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POST OCCUPANCY EVALUATION OF INDOOR ENVIRONMENTAL QUALITY OF A RESIDENTIAL APARTMENT AT LUCKNOW

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Abstract: The study reports a Post Occupancy Evaluation performed on a residential area of Shalimar gallant, in which IEQ parameters like indoor environment quality, visual comfort and thermal comfort needed investigation. The resulting knowledge is of special interest for other projects designed to be mass-produced such as residential apartments. Large costs for repairs can be reduced by applying measures to avoid IEQ issues in indoor environments. The study was conducted in the residential apartment known as Shalimar Gallant in Mahanagar, Lucknow. The evaluation was performed over first stages i.e. indicative. The process was mapped and the data was recorded with devices like WBGT, temtop, luxmeter, etc. In the indicative stage, data was collected through questionnaires and surveys, and a quick evaluation was conducted of the affected units. The results show that many factors were involved in the IEQ, whose main cause was poor indoor air quality. The thermal and visual comfort met the occupants' satisfaction need. The only parameter which is lacking is the indoor air quality, IAQ. Therefore, some of the design guidelines can be adapted that can be implemented post occupancy for improving indoor air quality.

Index Terms **- Visual Comfort, Thermal Comfort, Indoor Air Quality, Residential Apartments, Likert Scale**

1. INTRODUCTION

1.1 Background study

"The process of evaluating buildings in a systematic and rigorous manner after they have been built and occupied for some time" (Riley, Kokkarinen, & Pitt, 2010) is the common definition of Post Occupancy Evaluation (POE). Numerous other terms, including Building-In-Use Studies, Building Diagnostics, and Building Pathology, have been employed. Combining the technical (structural, mechanical, etc.) and occupant-focused aspects of building performance is known as building pathology (Riley, Kokkarinen, & Pitt, 2010) Watson (2003) therefore defines post occupancy evaluation as "a systematic evaluation of opinion about buildings in use, from the perspective of the people who use them," which is a more precise definition. The assessment of buildings can be approached from three different angles. These consist of economic value, environmental performance, and occupant satisfaction. Post occupancy evaluation achieves the goal of identifying what should be avoided and what should be repeated in subsequent designs. Post occupancy evaluation is also used to record building project successes and failures, which helps to support requests for additions, remodels, and new construction (Building evaluation: practice and principles, 2010).

1.2 Aim

The aim of this research paper is to conduct post occupancy evaluation for indoor environmental quality parameters like thermal comfort, indoor air quality and visual comfort in a residential apartment.

1.3 Objectives

- To understand the relevancy of Post Occupancy Evaluation
- To identify the parameters of Indoor Environmental Quality
- To investigate the 3 IEQ parameters: thermal comfort, indoor air quality and visual comfort through physical measurements and survey questionnaires
- To analyse the collected data

2. LITERATURE REVIEW

2.1 Post Occupancy Evaluation

The concept of Post Occupancy Evaluation in recent years has gained attention amongst various researchers globally, for assessing the performance of a building. Researchers worldwide are working on post occupancy evaluation of housing sector using various methods and tools.

Ye (2022) in his paper presented an assessment of various green technologies implemented in a 17-year-old high-rise building, based on user experience. The building's occupants completed a questionnaire, and environmental variables were measured on the spot to gather data. The findings indicate that the natural lighting and ventilation in the public areas, the thermal and acoustic conditions of the rooms with the double facade, and three-dimensional greening were the features that the occupants were most pleased with. The double facade did not satisfy them in terms of lighting control, solar shading, or room ventilation. Additionally, the building's occupants did not seem to recognize the circular building's aesthetic appeal; instead, they seemed to be more concerned with the building's efficient use of space. This was particularly true for the elderly residents. The users made clear how much they need greenery and outdoor recreation areas (Ye, 2022).

In the research conducted by Joon (2020) the detailed survey contents were chosen based on livability, convenience, comfort, safety, economy, and sociality as evaluation elements. The study's six POE categories demonstrated that high satisfaction with convenience and safety led to the development of a high recognition of the importance of quality of life and safety. In terms of satisfaction, sociality ranked lowest among livability, comfort, economy, and sociality. Low satisfaction with neighbourhood interactions, sense of community, and other aspects of living appears to indicate that additional and improved infrastructure is required for the development of mixed-use apartment complexes in the future. High satisfaction with the living room, front door, and main room—the three main rooms in a house—was found in the detailed livability characteristics, whereas low satisfaction was found with the storage capacity. Convenient public transportation scored highest in the convenience analysis, while the educational environment and extra amenities scored lowest, illustrating the benefits and drawbacks of different location-specific attributes. The comfort analysis revealed that there was little satisfaction with the landscape area, and it appears that green space will be necessary for the development of mixed-use apartment complexes in the future. Last but not least, there was little separation of circulation despite high ratings for safety, access control satisfaction, security office location, etc. As a result, the passage between the residence and other amenities in the mixed-use apartment building must be clearly marked (Joon, 2020).

