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Effects of Lighting and Human Behaviour on **Indoor Visual Comfort in Residential Buildings**

MAHINDRA - TERI
Centre of Excellence (CoE)

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Introduction

In India, the real estate sector is the second-highest employment generator, after the agriculture sector. The real estate sector in India is expected to reach US$ 1 trillion by 2030. By 2025, it will contribute 13% to the country's GDP. [1] The emergence of nuclear families, rapid urbanisation and rising household income are likely to remain the key drivers for growth in all spheres of real estate, including residential, commercial, and retail. With rapid urbanization, the importance of understanding relationships between the changing urban environment and human health and wellbeing is being increasingly recognized. [2]

Lighting system plays a very important role in the infrastructure of a modern building. [3] Good lighting in a building provides sufficient light in the right place. This enables the occupants to see easily and in comfort allowing them to perform their work efficiently without strain or fatigue. In addition, good lighting enhances the appearance of space to provide a pleasant internal environment and can contribute to the creation of different atmospheres appropriate to different activities. However, inappropriate design of artificial lighting systems and unsymmetrical introduction to daylight scenes can add to the discomfort of the users. The perception of space is directly connected to the way light integrates with it. How we respond to a certain light scene, what we experience and how we interpret different elements are greatly affected by how light interacts with us and with the environment that has a further co-relation with the user's visual comfort.

Visual comfort is essential for the well-being and productivity of the occupants in buildings [4]. Many studies in the past have analysed the effect of visual comfort on occupant work performance, productivity, comfort, and satisfaction [5] and defines the lighting conditions and the views from one's work area. The preference for windows and therapeutic effects of any natural views is well established in the literature [6]. Insufficient light and especially daylight or glare reduces the ability to see objects or details. Access to natural lighting as well as artificial lighting is, therefore, essential to ensure the well-being of occupants in areas where natural lighting is missing or during the evening when the natural lighting fades. [7]

Visual comfort at work has an impact on comfort after work as well [8]. There are studies that have looked at impact of visual comfort on sleep quality at home after work. These studies have documented differences in impacts by gender, age, and seasons on the overall discomfort levels and impacts on health. Several visual comfort criteria such as view type, view quality and social density have an impact on physical and psychological health of the occupants. Geometry of windows, photometry of surfaces, amount of glazing etc., all have an impact on the illumination levels in a work area [9]. It also plays a vital role in the overall productivity, comfort and well-being of the occupants that buildings need to avoid excessive use of artificial lighting yet still maintain some level of optimality. [10] There are several studies that showcase that design of buildings may also benefit from views and interaction of occupants with their natural environment. Lighting design does not start with the selection of luminaires, but with an evaluation of the occupants' needs, visual and physical capabilities, age, and lifestyle. [11] It is beneficial to use natural lighting and at the same time use shading devices to reduce direct glare in the field of view. Other factors like the use of light colours on the walls may also improve visual comfort. In addition, if occupants could be given control of lighting through dimming controls, then it might further help achieve visual comfort.

[13] Therefore, one needs to study daylight, artificial lighting, glare and visual comfort together in order get a more holistic picture. [11] [12]

Objective

One of the activities of the Mahindra TERI Centre of Excellence project is Visual Comfort Module under which a questionnaire survey is developed to investigate the effects of lighting and human behaviour patterns on subjective visual comfort. The objective of the survey is to develop a relationship between the results of the literature survey and the practical experience of occupants.

The questionnaire proposed for the project is the result of a survey of reports from similar research studies and is designed considering certain parameters such as age, gender, physical environment as these play a vital role in the achievement of visual comfort. The questionnaire consists of 3 parts as per the current study and takes into account both natural and electric lighting conditions. Questions are based in a way that it will help in the assessment of the occupant perception, building as a whole, the work station, lighting and other environmental parameters

The results of this study will further help to generate awareness of the detailed factors involved in visual comfort. The study also shows the importance of daylighting for people's overall satisfaction, and this evidence may assist policy-makers in establishing appropriate guidelines and standards. The findings would also help planners and architects implement improved daylighting in their housing projects, and provide residents with better visual environments.

Methodology

Pilot study

A pilot study with a sample size of 35 people was conducted before the actual study, to develop the questions and check the reliability of the questionnaire. The questions focused on preference for natural light, control on light, sufficiency of illuminance levels for working, concentration due to task lighting, strain and fatigue due to lighting conditions, position of windows for day light and period of the day with higher concentration levels due to lighting. The pilot study also tested the feasibility of the statistical methods for analysing the respondents' 'answers. A preliminary analysis of the pilot study results and respondents' comments showed that most of the items in the questionnaire were clear and well organized, although some questions needed to be modified.

Sampling

The residential sector was divided into two categories namely High-rise and Low-rise. For low-rise typology, the survey was conducted in Dhurva Apartments, I.P Extension, New Delhi. This is a G+3 society consisting of 17 blocks and in total 196 flats.

Since the pandemic outbreak, conducting the survey and collecting responses from residents became a task. Hence to collect the responses for high-rise typology inputs from multiple societies were considered. The societies were selected based on our past associations.

