*International Journal of Research in Engineering and Science (IJRES)*
*ISSN (Online): 2320-9364, ISSN (Print): 2320-9356*
*www.ijres.org Volume 12 Issue 4 ǁ April 2024 ǁ PP. 372-382*

# Assessing & Evaluating Indoor Environment Quality Of A 3 Star Bee Rated Office Building: A Case Of Lucknow

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***Abstract***
*This paper presents a comprehensive post-occupancy evaluation (POE) of a 3-star BEE rated office building, The Directorate of Environment, Dr. Bheem Rao Ambedkar Paryavaran Parishad at Lucknow focusing on the assessment of Indoor Environmental Quality (IEQ). The study employs quantitative measurements analyses to provide a holistic understanding of the building's performance. The research emphasizes key IEQ parameters, including thermal comfort, visual comfort, air quality. Objective measurements such as temperature, humidity, lighting levels, and air quality indices were collected. The findings from the POE were analysed to identify potential areas for improvement and to correlate IEQ to ISHRAE standards. Insights derived from the evaluation contribute to the development of evidence-based design strategies for optimizing the indoor environment, fostering a healthier workspace. The paper concludes with recommendations for facility managers, designers, and policymakers to enhance the indoor environment of office buildings, fostering improved occupant well-being and productivity stating that the building is thermally comfortable and healthy.*
***Keywords:*** *Indoor Environmental Quality, Thermal Comfort, Visual Comfort.*

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Date of Submission: 15-04-2024 Date of acceptance: 27-04-2024

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## I. INTRODUCTION

Office buildings are more than just physical structures; they are dynamic environments where people spend a significant portion of their lives. The quality of these spaces can have a profound impact on the well-being, productivity, and satisfaction of the individuals who occupy them. As such, ensuring that office buildings are designed and operated in a manner that meets the needs and expectations of their users is of paramount importance. Post-occupancy evaluation (POE) is a systematic process aimed at assessing the performance and functionality of office buildings after they have been occupied and are in active use. It provides a valuable opportunity to gather insights, feedback, and data from building occupants, facility managers, and other stakeholders. By doing so, it offers a means to critically analyze whether the design, layout, and operational aspects of the office building align with the objectives set during its initial planning and design phases. This evaluation process is essential not only for the well-being and satisfaction of office occupants but also for the optimization of resource utilization, sustainability, and cost-effectiveness. It aids in identifying any challenges, opportunities for improvement, and areas of success within the office building, serving as a critical feedback loop for architects, designers, and facility managers.

### 1.1 Aim

The aim of this research paper is to conduct post occupancy evaluation of BEE certified office building for indoor environmental quality thermal comfort, indoor air quality and visual comfort.

### 1.2 Objectives

1. To identify and understand the indoor environmental quality parameters from the literature study.
2. To analyze the indoor environmental quality parameters for an office building.
3. To analyze the data collected from the site.

4. To collate the evaluated results with ISHRAE standards on Indoor Environmental quality of the building.

**1.3. Methodology**

The methodology employed in the post-occupancy evaluation of the office building involved a mixed-methods approach combining quantitative measurements and qualitative analyses. Objective measurements such as temperature, humidity, lighting levels, and air quality indices were collected to assess Indoor Environmental Quality (IEQ). This comprehensive data collection strategy aimed to provide a holistic understanding of the building's performance in terms of Indoor Environmental Quality. The analysis of the findings from the evaluation allowed for the identification of potential areas for improvement and the correlation of IEQ factors with occupant satisfaction and performance metrics. Insights derived from this methodology contributed to the development of evidence-based design strategies for optimizing the indoor environment and creating a healthier and more productive workspace.

To assess the IEQ of a building objectively, continuous measurements were performed to obtain profiles of air temperature (ºC) and relative humidity (RH in %), using the Heat index WBGT meter in selected zones at ten-minute intervals. Spot measurements were also performed to identify concentrations of particulate matter (PM2.5 and PM10 in $\mu g/m^3$), carbon dioxide (CO2 in ppm), in the indoor air. These IAQ parameters were collected in a walkthrough manner at ten-minute intervals, random using the Multi-functional air quality Detector. For the level of lighting exposure in the workspace, a hand-held Lux Light Meter was used to obtain a realistic approximation of the illumination (in lux) in a walkthrough manner similar to like the Multi-Functional Air Quality Detector.

