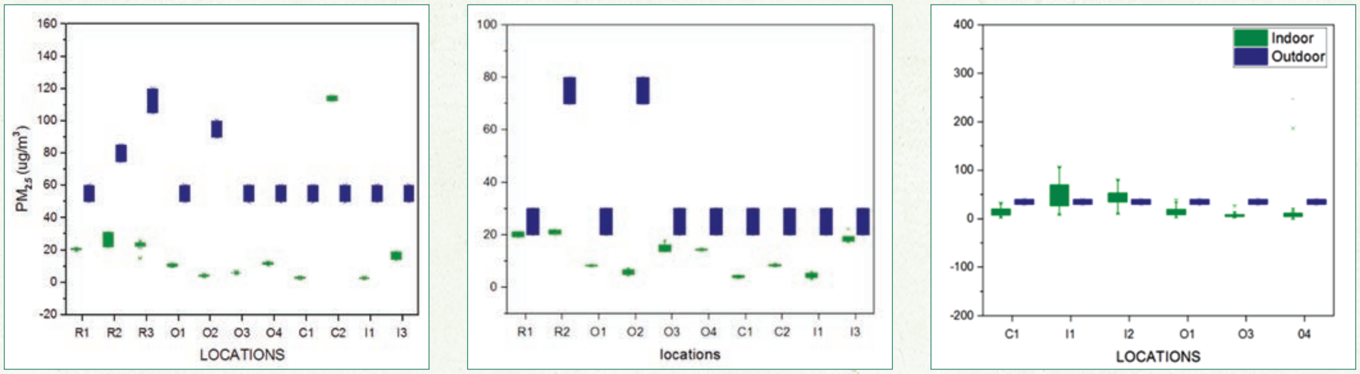

Figure 13: Location-wise variations in indoor and outdoor $PM_{2.5}$ concentration for summer, monsoon and winter

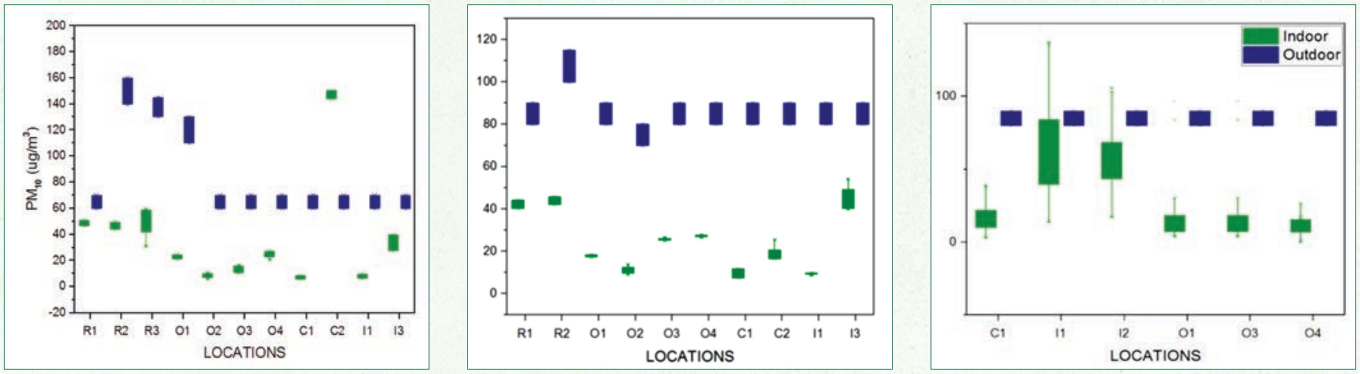

Figure 14: Location-wise variations in indoor and outdoor PM_{10} concentration for summer, monsoon and winter

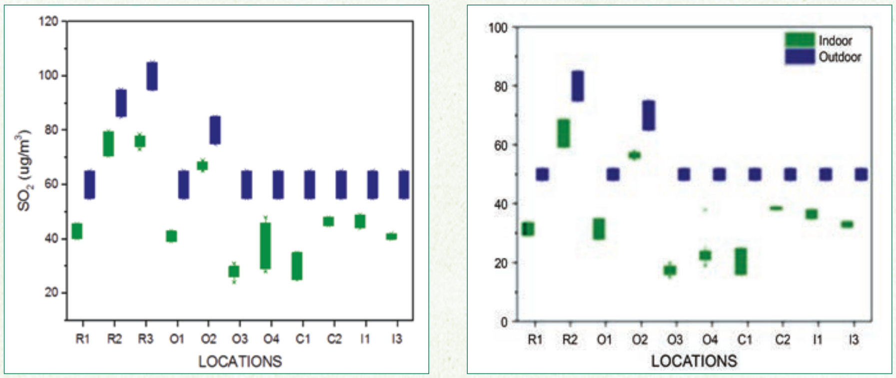

Figure 15: Location-wise variations in indoor and outdoor SO_2 concentration for summer and monsoon