Questionnaire Survey

The survey was conducted in two phases. Phase-I was conducted in March 2021 in Dhurva Apartments, I.P Extension, New Delhi. Before the necessary permissions from the society secretary, the survey forms were circulated in the online group of the residents. Along with the online presence, a door-to-door campaign was also conducted to collect the responses. A total of 150+ flats were reached through SMS & a door-to-door campaign. A total of 95 responses were collected from this society.

The door-to-door campaign was stopped due to the outbreak of the second wave. Post the normalisation the Phase-II was initiated. Since conducting door-to-door campaigns was not possible, the residents of multiple societies were contacted over mails. The responses was collected in online forms and collated to formulate the analysis and results.

Survey Questionnaire

Table 1 Survey Questionnaire

Age Group					
16-19	20-29	30-39	40-49	50-59	60 and above

Gender	
Male	Female

The floor of the building you are located at							
Ground Floor	1st Floor	2nd Floor	3rd Floor	4th Floor	5th to 8th Floor	9th to 14th Floor	15th Floor & above

How much of sky is visible above the window of your living room?				
Almost All	Almost None	Half	Little	Much

In general, how many hours of a day (24hrs) can you perform your daily tasks, only with available natural light?				
Less than 1	Between 1 to 3	Between 3 to 5	Between 5 to 7	More than 7

How many hours of sunlight shines into the living room in summer?				
Less than 1	Between 1 to 2	Between 2 to 3	Between 3 to 4	More than 4

How many hours of sunlight do you prefer in the living room in summer?				
Less than 1	Between 1 to 2	Between 2 to 3	Between 3 to 4	More than 4

How many hours of sunlight shines into the living room in winter?				
Less than 1	Between 1 to 2	Between 2 to 3	Between 3 to 4	More than 4

How many hours of sunlight do you prefer in the living room in winter?				
Less than 1	Between 1 to 2	Between 2 to 3	Between 3 to 4	More than 4

How often do you face Thermal Discomfort (lack of satisfaction with the ambient temperature) from sunlight?				
Always	Never	Often	Rarely	Sometimes

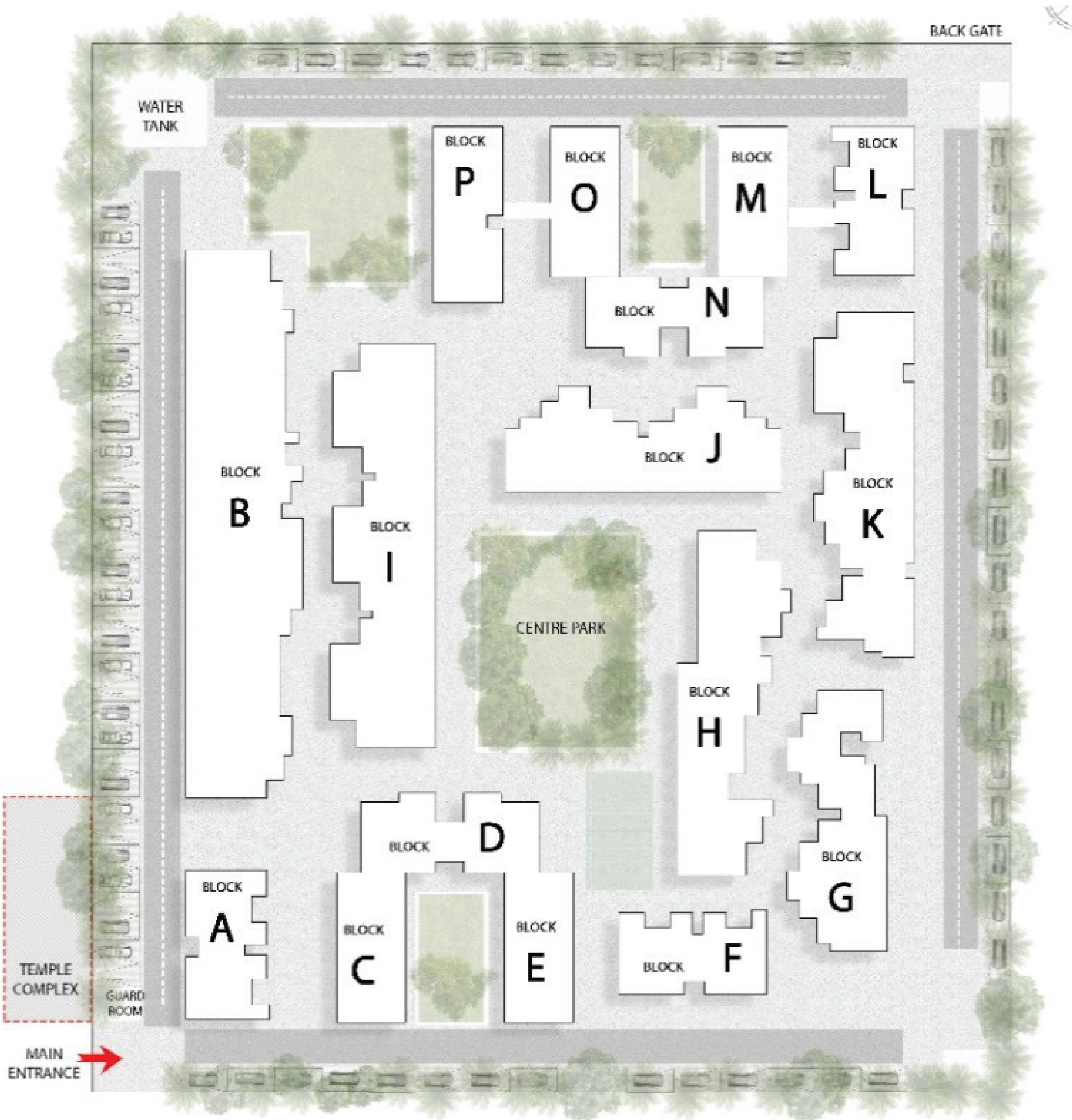
How often do you face the Glare (difficulty of seeing in the presence of bright light such as direct or reflected sunlight or electric light) from sunlight?				
Always	Never	Often	Rarely	Sometimes