Table 2.Devices used; Parameters measured

| IEQ FACTOR | DEVICE | PICTURE | PARAMETERS MEASURED |
|---|---|---|---|
| Thermal Comfort | Heat Index WBGT Meter |  | Temperature Relative humidity |
| IAQ | Multi-Functional Air Quality Detector |  | PM2.5 PM10 CO2 |
| Lighting | Lux Light Meter |  | Lux |

## II. Literature Study

The importance of literature study in post-occupancy evaluation (POE) of an office building lies in its ability to provide a theoretical and empirical foundation for understanding the various factors that contribute to the effectiveness, functionality, and overall performance of office spaces (Table 1). According to Ukpong et al. (2022), daylighting is one of the components of indoor environmental quality and is significant in relation to the lecture room's efficiency.

IEQ is affected by a number of factors, including facility management, occupant behaviour, and various ventilation typologies. IAQ and total IEQ are impacted by the upkeep and operation of air conditioners. For instance, installing a high-quality air filtration system can greatly lower the quantity of PMs or fine dust that enters the building from the outside, improving the residents' air quality. This strategy places an emphasis on the indoor occupants' behavioural activities, the facility management techniques, and the calibre of the ventilation system in use. (Kim et al., 2022)

The comfort, productivity, and health of building inhabitants can all be significantly impacted by the indoor environmental quality (IEQ) of such spaces. In order to evaluate the IEQ of the built environment, post-occupancy evaluation (POE) is required. POE usually depends on subjective surveys of temperature, air, visual, and auditory quality. The extensive post-occupancy evaluation and Indoor Environmental Quality (IEQ) measurements conducted across 64 office buildings have provided a comprehensive understanding of critical factors and thresholds influencing user satisfaction, particularly with regard to thermal quality.(Park et al., 2018).

Improving indoor environmental quality is one of the main advantages of green buildings (IEQ). Air quality, thermal comfort, lighting, and acoustic conditions are just a few examples of the several aspects that are usually referred to as IEQ. These factors are mostly the product of design choices and building operating protocols. The impact of diverse building design and operational tactics on IEQ is known to influence multiple human response elements, including but not limited to occupant comfort, well-being, health, and productivity.(24p LOKMAN HAKIM ISMAIL, n.d.)

Better Indoor Environment Quality (IEQ) has been maintained while resource consumption is decreased thanks to improvisation in built environment design consideration. The Built Environment Green Rating project has been adopted as a result of growing stakeholder awareness and societal responsibility for attaining sustainability. One way to increase the Built Environment's efficiency in using water, energy, and other natural resources is through this program. Throughout the whole Built Environment life cycle, it also lessens the effects of development on human health and the environment. The Built Environment's physical components are only one aspect of the Green Rating movement; other aspects may include community, land use, and site planning.(Sonar & Nalawade, 2019)

The quality of a building's environment in connection to the health and wellbeing of people who inhabit its space is known as its interior environmental quality, or IEQ. It primarily refers to four factors: thermal, visual, and auditory comfort; indoor air quality (IAQ). The comfort, wellness, and health of the occupants are directly impacted by these factors. The WGBC further states that the layout, aesthetics, amenities, and biophilia of an indoor space are examples of secondary physical variables that may also affect occupant happiness and comfort. (Elnaklah et al., 2020)

In addition to producing sound and heat, occupants also release odors and contaminants like carbon dioxide (CO2). Relevant environmental sensors can be used to measure these interactions and their impact on the interior environment. Human presence has an impact on the indoor environment since it releases heat and toxins. Zhang et al. (2012) found 35.70% for CO2, 32.49% for relative humidity, and 11.98% for temperature to indicate substantial relationships between occupancy and environmental factors.(Mora et al., 2018)

Originally developed in the 1970s, the term "sick building syndrome" refers to circumstances in which building occupants have acute health and comfort consequences that appear to be related to time spent in a structure; yet, no specific illness or cause is frequently known. The complaints may either be disseminated throughout the entire structure or restricted to a specific area or zone. Otherwise, symptoms that arise from a known or diagnosable sickness that may be connected to airborne toxins within the structure are referred to as "building related illness" (BRI).(Mahmoud et al., 2018).