To address the concerns and determine whether the underprivileged can benefit from the building's features such as operable openings, cross-ventilation, lightweight concrete floors, prefabricated building façades, and cooling systems for individual apartments, more research on the effects of building design on occupants is required. (Woo, 2017). As per the study conducted by Gonzalez and Caceresa (2019) three phases comprised the evaluation process: indicative, investigative, and diagnostic. The findings indicate that a variety of factors contributed to the moisture damage, with the primary culprits being crowded areas, insufficient thermal regulation due to the local climate, subpar apartment and complex design, and defects and inconsistencies in the quality of construction.

The review indicated the significance of both physical measurements and user's perception and feedback through questionnaire survey for conducting a post occupancy evaluation.

2.2 POE Levels of Investigation

Drawing from a range of post occupancy evaluations (POEs) carried out since the 1970s, it is feasible to categorize the degrees of inquiry into three discrete, noncumulative levels based on the amount of time needed, the resources—material and human, the scope of the evaluation, and ultimately the associated costs.

2.2.1 Level 1: Indicative POEs

Information regarding the significant setbacks and achievements of a building's performance is provided by indicative POEs. It can be characterized as a broad approach that incorporates a building walkthrough along with a few interviews. Interviews, walkthroughs, still photos, questionnaire surveys, and archival and document evaluation are some of the techniques used to collect data. (Anibire & O, 2016)

2.2.2 Level 2: Investigative POEs

Investigative POEs are frequently conducted following the identification of problems by an indicative POE that call for additional investigation. They typically call for 160–240 hours of labor, in addition to staff time for support services. In order to obtain additional qualitative input based on the concerns mentioned by the questionnaire respondents, focus groups and interviews will be held after the questionnaires are administered. Numerous typical buildings will be included in the evaluation, which may be assisted by physical measurements, photographic or video recordings, or both. (Anibire & O, 2016)

2.2.3 Level 3: Diagnostic POEs

Comparable to conventional, in-depth research with a defined scope and limit are diagnostics POEs. They typically take a few months to a year or longer to finish. They make use of more sophisticated instruments and more sophisticated data-gathering techniques. This type of study yields long-term results and recommendations that provide feedback not only for a particular facility but also for a particular building type (Anibire & O, 2016).

2.3 Parameters taken for POE

2.3.1 Thermal comfort

The state of mind that communicates contentment with the thermal surroundings is known as thermal comfort. When defining conditions for thermal comfort, there are six main factors that need to be taken into consideration. In certain situations, comfort is influenced by a variety of additional, secondary factors. The six primary factors are Metabolic rate, Clothing insulation, Air temperature, Radiant temperature, Air speed and Humidity (ASHRAE standards, 2004). In this report thermal comfort has been found out through questionnaire surveys.

2.3.2 IAQ

The air quality inside and around buildings and other structures is known as indoor air quality, or IAQ. IAQ is known to have an impact on building occupants' comfort, health, and general well-being. Reduced productivity, learning impairments in schools, and sick building syndrome have all been related to poor indoor air quality. The main strategies for enhancing indoor air quality are source control, filtration, and the use of ventilation to dilute pollutants. IAQ is a component of indoor environmental quality (IEQ), which also includes other elements like light, visual quality, acoustics, and thermal comfort that affect the psychological and physical aspects of living indoors. (Kumar & Rangel, 2023)

2.3.3 Visual comfort- daylight

The sun is the main source of illumination for daylight. There are two types of light that the earth receives from the sun: sky illumination and direct solar illumination. Direct solar illumination is not to be taken into account for daylight design purposes; instead, only sky illumination is to be taken into account as contributing to daytime interior building illumination. The distribution of sky luminance is a function of atmospheric conditions and determines the daylight factor. For design purposes, a clear design sky with its irregular luminance distribution is used. (NBC, 2016)

3. METHODOLOGY

The study was conducted using a mixed method approach. The secondary data collection was done through research papers, books, and articles related to the topic. A thorough literature review was conducted for the background study. For primary study, data was collected through surveys, questionnaires and reading through suitable devices. Both qualitative and quantitative data collection mix method approach was used to conduct this post occupancy evaluation.