How do you perceive the following elements of your house?	
a. Walls	
Light	Dark
b. Interiors	
Light	Dark

Do you agree that overall daylighting in your room is satisfactory?				
Agree	Disagree	Neutral	Strongly Agree	Strongly Disagree

How many hours do you turn on the electric light in the daytime when at home?				
Less than 1	Between 1 to 3	Between 3 to 5	Between 5 to 7	More than 7

Do you agree that overall electric lighting in your room is satisfactory?				
Agree	Disagree	Neutral	Strongly Agree	Strongly Disagree



Statistical Analysis

The data was segregated based on different parameters. The statistical reliability was tested to assess the consistency of the survey results. The Cronbach's alpha coefficient was used to estimate the internal consistency of the two scales, the level of satisfaction with daylighting and human behaviour in relation to lighting.

Chi-square test is a statistical test applied to sets of categorical data to evaluate how likely it is that any observed difference between the sets arose by chance. To test whether the factors of gender, age or type of housing caused significant differences in terms of luminous comfort, Chi-square test was used to show the bivariate associations.

A five-point Likert scale is used to quantify the occupants' satisfaction levels with indoor visual comfort in residential buildings. Likert scale is one of the most common ranking scales applied in lighting researches. [14]

Further, Spearman's rank correlation coefficient is used for defining the correlation among environmental parameters in ordinal scale and subjective responses. [14] It is being used in the ranking the factors affecting the daylighting and electric lighting like external obstructions, floor level, etc.

A negative correlation can indicate a strong relationship or a weak relationship. Many people think that a correlation of –1 indicates no relationship. But the opposite is true. A correlation of -1 indicates a near perfect relationship along a straight line, which is the strongest relationship possible. The minus sign simply indicates that the line slopes downwards, and it is a negative relationship.

Results

Reliability of the questions

Cronbach's Alpha is a way to measure the internal consistency of a questionnaire or survey. Cronbach's Alpha ranges between 0 and 1, with higher values indicating that the survey or questionnaire is more reliable. To check the internal consistency of the responses towards the questionnaire, Cronbach's Alpha coefficient is calculated for the questions concerning towards daylighting shown in the Table 2.

Table 2 Cronbach's Alpha co-efficient

Feelings toward daylight	Cronbach's Alpha
Abundance of daylight hours	0.838
Problems sunlight brings: 1 (Thermal Discomfort)	0.860
Problems sunlight brings: 2 (Glare)	0.807

Demographic characteristics of the participants

Out of the total 210 responses received, 32% were female and 68% were male. The age group of the participants varied with the youngest participant 18 and the oldest being 65 years old. The bifurcation of responses based on gender and various age group is depicted below in Figure 1 and Figure 2.

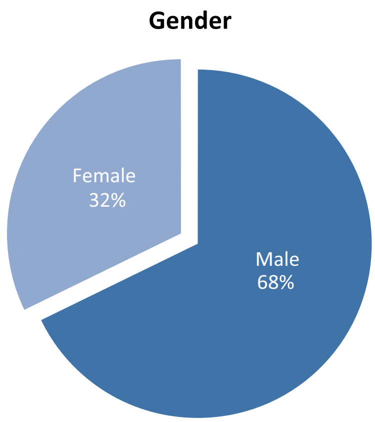


Figure 1 Responses based on Gender

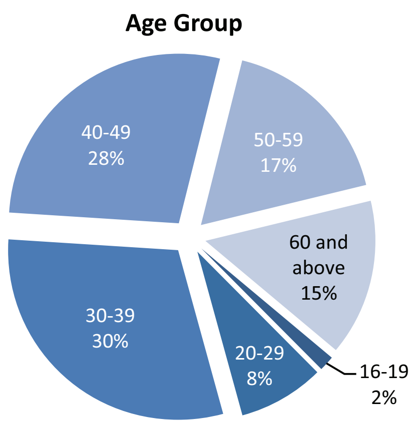


Figure 2 Responses based on Age Group

Satisfaction levels

Satisfaction with daylighting - Gender

Out of total responses collected 59% participants were satisfied with the daylighting, 20% were dissatisfied and around 21% were neutral as depicted in Figure 3.