**Table 1:** Literature Review

| AUTHOR | TITLE | OBJECTIVE | PARAMETERS | CONCLUSION |
|---|---|---|---|---|
| | | | | |
| Park, Jihyun, Aziz, Azizan | Post-occupancy evaluation and IEQ measurements from 64 office buildings: Critical factors and thresholds for user satisfaction on thermal quality | To study both objective IEQ measurements and the technical attributes of building systems (TABS) that may affect indoor environment and user satisfaction. | User satisfaction survey, Workstation IEQ measurements, TABS in the National Environmental Assessment Toolkit (NEAT) | The results showed that overall, 55% of occupants responded as “satisfied” or “neutral”, and 45% reported being “dissatisfied” in their thermal quality. Given the dataset, air temperature in work area, size of thermal zone, window quality, level of temperature control, and radiant temperature asymmetry with façade are the critical factors for thermal quality satisfaction in the field. As a result, the outcome of this research contributes to identifying correlations between occupant satisfaction, measured data, and technical attributes of building systems. |

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|---|---|---|---|---|
| Kim, Young Ki<br>Abdou, Yasmin<br>Abdou, Alaa<br>Altan, Hasim | Indoor Environmental Quality Assessment and Occupant Satisfaction: A Post-Occupancy Evaluation of a UAE University Office Building | The goal of this study is to undertake a comprehensive POE of a case study of a higher education office building in the UAE, aiming to measure, analyse, and compare perceived and actual results regarding IEQ and occupant satisfaction. | POE questionnaires, IEQ Data loggers | The use of a comprehensive POE helps to examine and discover IEQ faults, allowing them to be tracked and modified to deliver positive effects on the occupant's satisfaction, on overall comfort, as well as to increase companies' productivity level and other relative economic profits. |
| Ukpong, Edidiong Uzuegbunam, Francis Udomiaye, EmmanueL | Performance of combined daylighting strategies in varied sky conditions: post occupancy evaluation of lecture rooms in a tropical climate | The present study evaluates the effectiveness performance of three daylighting strategies of university lecture rooms in a tropical wet and dry climate. The daylighting strategies are combined strategies of bilateral, (a) glass louvre windows (covered with mesh net) complemented with terrace shading on both walls, WFR of 19% in E-W orientation, (b) glass louvre windows (with view and clerestory members) complemented with terrace shading on one wall and blank wall on the opposite end, WFR of 11% in N-S orientation, and (c) glass louvre windows (with view and clerestory members) complemented with terrace shading on one wall and egg-crate on the opposite end, WFR of 14%, in E-W orientation. | Field measurement | The results revealed that under the clear sky condition, combined strategies in LLH and BMS rooms were effective in illuminance performance except during evening hours while the one in ANB was ineffective. Both rooms recorded poor daylight uniformity. Similar performance was obtained under overcast sky but they produced effective daylight uniformity. |
| Lee, Kyeongsuk | Enhanced Post Occupancy Evaluation (POE) for Office Building: Improvement of current methodology to identify impact of ambient environment | To focus on advancing the current post occupancy evaluation (POE) methods to enable revealing the impact of seasonal changes on occupants' satisfaction and environmental perception. | on-site measurement, user satisfaction surveys, IEQ device | The results show that occupant has an adjustability to their ambient environments and have a constant satisfaction level with IEQ condition by different months. However, this result was not constant depending on the offices. The result of Office C indicated that occupant had a significant change of thermal satisfaction between different measurement times. |
| Liang, Han His<br>Chen, Chen Peng<br>Hwang, Ruey Lung<br>Shih, Wen Mei<br>Lo, Shih Chi<br>Liao, Huey Yan | Satisfaction of Occupants toward Indoor Environment Quality of Certified Green Office Buildings in Taiwan | To study, the levels of IEQ satisfaction of the occupants in green office buildings were assessed and compared to those in conventional office buildings during a active air-conditioning use. | field survey, on-site environmental measurements. | The analysis of overall IEQ and thermal comfort satisfaction between the respondents of different views on energy conservation indicated that the occupants sharing a concern of energy conservation were more amenable to the IEQ inside the building than those less concerned with the issue; the difference was statistically significant. Gender-wise, female participants were more satisfied with the overall IEQ and the state of thermal comfort than the male participants were. |