3.3.2 Uniformity and Ratio of Task Area to Adjacent Surroundings

The distribution of light across the task area should be uniform, to attain lighting comfort. The ratio of illuminance available in the task area to the illuminance available in immediate adjacent surrounding area should be within the threshold limits, as specified by ISHRAE IEQ standard. Location-wise variation in uniformity of illuminance and ratio of illuminance of task area

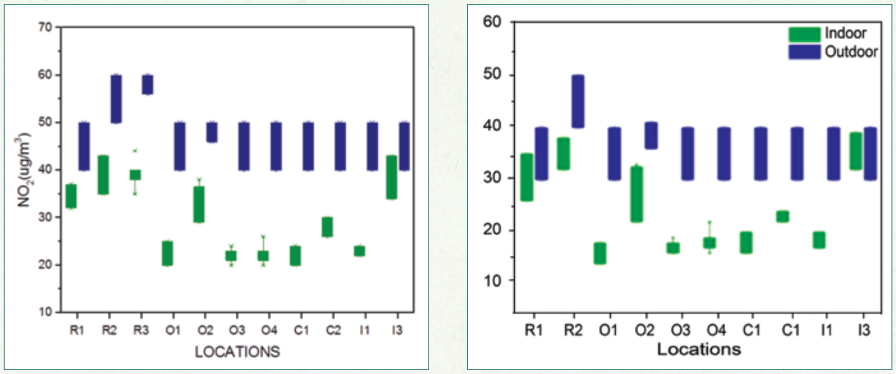

Figure 16: Location-wise variations in indoor and outdoor NO_2 concentration for summer, monsoon and winter

to immediately adjacent surroundings were always within the acceptable range (*Figure 21* and *22*).

3.4 Acoustic Comfort

3.4.1 Overall Sound Level

Many public sites are subject to severe noise impact from various sources. Acoustic discomfort occurs due to unwanted sound which causes stress, hearing loss and mental discomfort, alters sleep patterns and affects heart rate (Azimi et al., 2017). According to ISHRAE IEQ standard, the measurements

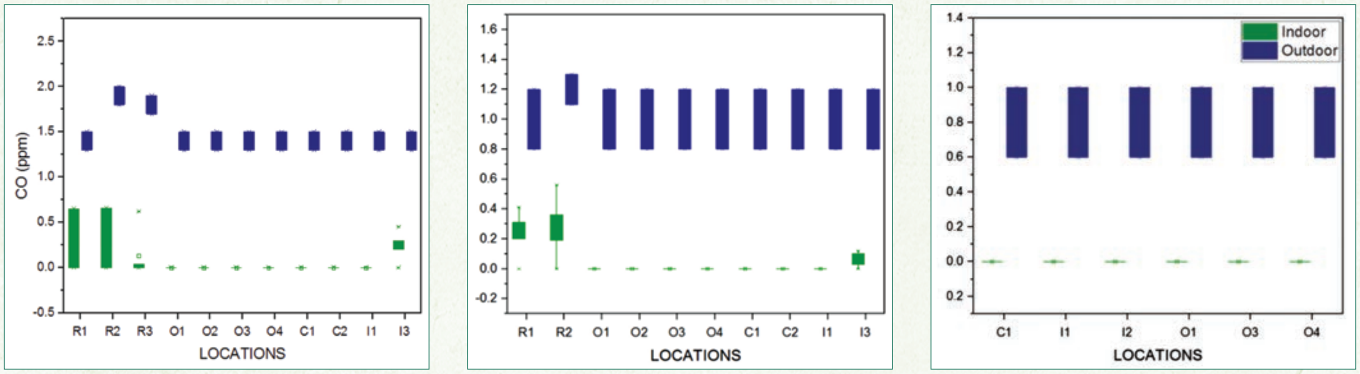

Figure 17: Location-wise variations in indoor and outdoor CO concentration for summer, monsoon and winter