Out of the responses received variation based on gender was studied. The deviations amongst the responses are depicted in figure 4 below. The satisfaction levels were relatively higher in male respondents in comparison to females. Overall out of total responses received, 60% of male respondents and 57% of

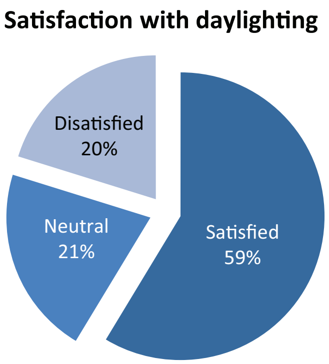


Figure 3 Satisfaction with daylighting - Overall

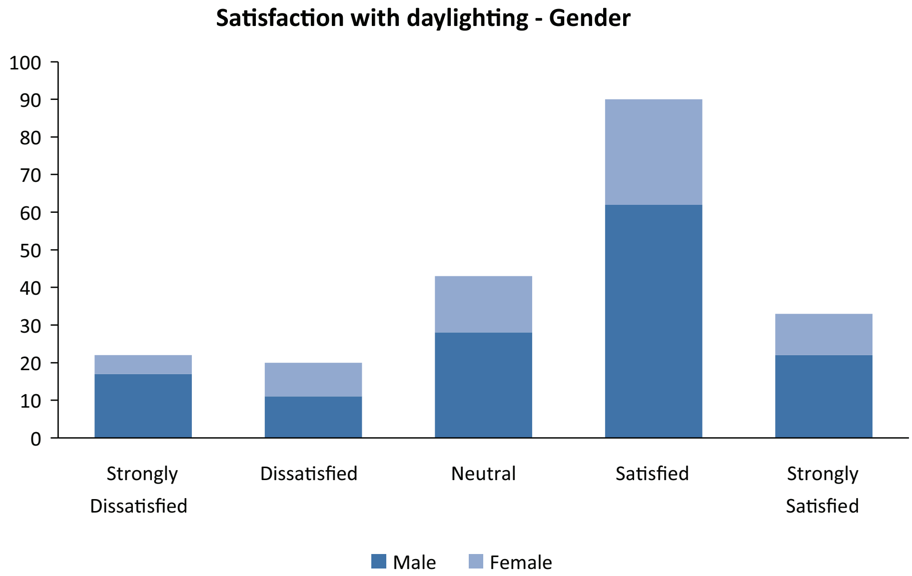


Figure 4 Satisfaction with daylighting - Gender

female respondents were satisfied with daylighting. As far as dissatisfaction with daylighting is concerned the variation was very marginal. Out of total responses received, 20% of male respondents and 21% of female respondents were satisfied with daylighting.

Satisfaction with daylighting – Age Group

Similar to the variation in satisfaction levels because of the gender, the variation was studied based on the various age groups. The satisfaction levels of various age groups are shown in the Figure 5.

As the age group increased the satisfaction levels also increased. For 20-29 age group it was 53%, which increased to 66% & 65% for 30-39 age group and 40-49 age group respectively. However it took a significant

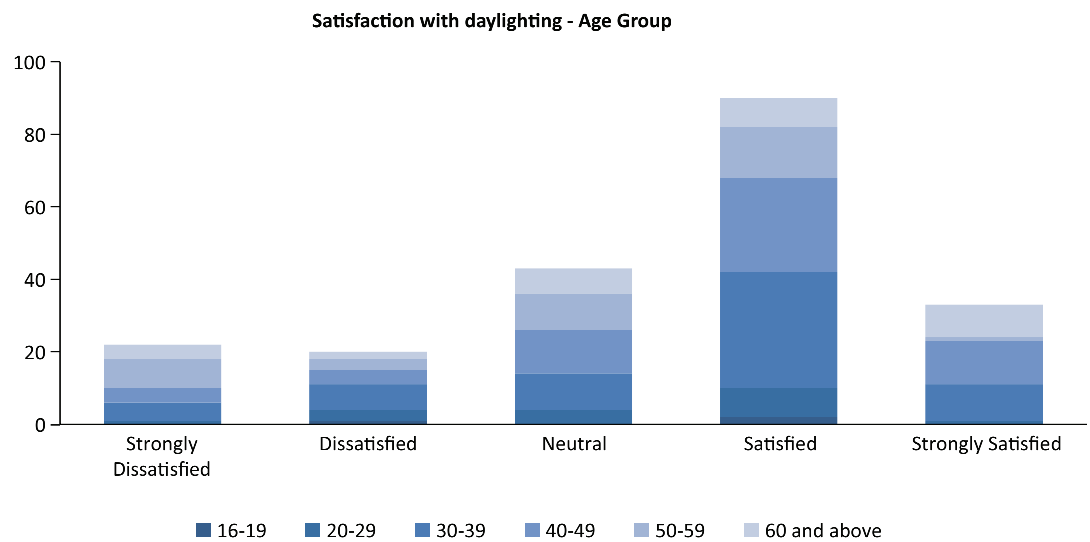


Figure 5 Satisfaction with daylighting - Age Group

dip to 42% for the 50-59 age group and for 60 & above age group satisfaction levels with daylighting was 57%. For the dissatisfaction levels the highest was 30% for the 50-59 age group and lowest was 14% for 40-49 age group. Variations in satisfaction levels with daylighting w.r.t age group are shown in Figures 6.