| | | | | |
|---|---|---|---|---|
| Hussein El-Salamouny, Amal A. Abdou. Mahmoud Ghoneem | Effects of Indoor Environmental Quality on Occupant's Satisfaction, Health and Productivity | This article aims to assess the effects of Indoor Environmental Quality (IEQ) on productivity, occupant satisfaction, and health in two particular office buildings located in the greater Cairo area. The study is to compare the perceived productivity levels in respect to IEQ elements between the two buildings and evaluate how well the LEED-certified office buildings serve as a comfortable and healthy interior environment for its occupants. Furthermore, the research aims to demonstrate how well-designed structures and the provision of high-quality, healthy interior spaces that satisfy tenants' basic needs can increase occupants' productivity in administrative buildings. | Building Design & Facilities Management Parameters:<br><br>The building overall, Health, Productivity, Effect on behavior, Response to problems | In conclusion, the study on Indoor Environmental Quality (IEQ) in two office buildings in greater Cairo highlighted the importance of creating healthy and comfortable indoor environments for occupants. The research found that Building A, a LEED certified office building, performed better in terms of air quality and thermal comfort compared to Building B, a conventional office building. While Building A showed higher occupant satisfaction with the overall environment, there were areas for improvement in lighting and acoustics quality. The study emphasized the potential for enhancing occupant productivity in administrative buildings through good building design and the provision of high-quality indoor environments that meet occupants' basic needs. |
| S.G. Sonar, R.V. Nalawade | Performance Assessment of Green Rated Built Environment using Post Occupancy Evaluation | To assess various Green Rating Systems used for Built Environment,<br>To identify Performance Parameters of Green Rated Built Environment,<br>To apply methods of Post Occupancy Evaluation (POE) for Green Rated Built Environment,<br>To assess Green Rated Built Environment using POE,<br>To provide findings and recommendations for improving Green Rating Systems. | Indoor Environmental Quality (IEQ), Energy Efficiency | The conclusion of the paper highlights the importance of Post Occupancy Evaluation (POE) as a crucial tool for assessing the performance of Green Rated Built Environment in warm and humid climatic zones. The research demonstrates the significance of POE in identifying critical performance parameters and stakeholders for improving Green Rating Systems. Additionally, the study emphasizes the role of Accredited Professionals in enhancing the Green Building initiative in India. |
| Rana Elnaklah, Daniel Fosas, Sukumar Natarajan | Indoor environment quality and work performance in "green" office buildings in the Middle East | The objectives of this paper are to investigate the relationship between Indoor Environment Quality (IEQ) and work performance in green office buildings in the Middle East, compare IEQ parameters between green and conventional office buildings, and provide insights for the design and operation of office buildings in the region. | survey data, physical measurements of air temperature, relative humidity, CO2 concentrations, mean radiant temperature, and air speed | The study found that green office buildings in the Middle East generally provide better Indoor Environment Quality (IEQ) compared to conventional buildings. Occupants in green buildings reported higher satisfaction with IEQ, which was associated with lower absenteeism and higher work performance. The physical measurements of air temperature, relative humidity, and CO2 concentrations also met recommended standards in green buildings. These findings suggest that investing in green building design can positively impact occupant well-being and work performance in the Middle East. |
| Dafni Mora, Marilena De Simone, Gianmarco Fajilla, José R. Fábrega | Occupancy profiles modelling based on indoor measurements and clustering analysis: Application in an office building | The objectives of this paper are to apply sensors in an office building to monitor user presence, analyze indoor parameters alongside occupancy, explore relationships between occupancy and indoor | User presence and absence intervals, Indoor parameters such as air temperature, Relative humidity, Carbon dioxide (CO2), Volatile | The conclusion of the paper "Occupancy profiles modelling based on indoor measurements and clustering analysis: Application in an office building" highlights the importance of sensor data in understanding occupancy |