3.1 Tools used for data collection

Tools used for evaluation were luxmeter and temptop for. Also surveys and questionnaires were conducted for occupant's perception and feedback. The data was collected for a period of 7 consecutive days and readings were taken 3 times a day. The first reading was taken at 10 am, second reading at 2 pm and third at 7 pm to observe variation and to find average data for more accuracy.

3.1.1 Luxmeter

Lux meters, also known as light meters, are devices that quantify light intensity as perceived by the human eye. Because the eye perceives different wavelengths within the visible spectrum with varying sensitivity, and because lux meters evaluate light intensity taking this variable into account, this value does not correlate to an objective value of energy radiated or reflected. (globalspec.com)

Luxmeter was used to evaluate the adequacy of daylight in all the 4 directions of the apartment. Through luxmeter, daylight in lux was measured near windows of different sizes and orientation and then compared with the standard daylight values.

3.1.2 Temtop

Temtop is a portable monitor that measures temperature, humidity, formaldehyde, carbon dioxide, and PM2.5 and PM10 levels. It shows precise readings and instantaneous outcomes when we adjust the surroundings. The CO2 sensor is appropriate for people who live close to industrial plants, wildfires, or busy roads where there is a lot of smoke. It can also be used to confirm that the air conditioner is operating as intended. Alternatively, we may just need a precise and trustworthy tool to measure the interior temperature of our house. Additionally, formaldehyde, a common chemical found in many wood floors and pressed wood furniture pieces that directly affects our air quality, is taken into account. (temtopus.com)

Temtop was used to record reading of pm 10, pm 2.5 and C02 for over a period of 7 days. The three different time periods were chosen i.e. 10 am, 02 pm and 07 pm to collect the data and the results were observed and compared with standard AQI values.

3.1.3 Questionnaire survey

Using a structured or unstructured set of questions, questionnaire surveys are a technique for collecting statistical data about the characteristics, attitudes, or behaviors of a population. A survey comprises the questions and the procedure for gathering, combining, and evaluating the answers to those questions. A questionnaire survey was conducted to get insight into the perception of users and their feedback. A Likert scale based on a 5-point scale was developed to collect survey responses.

Questionnaire was divided into 5 categories: safety and security, visual comfort, thermal comfort, indoor air quality and building layout with sub categories questions to bring out more clarity and perspective of user's satisfaction.

4. STUDY AREA

4.1 Residential apartment building

In the case of residential apartments, the level of complexity in determining the user requirements is higher. However, the housing in such building are customized, the occupants move into pre-existing units and make changes while occupying them. However, the extent of modification is usually confined to their personal area. Usually, they are found on the evolving design specifications and the minimum standards for the housing development. After that, the design brief is duplicated, albeit slightly different, in each new housing development. Without empirical support, the "one size fits all" and "surrogacy" approaches for end users frequently result in the creation of design solutions that are unsatisfactory for long-term use. (Jacob & Chander, 2020)

4.2 Shalimar gallant

Shalimar Gallant in Mahanagar, Lucknow is a ready-to-move housing society (Figure 1 and 2). It offers apartments in varied budget range. These units are a perfect combination of comfort and style, specifically designed to suit the users' requirements and conveniences. There are 2BHK, 3BHK and 4BHK Apartments available in this housing society. This housing society is now ready to be called home as families have started moving in. Shalimar Gallant Mahanagar has 12 towers, with 13 floors each and 605 units on offer. Spread over an area of 14.85 acres, Shalimar Gallant is one of the spacious housing societies in the Lucknow region. (https://www.shalimarcorp.com/)

Figure 1: Shalimar Gallant location map *(https://www.shalimarcorp.com/)*

Figure 2: Site plan of Shalimar Gallant *(https://www.shalimarcorp.com/)*

5. ANALYSIS AND RESULTS

After conducting surveys and taking readings from suitable device, following are the results and analysis of each indoor environmental quality parameters.

5.1 Thermal comfort

The level of thermal comfort has been found out through questionnaire surveys. The questionnaire asked about the degree of satisfaction. Every respondent was asked to indicate their level of satisfaction using a five-point Likert scale that went from extremely poor to very good.