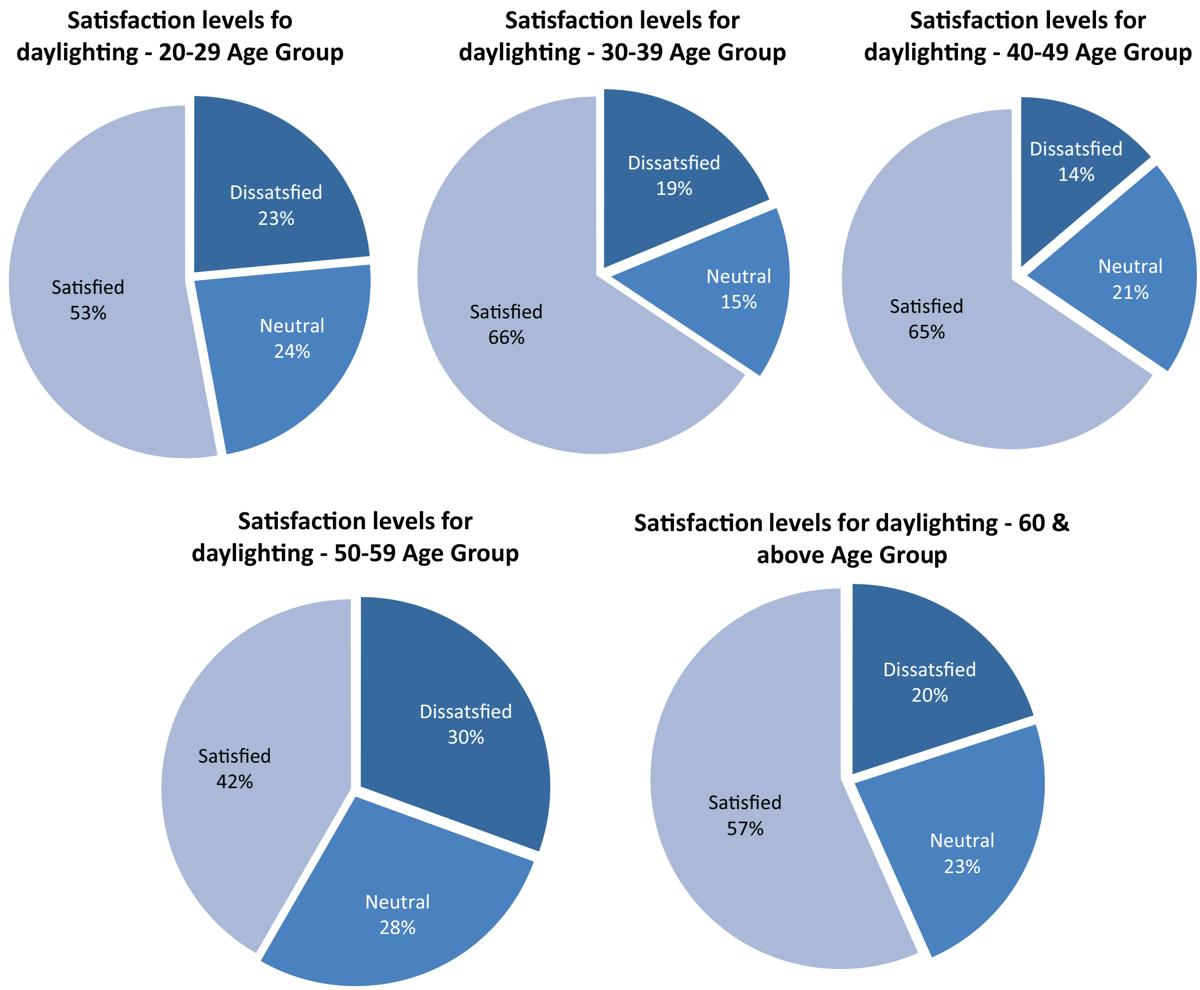


Figure 6 Satisfaction of daylighting for different age group

Satisfaction with electric lighting - Gender

Out of total responses collected 71% participants were satisfied with the daylighting, 12% were dissatisfied and around 17% were neutralas shown in Figure 7.

Out of the responses received variation based on gender was studied. The deviations amongst the responses are depicted in figure 8 below. The satisfaction levels were relatively higher in female respondents in comparison to males. Overall out of total responses received, 69% of male respondents and 76% of female respondents were satisfied with electric lighting. As far as dissatisfaction with electric lighting is concerned the response was same at 12%.