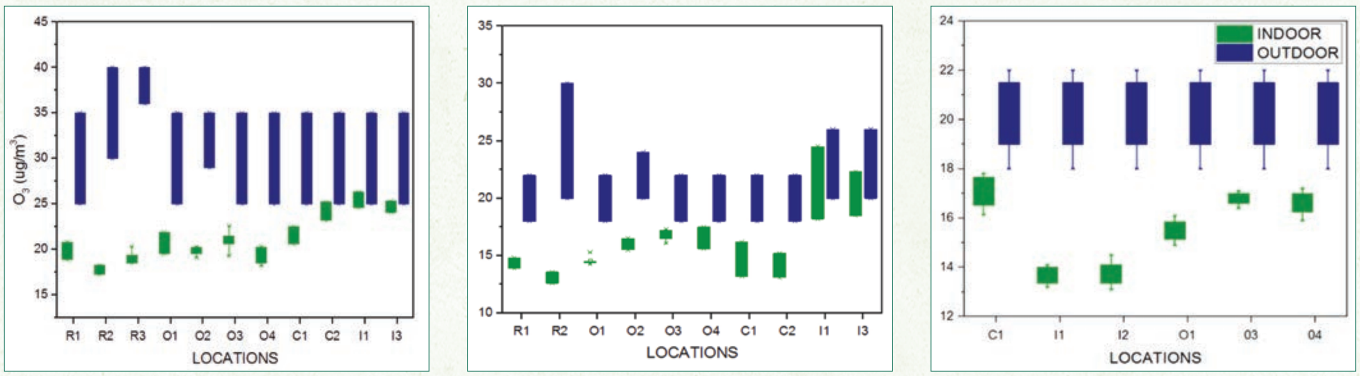

Figure 18: Location-wise variations in indoor and outdoor O_3 concentration for summer, monsoon and winter

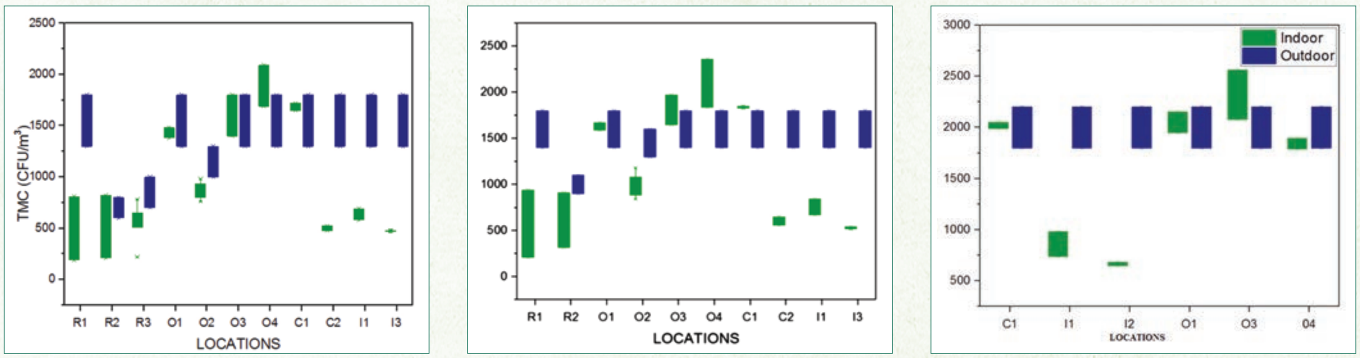

Figure 19: Location-wise variations in indoor and outdoor total microbial count concentration for summer, monsoon and winter