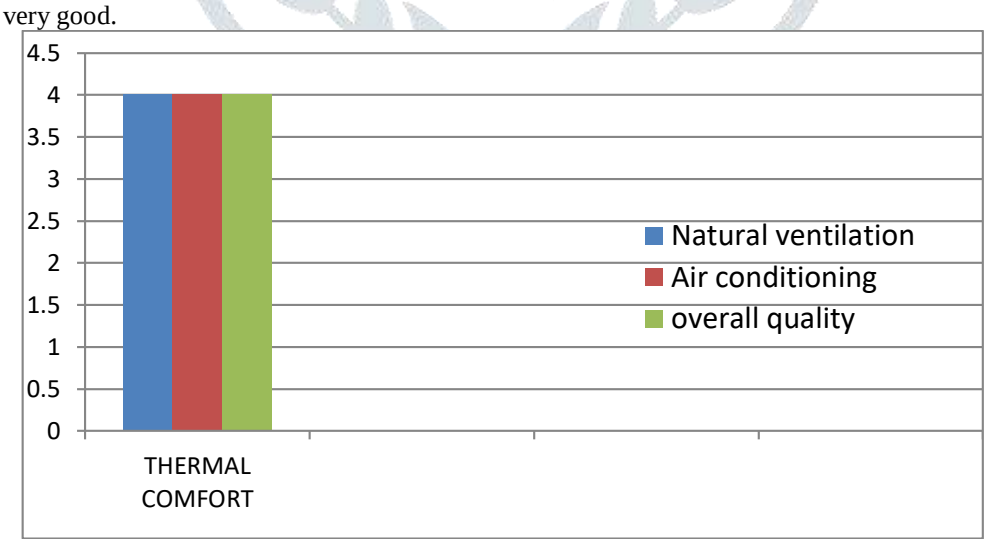

Figure 1: Results of resident's thermal comfort

After conducting questionnaire survey, the average response of the occupants was 4 points on likert scale which is considered as good for the provision of natural ventilation, air conditioning and overall quality of thermal comfort (Figure 3). Hence the occupants are satisfied with the HVAC, natural ventilation and overall thermal comfort.

5.2 Indoor Air Quality

The occupants rated poor rating when asked about IAQ. They are not at all satisfied with the indoor air quality of rooms, lobby, common spaces and overall IAQ. Although they are quite satisfied with the IAQ of the washrooms, less occupancy hours being one of the reasons (Figure 4).

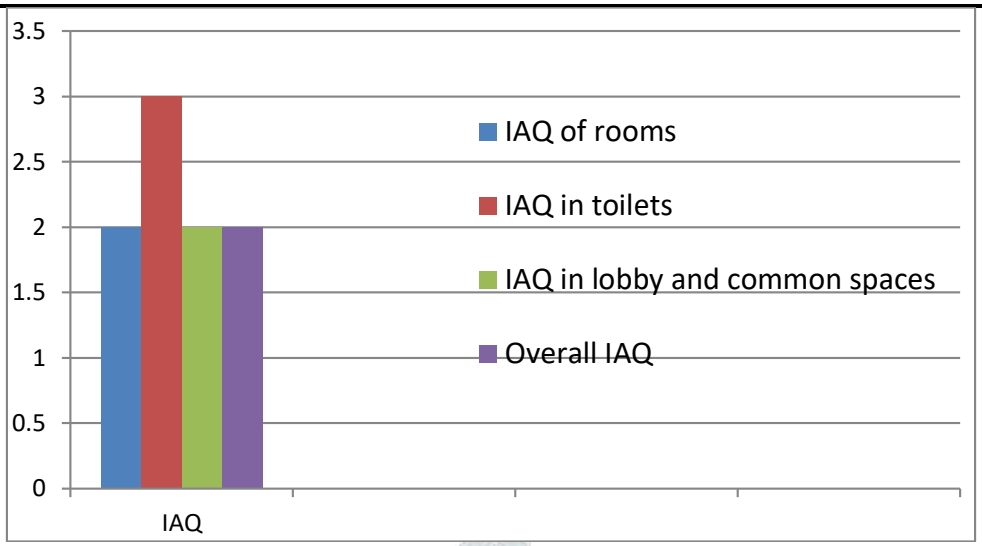

Figure 4: Results of resident's perspective on IAQ

IAQ was also measured through temtop device and it recorded 3 components of IAQ which are PM2.5, PM10 and CO2. The reading was taken three times per day for over a period of 7 days. The three different zones were chosen i.e. 10 am, 02 pm and 07 pm and the results has been observed and compared with standard AQI values.