| | | | | |
|---|---|---|---|---|
| | | environmental changes, identify the most suitable sensor for occupancy detection, and use clustering analysis to identify occupancy patterns. | organic compounds (VOC), Electricity consumption, Door/window position (open/closed) | patterns and indoor environmental changes. The study identified relationships between occupancy and various parameters, such as CO2 levels and electricity consumption. Clustering analysis proved effective in identifying occupancy profiles and sensor effectiveness. The research contributes to enhancing energy efficiency in buildings by studying occupant behaviors and interactions with the indoor environment. |
| Osama Mahmoud Abu Eleinen, Ghada Mohamed Elries, Marwa Mohamed Elnahas | Indoor environmental quality and Sick Building Syndrome in office buildings | To investigate indoor environmental quality (IEQ) and people's complaints in office buildings in Egypt, to measure indoor environment parameters such as air temperature, relative humidity, air speed, TVOC, formaldehyde, Benzene, and Toluene, to survey occupants' perception of IEQ and symptoms related to Sick Building Syndrome (SBS) through questionnaires, to assess the impact of indoor air quality on occupants' health and well-being in office buildings. | Air temperature, Relative humidity, Air speed, Total Volatile Organic Compounds (TVOC), Formaldehyde, Benzene, Toluene | The study concludes that indoor environmental quality (IEQ) parameters such as TVOCs, formaldehyde, Benzene, and Toluene can reach toxic levels in office buildings, contributing to Sick Building Syndrome (SBS) symptoms among occupants. Improving ventilation and reducing indoor pollutant levels are crucial for enhancing occupants' health and well-being in office environments. |

## III. Study Area

The office building selected for the study is The Directorate of Environment, Dr. Bheem Rao Ambedkar Paryavaran Parishad which is located in Gomti Nagar, Lucknow, Uttar Pradesh. Lucknow has an average summer temperature of 38ºC, and average winter temperature of 5ºC. The city has a composite climate with long, scorching summers and brutally frigid winters. The average relative humidity is 60%. The office is situated at a distance of 363m near Shaheed path (Figure 1). It is a two storeyed, 3-Star BEE certified government office building that houses an estimated 50 people (Figure 2). It performs Environmental Impact Assessment (EIA) and provide environmental clearance.


Figure 1.Location: - Directorate of Environment, Dr. Bheem Rao Ambedkar Paryavaran Parishad, Vineet Khand 1, Gomti Nagar. Source: Author

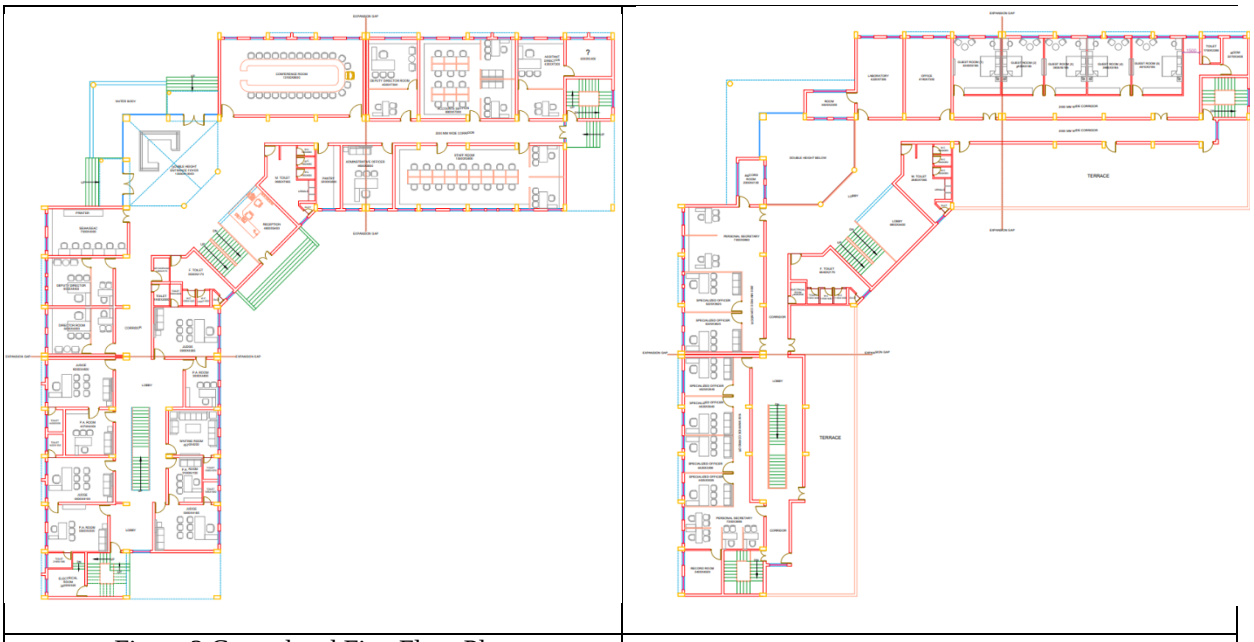
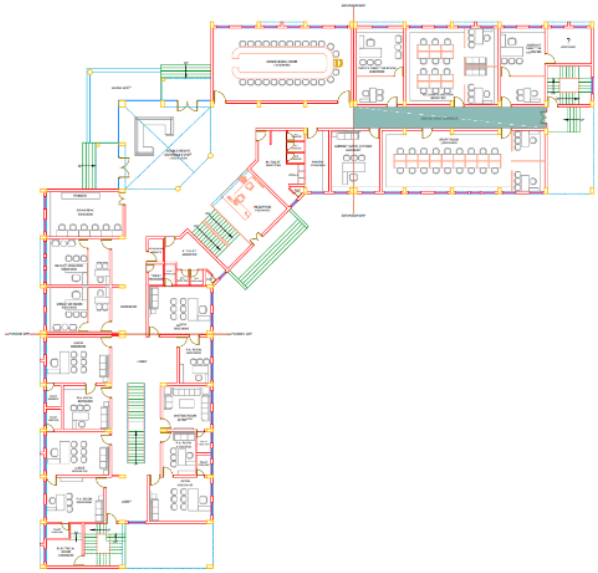
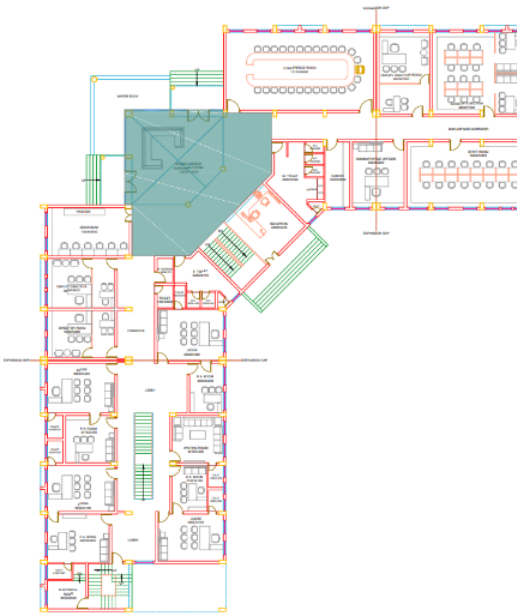