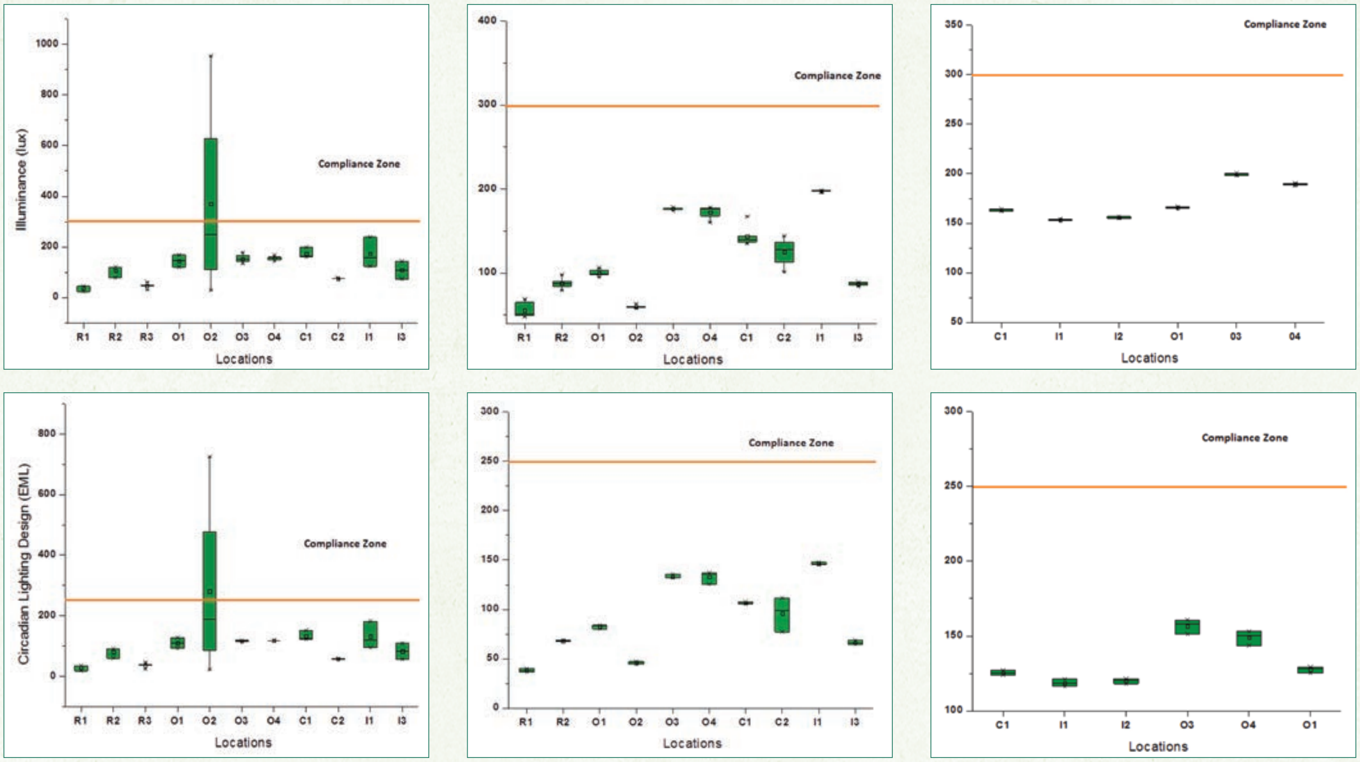

Figure 20: Location-wise variations in illuminance and circadian light design for summer, monsoon and winter

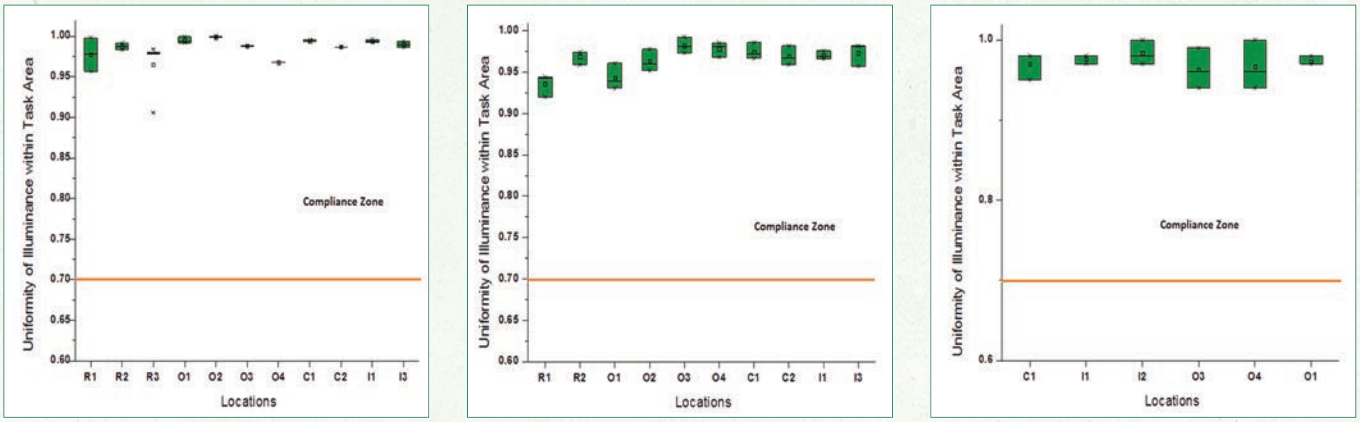

Figure 21: Location-wise variation in uniformity of illuminance for summer, monsoon and winter