5.2.1 C02

The American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) currently recommended that CO2 levels be maintained below 1,000 ppm. (Ashrae standards, 2004)

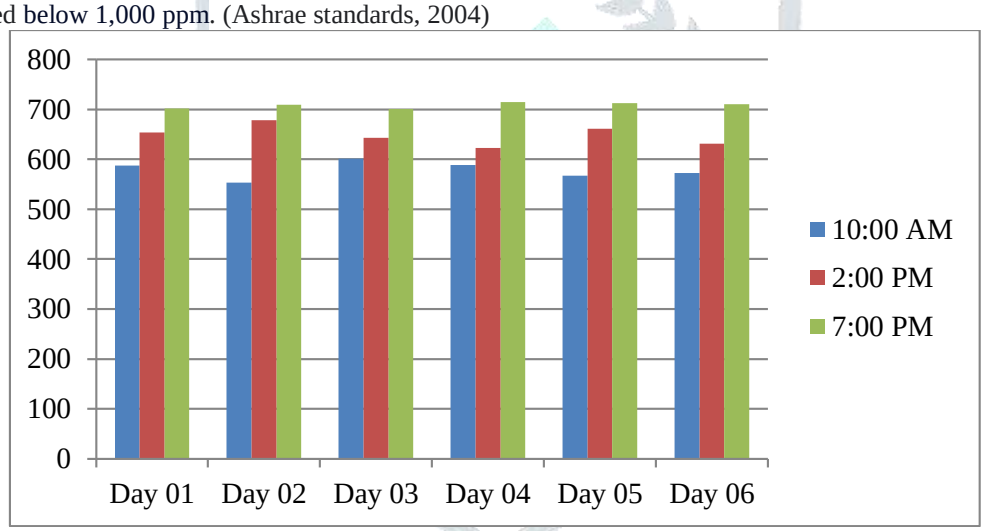

Figure 5: Graph of recorded CO2 values

Each CO2 reading values were compared with the standard CO2 value as per IAQ standards and the status was found to be good (Figure 5 & Table 1).

Table 1: Reading in ppm for CO2

Time	10:00 AM (ppm)	2:00 PM (ppm)	7:00 PM (ppm)
02-12-23	588	654	702
03-12-23	553	678	709
04-12-23	601	643	701
05-12-23	589	623	715
06-12-23	567	661	712
07-12-23	572	631	710
08-12-23	581	657	707

5.2.2 PM 2.5

Most studies indicate PM2. 5 at or below 12 µg/m^3 is considered healthy with little to no risk from exposure. If the level goes above 35µg/m^3 during a 24-hour period, the air is considered unhealthy and can cause issues for people with existing breathing issues such as asthma (ASHRAE standards, 2004).

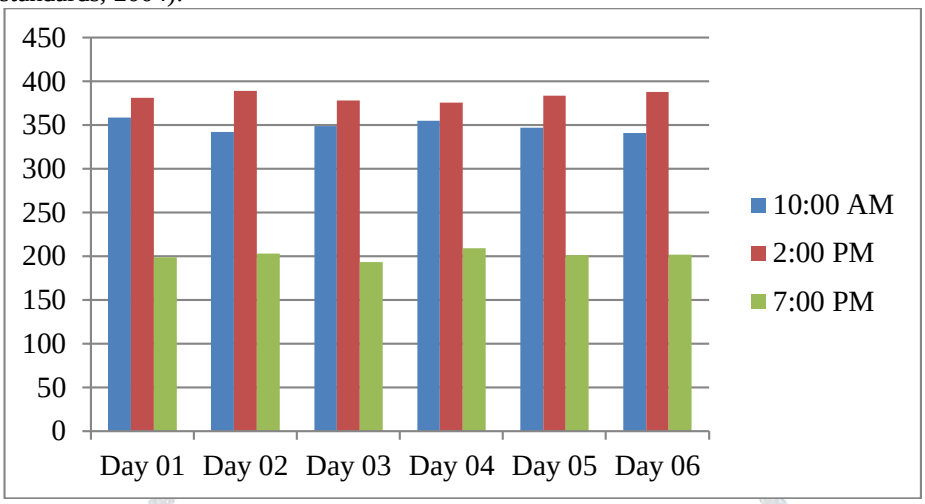

Figure 6: Graph of recorded PM2.5 values

Each PM2.5 reading values were compared with the standard PM2.5 value as per IAQ standards and the status was found to be hazardous.