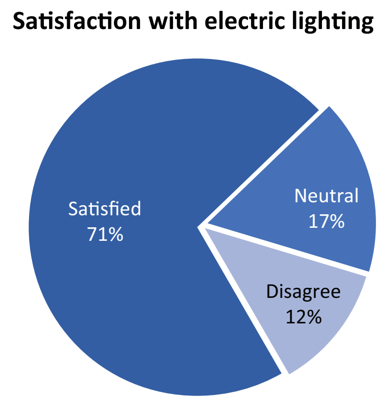


Figure 7 Satisfaction with electric lighting

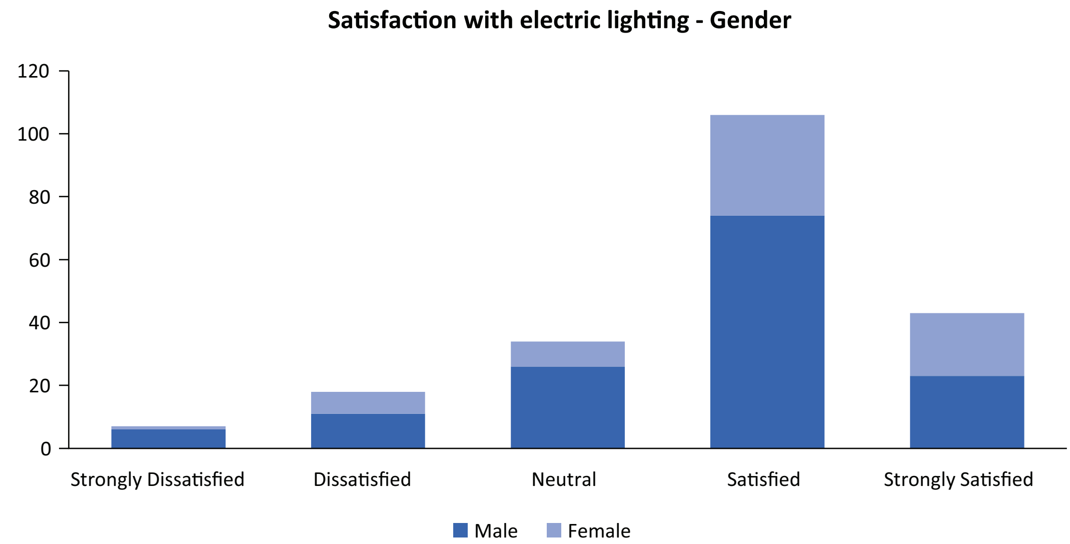


Figure 8 Satisfaction with electric lighting- Gender

Satisfaction with electric lighting – Age Group

Similar to the variation in satisfaction levels because of the gender, the variation was studied based on the various age groups. The satisfaction levels of various age groups are shown in the Figure 9.

As the age group increased the satisfaction levels also increased. For 20-29 age group it was 70%, which increased marginally to 72% & further dipped down 64% for 30-39 age group and 40-49 age group respectively. For the age group 50-59, it increased to 71% and subsequently achieved 89% satisfaction for 60 & above age group. For the dissatisfaction levels the highest was 16% for the 50-59 age group and lowest at 12% for both 20-29 and 30-39 age group. However it is to be noted that for the age group 60 & above, there was no response stating dissatisfaction with electric lighting. Variations in satisfaction levels with daylighting w.r.t age group are shown in Figures 10.