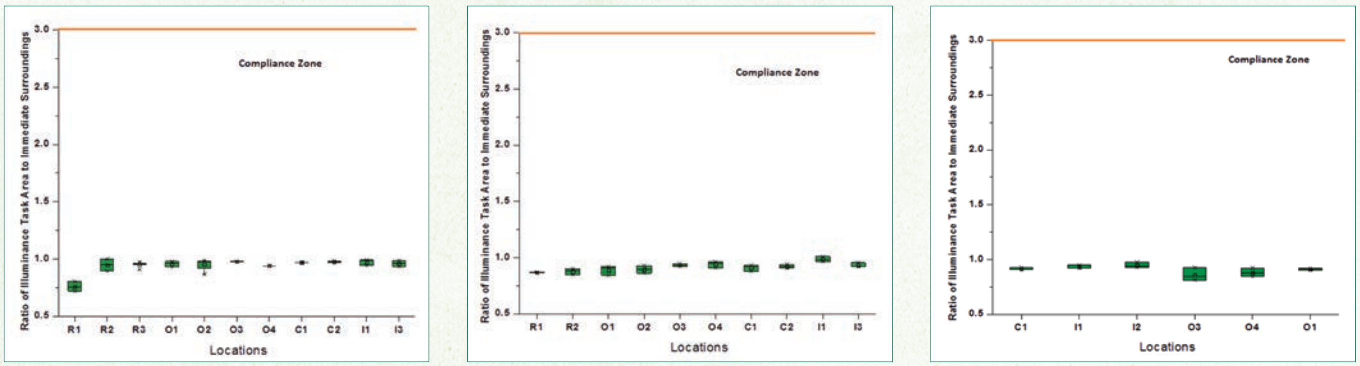

Figure 22: Location-wise variation in ratio of illuminance of task area to immediate surroundings for summer, monsoon and winter

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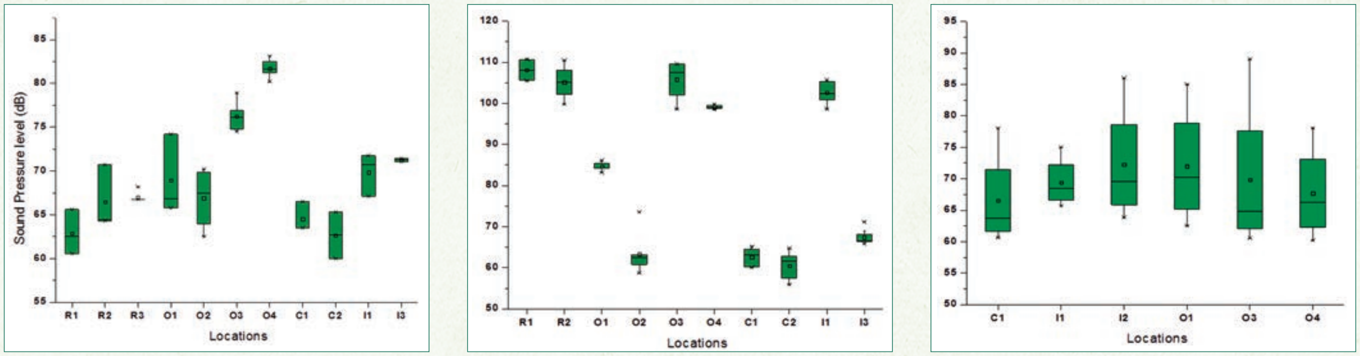

Figure 23: Location-wise variations in sound pressure level for summer, monsoon and winter