Table 2: Readings for µg/m3 for PM2.5

Time	10:00 AM (µg/m3)	2:00 PM (µg/m3)	7:00 PM (µg/m3)
Day 01	359	381	199
Day 02	342	389	203
Day 03	349	378	193
Day 04	355	376	209
Day 05	347	384	201
Day 06	341	388	202
Day 07	353	379	198

5.2.3 PM 10

EPA is retaining the existing primary 24-hour standard for coarse particles at 150 µg/m3. An area meets the 24-hour PM10 standard if it does not exceed the 150 µg/m3 level more than once per year on average over a three-year period. (National Ambient Air Quality Standards (NAAQS) for PM)

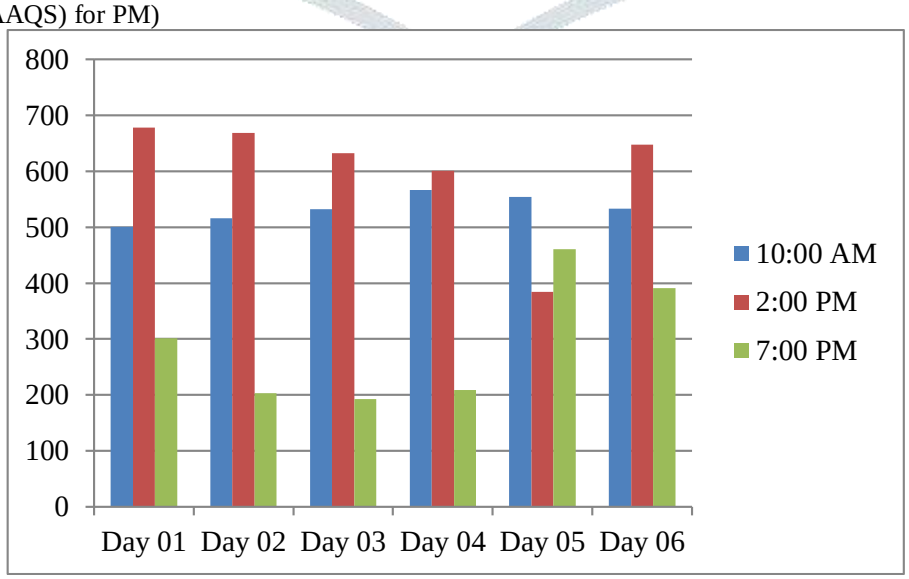

Figure 7: Graph of recorded PM10 values

Each PM10 reading values were compared with the standard PM10 value as per IAQ standards and the status was found to be hazardous.

Table 3: Readings for µg/m3 for PM10

Time	10:00 AM (µg/m3)	2:00 PM (µg/m3)	7:00 PM (µg/m3)
Day 01	501	678	301
Day 02	516	669	203
Day 03	532	632	193
Day 04	567	601	209
Day 05	554	384	461
Day 06	533	648	391
Day 07	529	621	198

5.3 Visual comfort

Occupants are not satisfied with the uniform illumination inside the habitable areas and control to natural lighting, though they are satisfied with the presence of natural lighting and safety. After survey it was also observed that the occupants are highly satisfied with the artificial lighting and its controlling methods.

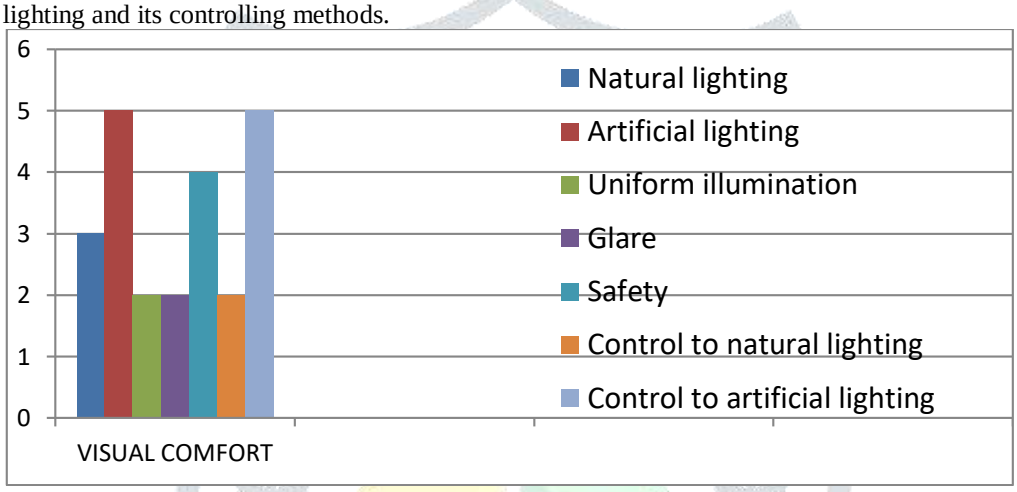

Figure 8: Results of resident's perspective on visual comfort

5.3.1 Visual comfort- Measuring daylight through luxmeter

It is recommended that the illuminance of all working areas within a building should generally be 120 lux. (NBC, 2016)