Figure 2.Ground and First Floor Plan

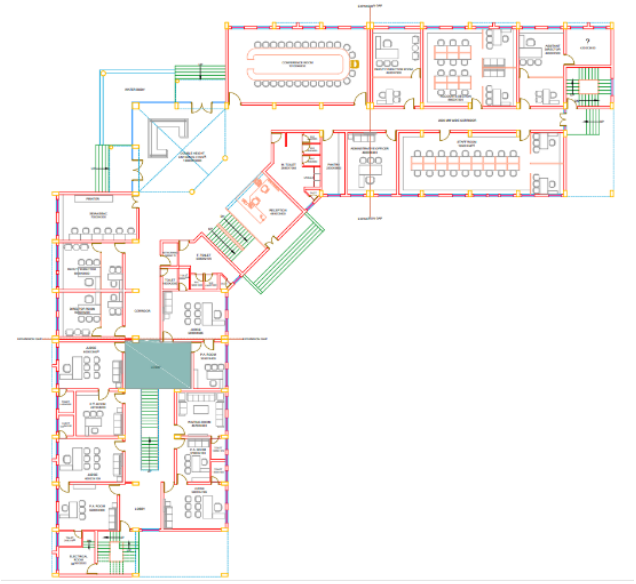
On each floor, 4 zones were selected for continuous measurements that were; the double heighted entrance foyer, corridor, account's section and PA room lobby. The selected zones were based upon a characterization set: to have similar furniture layout, lighting arrangement, exposure to noise, and the same level of control over temperature, lighting, and ventilation and were from every part of the building (Figure 3).