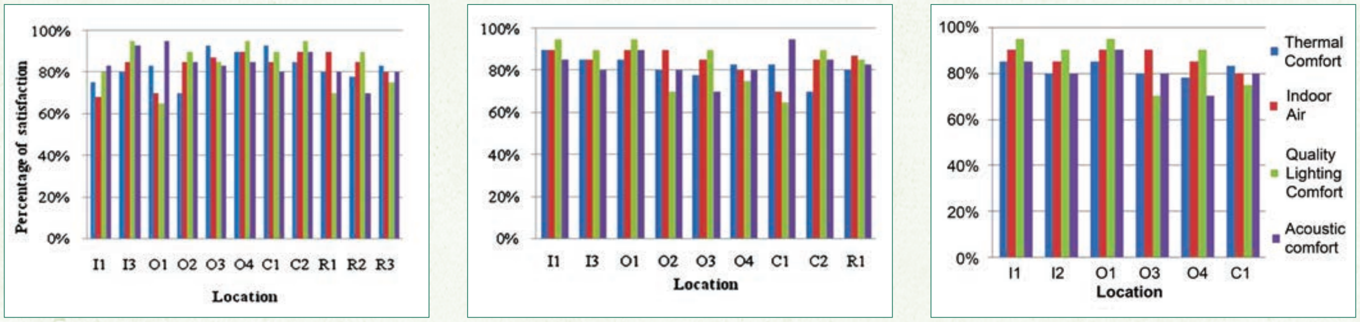

Figure 24: Location-wise occupant satisfaction for summer, monsoon and winter

related to acoustic comfort can be performed in terms of noise isolation class, reverberation time and noise criteria. Location-wise variations in sound pressure levels for different seasons were measured (*Figure 23*). The major sources are humans, outdoor traffic, sound pressure levels in offices and air flow sounds in ducts and evaporative cooling systems.

3.5 Occupant Satisfaction Survey

Subjective method is used to record responses from occupants using a 7-point subjective scale for the given environment as specified in the ISHRAE IEQ standard. The questionnaire is designed to record various effects to enable a subjective assessment of occupant comfort. Qualitative impact of parameters such as room temperature, relative humidity, air flow, stale air, overall lighting, an external view and daylight availability are recorded in the questionnaire. The questionnaire is developed in such a way that all the responses can be recorded with ease using a 7-point scale. The most unsatisfactory response is represented by 1 and the most satisfactory response by 7. Each parameter is represented in term of % satisfaction, where 1, 2 and 3 are unsatisfactory responses and 4, 5, 6 and 7 are satisfactory responses. The location wise variation in occupant satisfaction for different seasons was surveyed in Chennai (*Figure 24*). The overall IEQ satisfaction expressed by the occupants for different buildings is given in *Table 2*.

Table 2: Overall IEQ satisfactions recorded at different buildings

Monitoring Location	Overall IEQ Satisfaction
I1	86%
I3	88%
O1	86%
O2	81%
O3	83%
O4	83%
C1	82%
C2	86%
R1	84%

4. Conclusions

The study presents the implementation of Indoor Air Quality (IAQ) standards proposed by ISHRAE at selected microenvironments in Chennai city. The IEQ investigations were carried out in diverse end use buildings that include commercial, office, residential and institutional buildings. This paper presents the onsite measurement of 12 different buildings, with at least one building in each category as specified in ISHRAE standard. IAQ and comfort parameters were measured using air quality monitoring instruments. The results show that operative temperatures for O1, O3 and O4 in summer season and C1, O1, O3, O4 in winter season are within the compliance zone. Average air velocities for summer, monsoon and winter season are 0.25m/s, 0.30m/s and 0.04m/s respectively. All the recorded relative humidity values are within the compliance zone. Floor surface temperatures for monsoon and winter seasons are found to be within the compliance zone. Higher CO_2 concentration was observed in air conditioned buildings and offices and the lowest in residential buildings where the number of occupants is less. SO_2, NO_2 and CO concentrations are observed within the threshold range and these concentrations were found to be higher outdoor. O_3 concentration is observed higher outdoor as compared to indoor due to sunlight. Higher occupancy, inadequate ventilation and lack of maintenance activities in buildings can cause high total microbial concentration indoors. It was seen that the illuminance and circadian light design in O_2 was higher than other locations. During all the three seasons, illuminance and circadian light design did not meet with the ISHRAE standard at any of the locations, but the occupants at all the locations were satisfied with the lighting. It was seen that uniformity of illuminanace and ratio of illuminanace of task area to immediately adjacent surroundings was within the acceptable range in all the seasons. Major acoustic discomfort was observed due to chanting by the students, air flow sounds in ducts and television sounds. Occupant satisfaction survey along with physical parameter measurement is the most effective way for IEQ assessment. Occupant satisfaction level of more than 80% was calculated for all IEQ elements. For achieving overall satisfaction with IEQ, a comfortable thermal environment is necessary. The type of building, outdoor climate and seasonal changes should be taken into account for developing system for controlling environment.

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