This study intended to search for the best daylight performance of apartment units concerning the layout plan. As specified by the national building standard, habitable areas in a residential unit with a minimum luminance level of 120 lux should be considered to have sufficient access to natural light. Referring to the dynamic nature of the sun, the distribution of sunlight in the room will vary throughout the day. Table 4 shows the level of daylight illuminance inside the apartment unit (Figure 9) based on the luxmeter reading with the average sky condition. The kitchen has the minimum luminance levels of 399 lux. Meanwhile, the living area has the maximum luminance level is 834 lux. While in tower G, 4 BHK (Figure 10 & Table 5) the kitchen has the minimum luminance levels of 376 lux. Meanwhile, the living area has the maximum luminance level is 919 lux.

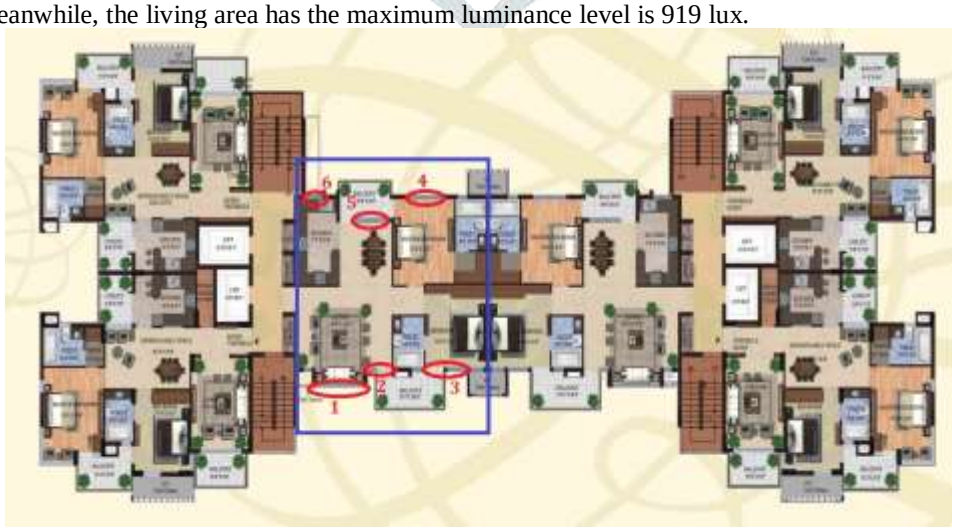

Figure 9: Location of windows in 2 BHK tower A *(https://www.shalimarcorp.com/)*

Table 2: Daylight analysis for tower A through luxmeter

SR NO.	WINDOWS	LUX
1	Window 1	834
2	Window 2	456
3	Window 3	707
4	Window 4	576
5	Window 5	649
6	Window 6	399

Figure 10: Location of windows in 4 BHK tower D and G *(https://www.shalimarcorp.com/)*

Table 3: Daylight analysis for tower G through luxmeter

SR NO.	WINDOWS	LUX
1	Window 1	919
2	Window 2	416
3	Window 3	578
4	Window 4	643
5	Window 5	411
6	Window 6	376

The analysis stipulates that both the towers have adequate daylight to each one of the habitable rooms. Even with the lowest daylight of 376 lux in the kitchen, there is still adequate amount of daylight. Thus the apartment is visually comfortable and is fulfilling every standards of daylight in all the rooms.

5.4 Building layout

Occupants were satisfied with the horizontal circulation. They were quite satisfied with the ceiling height, window and door opening and overall quality of the building layout. After survey it was observed that the occupants are highly satisfied with the vertical circulation and green open spaces (Figure 11).