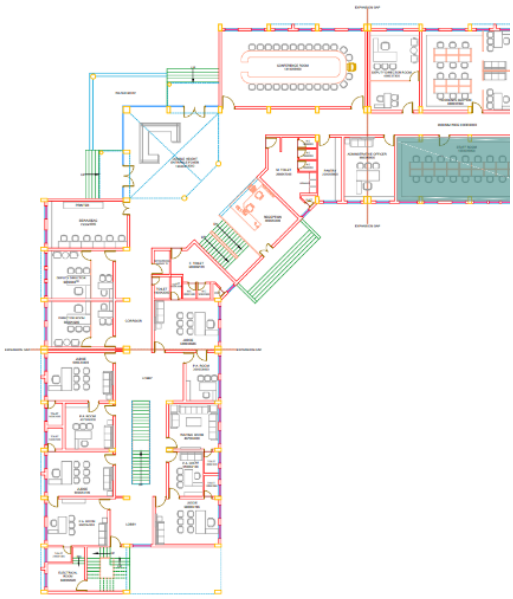


Corridor



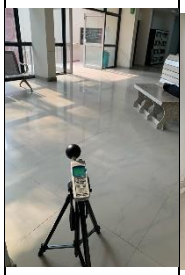
Double Height Entrance Foyer





PA Room Lobby Accounts section

Figure 3.Selected Zones for Study



| Entrance foyer | corridor | Staff room | PA Lobby |
|---|---|---|---|

Figure 4.Selected zones for data collection

## IV. Results and Discussion

These results are based on the on-site measurements with the instruments.

**Thermal Comfort**

Thermal comfort was monitored by recording temperature and relative humidity (RH) values continuously for 1 minutes in 4 zones.

**Double Height Entrance Foyer**

| Table 3.Temperature and humidity in Double height entrance foyer | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Temperature ºC** | 15.7 | 15.8 | 16 | 16 | 16.1 | 16.1 | 16.1 | 16 | 15.9 | 16 | **15.9** |
| **Relative Humidity %** | 54.9 | 54.5 | 54.4 | 54.6 | 54.4 | 54.6 | 54.5 | 54.7 | 54.6 | 54.7 | **54.5** |

**Corridor**

| Table 1.Temperature and humidity in corridor | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Temperature ºC** | 15.9 | 15.9 | 15.8 | 15.7 | 15.6 | 15.5 | 15.6 | 15.5 | 15.5 | 15.5 | **15.6** |
| **Relative Humidity %** | 54.5 | 58.1 | 57.3 | 57.1 | 58 | 56.8 | 57.7 | 57.2 | 57.5 | 57.8 | **57.2** |

| Table 2. Temperature and humidity in Accounts section | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Temperature ºC** | 15.5 | 15.5 | 15.9 | 16.2 | 16.3 | 16.4 | 16.4 | 15.5 | 16.5 | 16.5 | **16.1** |
| **Relative Humidity %** | 58.2 | 58.2 | 63.7 | 62.7 | 61.7 | 61.5 | 60.9 | 61.1 | 60.5 | 60 | **60.8** |

**Accounts Section**

| Table 5.Temperature and humidity in PA room lobby | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Temperature ºC** | 15.1 | 15.1 | 15.1 | 15.1 | 15.1 | 15.1 | 15.1 | 15.1 | 15.1 | 15.1 | **16.0** |
| **Relative Humidity %** | 56 | 54.9 | 54.6 | 54.2 | 54.1 | 53.9 | 54.2 | 54.2 | 54.1 | 54.2 | **54.4** |

**P.A. Room Lobby**

The tables above show the recorded data from each area selected for the survey. All the data collected was for a time limit of 10 minutes in every area.

**Indoor Air Quality**

The IAQ assessment was covered by recording spot measurements of the concentrations of PM2.5, PM10 and CO2 in the air. There were no major flaws exhibited by the results; however, design factors and occupant behavioural trends have been noted.

PM10 results recorded lower than 50 µg/m3 as suggested by the ISHRAE standards. As for the CO2 concentration, the total mean concentration was found to be 457 ppm, which is lower than the 800-ppm suggested by the ISHRAE standards.

Corridor area

PA Lobby

Accounts section

Figure 4: Indoor Air quality measurement

**Visual Comfort**

Lux levels have been recorded across 4 open offices as spot measurements throughout the office building. The total average is 395.75 lux, which is between 300–500 lux, as recommended by the ISHRAE standards. Measurements vary broadly between each open office as they are greatly affected by different orientations since each open office integrates large windows.

| AREA | LUX |
|---|---|
| ENTRANCE | 363 lux |
| CORRIDOR | 163 lux |
| OFFICE | 932 lux |
| CORRIDOR 1 | 125 lux |

Table 3.The lux levels in different areas

Measurements were conducted in different areas of the buildings to assess the air quality of the space and determine the energy levels at the workstations. The air quality and light intensity levels were sufficiently high for the workplace.