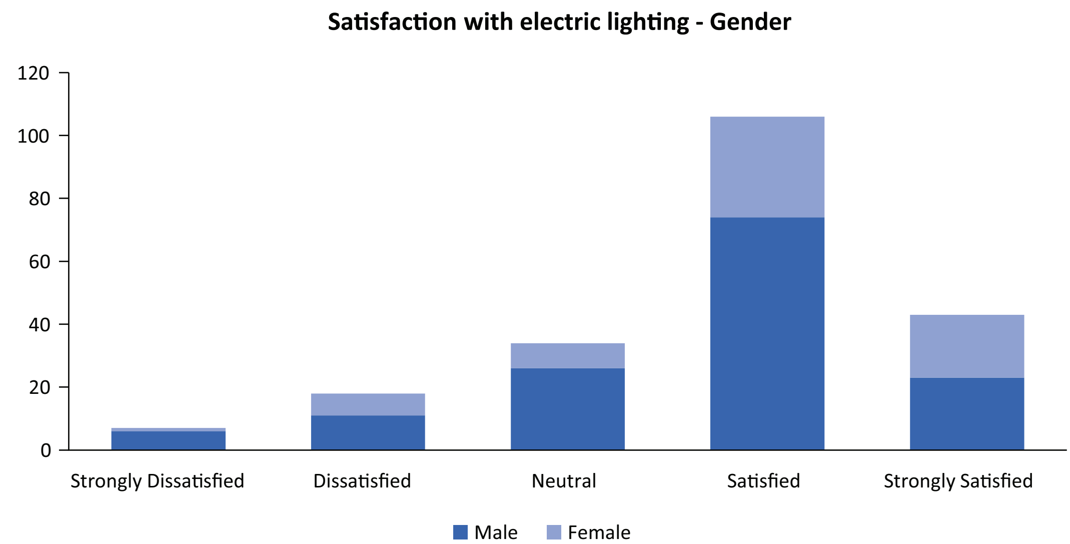


Figure 9 Satisfaction with electric lighting- Age Group

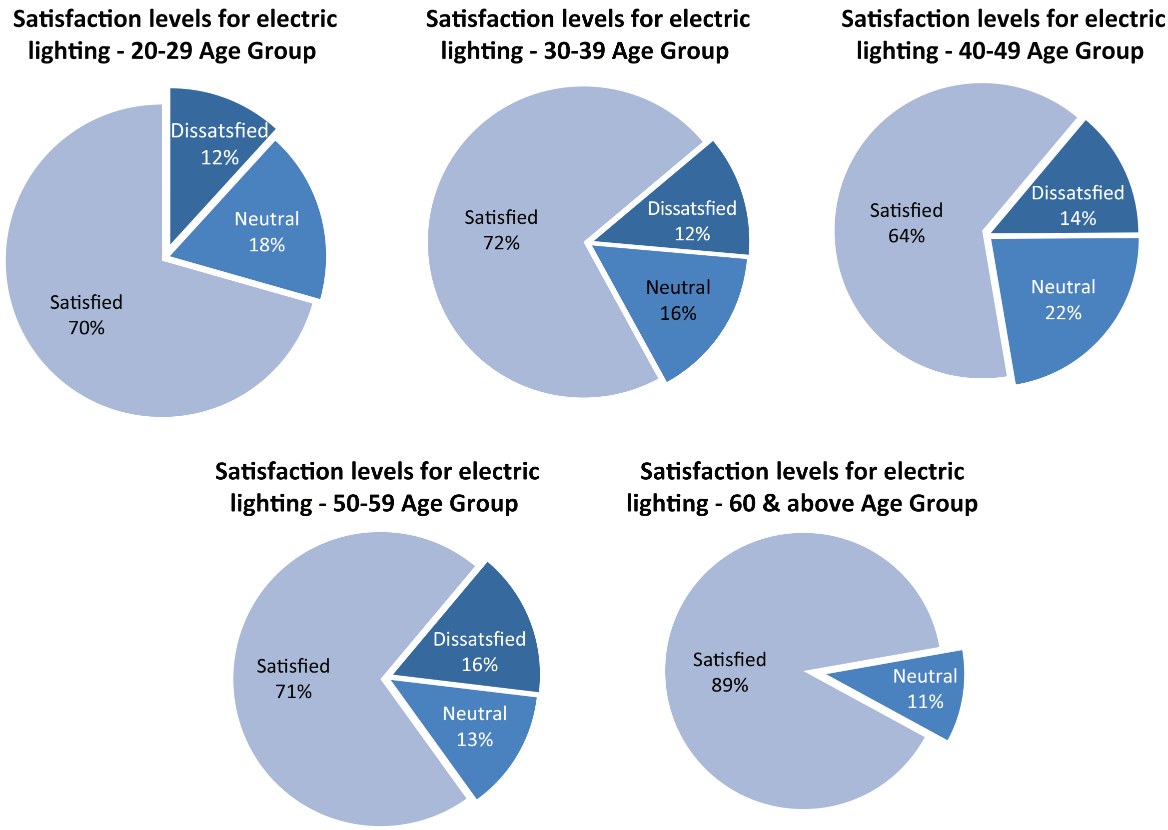


Figure 10 Satisfaction of electric lighting for different age group

Sunlight time is another important factor, as this has a great effect on satisfaction with daylighting. The actual sunlight hours in summer and the expected hours in winter are key factors for predicting satisfaction with daylighting. In actuality, the duration of sunlight hours decreases from summer to winter, and the participants would have had fewer sunlight hours in winter. In addition, the detailed results of this study confirm the findings of an earlier survey conducted by Lau et al. [16] that showed exactly the same tendency of expected hours for living room in summer. Most residents preferred to have more than four hours of sunlight on a summer day. The amounts of sunlight time that they hoped for in winter were also similar. We confirm that our participants preferred as much sunlight time as possible in the winter as in summer. This result may be due to the way that winter sunlight serves as an efficient heating source for living rooms.