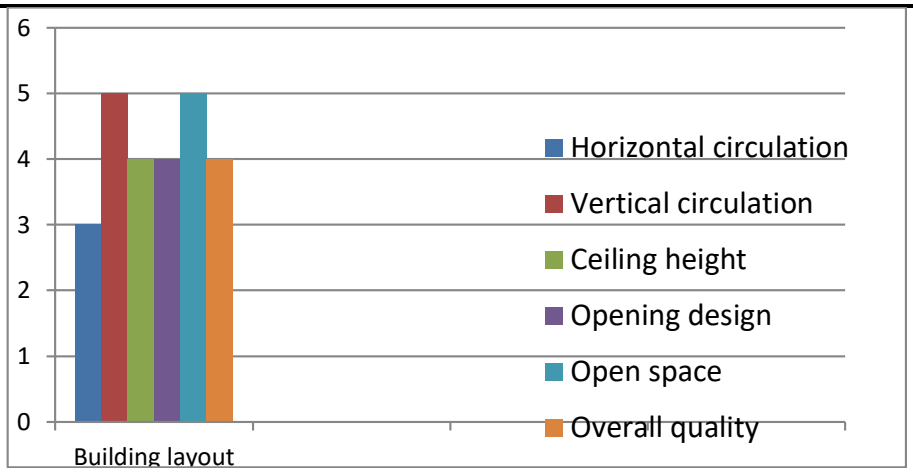

Figure 11: Results of resident's perspective on building layout

5.5 Security and safety

Occupants were neutral when it came to fire escape route, ventilation for firefighting and protection form insects. They are quite satisfied with the safety of falling against window and balcony. After survey it was also observed that the occupants are highly satisfied with the physical safety, firefighting equipment in the building. The safety of location also satisfied the occupants of the building (Figure 12).

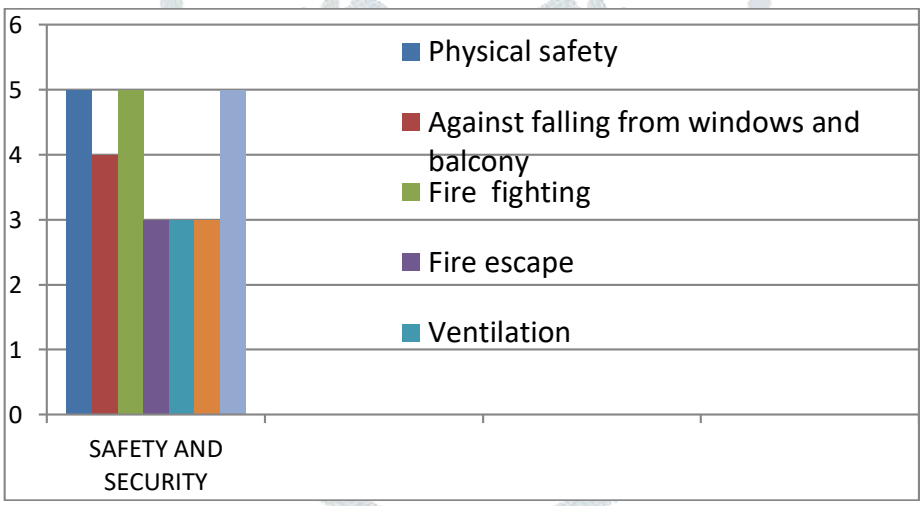

Figure 12: Results of resident's perspective on safety and security

6. CONCLUSION

The main aim of the study was to conduct post occupancy evaluation for indoor environmental quality parameters like thermal comfort, indoor air quality and visual comfort in a residential apartment. Building layout and security and safety were also analyzed based on user's perception.

The occupants were satisfied with the HVAC, natural ventilation and overall thermal comfort in the building. But they gave poor rating when asked about Indoor air quality. Each CO2 reading values were compared with the standard CO2 value as per IAQ standards and the status was found to be good. Each PM2.5 and PM10 reading values were compared with the standard PM2.5 and PM10 value as per IAQ standards and the status was found to be hazardous. The visual comfort with respect to daylight analysis stipulates that the towers had adequate daylight to each one of the habitable rooms. Even with the lowest daylight of 376 lux in the kitchen, there is still adequate amount of daylight. Thus the apartment is visually comfortable and is fulfilling every standards of daylight in all the rooms. The occupants were highly satisfied with the vertical circulation and green open spaces. They were quite satisfied with the ceiling height, window and door opening and overall quality of the building layout and also their safety and security.

Hence the thermal and visual comfort met the occupants' satisfaction needs. The only parameter which was lacking was the indoor air quality (IAQ), therefore some strategies have to be implemented post occupancy in order to improve indoor air quality. Some suggestive strategies include:

1. Integrating Plants with Air-Cleaning Technologies (Brilli & Fares, 2018)
2. Use of ozone generating devices to improve indoor air quality: Ozone is thought to be encouraged on the assumption that it will oxidize organic compounds until only carbon dioxide and water vapour are left. It involves the simultaneous use of air ionization and ozone as an efficient anti-microbiological agent and for surface odour removal (e.g., following fire damage). (Boeniger, 1995)

Air cleaners: An air purification plant can be a stand-alone, portable, or fixed device (wall, window, or ceiling mounted) that purifies a room or a section of it. It can also be a component of the ventilation and air conditioning system that serves multiple spaces in a

building. When choosing the best air cleaning system, factors like the target pollutant phase, long-term performance, energy consumption, and the production of unwanted by-products should be taken into account. (Kelly & Fussell, 2019)

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