*Table 6: AQI reading of the building*

| | Conference Room | Account Section | Staff Room | Entrance |
|---|---|---|---|---|
| PM 2.5 | 48 | 53.4 | 59.4 | 31.7 |
| PM 10 | 80.5 | 91.3 | 45.2 | 48.1 |
| Particles | 4735 | 5899 | 9069 | 6895 |
| CO2 | 166 | 755 | 548 | 403 |
| HCHO | 0.039 | 0.028 | 0.042 | 0.028 |
| LUX | 932 | 876 | 587 | 1124 |

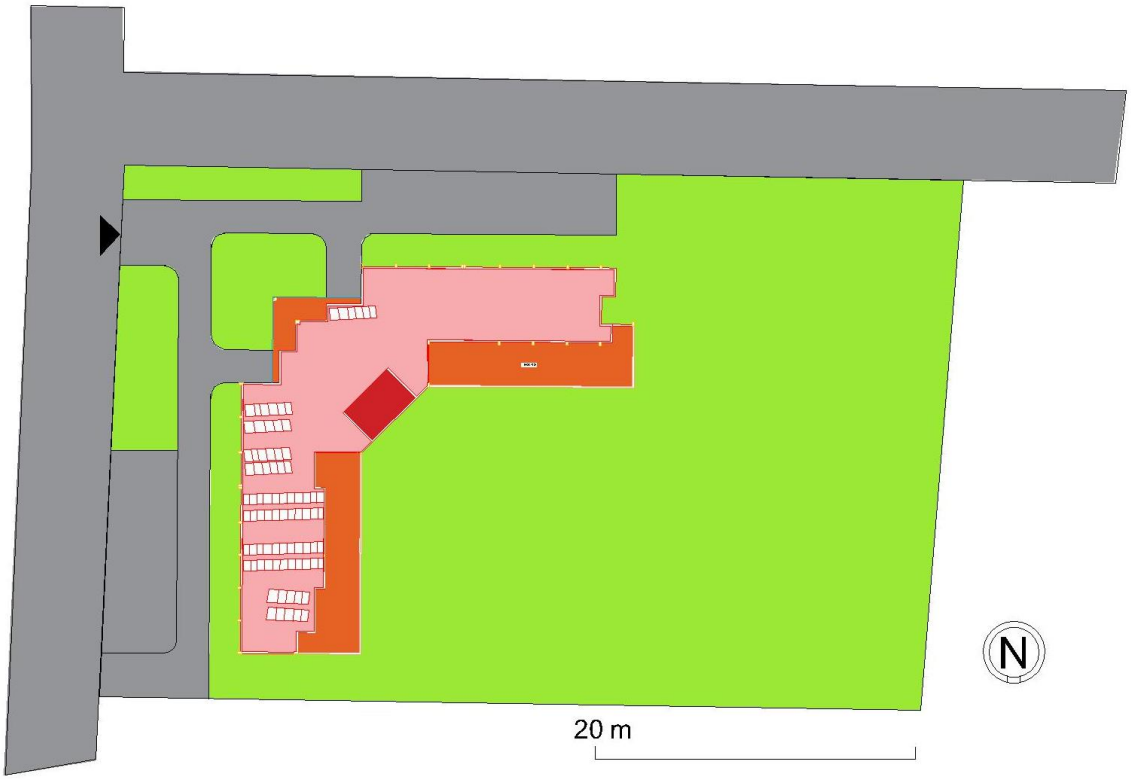



*Figure 5: Site Plan of Directorate of Environment*

## V. Conclusion

The office building was a comfortable space to work in as suggested by the data acquired on site. With ample of natural light, green view from every room, good indoor air quality, proper cross-ventilation, etc. Although the physical measurements discussed in the previous section show a level of compliance with common environmental standards of office buildings, the results of such measurements do not indicate if the occupants are comfortable with the overall IEQ in these buildings. The office building complied with the BEE standards and the indoor environment quality was optimum. The lux levels in every zone show optimum visual comfort for the occupants. Although there are some practices that can be used to further improve the indoor air quality of the internal spaces such as indoor plants and proper cross ventilation should be encouraged in side using the windows.

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