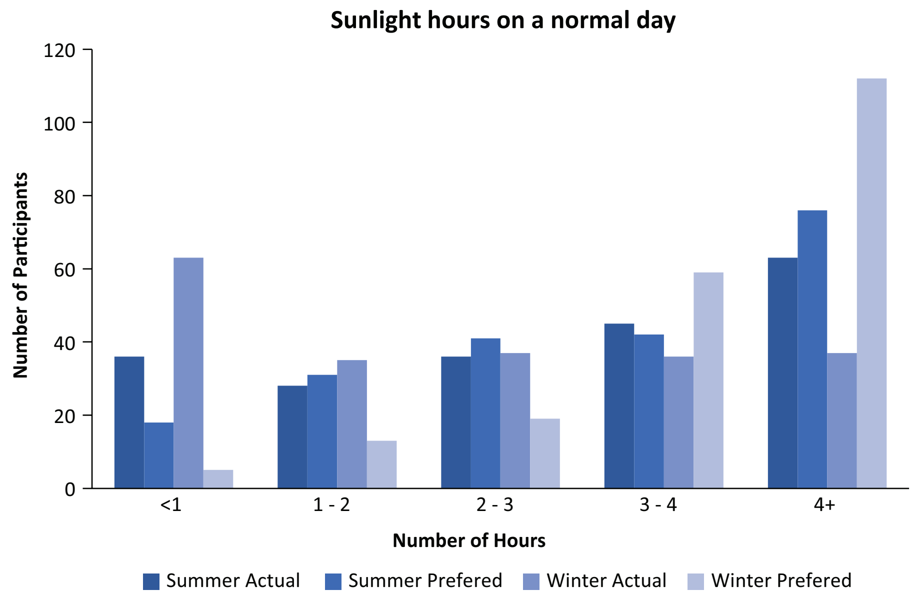


Figure 11 Sunlight hours on a normal day

The rank order of the factors affecting the satisfaction with electric lighting and daylighting

A major outcome of this survey report is the satisfaction level of the occupants from electric lighting and daylighting.

The Spearman rank correlation coefficient was applied for quantitative variables. The Spearman rank correlation coefficient is a non-parametric measure that assesses statistical dependence between two variables using a monotonic function to describe the relationship between them (Field, 2017; Xue et al., 2014).The Spearman rank coefficient for satisfaction levels w.r.t. parameters like Electric light hours in daytime, external obstruction, natural light hours in daytime and is shown in the Table 3.

Table 3 Spearman rank coefficient for satisfaction with electric lighting

	Electric light hours in daytime	External obstruction	Natural light hours in daytime	Glare
Satisfaction with Electric lighting	-0.94	0.112	0.142*	-0.363**

*Correlation significant at the 0.05 level (two-tailed).
**Correlation significant at the 0.01 level (two-tailed).

As seen in Table 4, glare had a strong and significantly negative correlation with satisfaction with electric lighting.

Table 4 Spearman rank coefficient for satisfaction with daylighting

	Electric light hours in daytime	External obstruction	Natural light hours in daytime	Glare	Solar Access Hours		Expected Hours	
					Summer	Winter	Summer	Winter
Satisfaction with Daylighting	-0.208**	0.023	0.019	-0.053	0.040	-0.228**	0.089	-0.023

Human behaviour

Human behaviour plays a very vital role while determining visual comfort. Different kind of activities needs different kind of illumination levels and these illumination levels do depend on human behaviour.

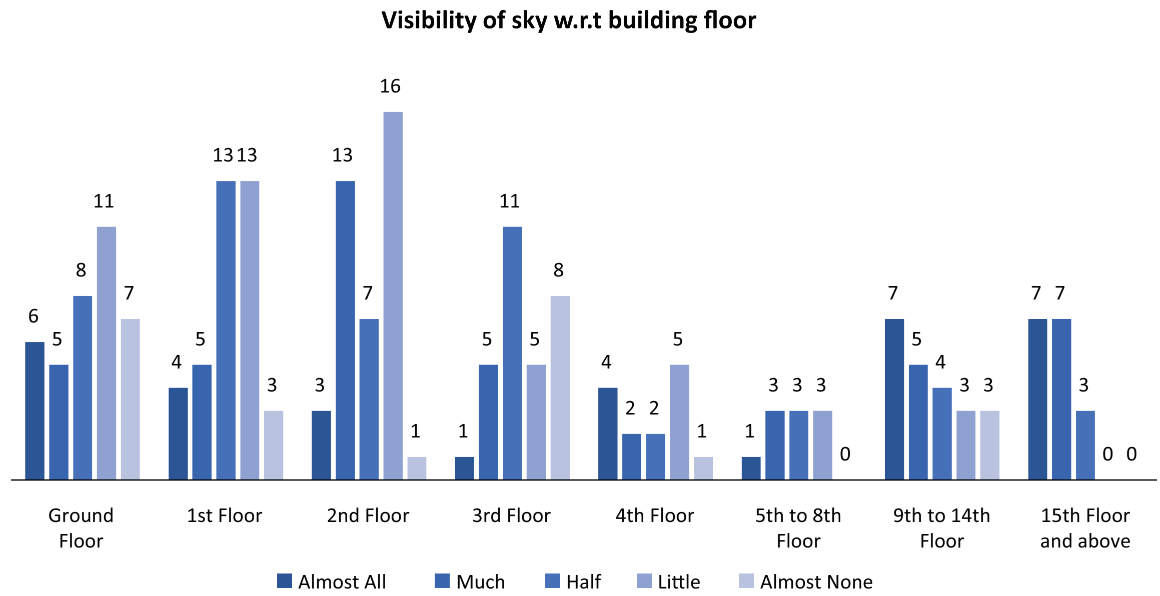


Figure 12 Visibility of sky w.r.t building floor

As shown in Figure 12 above, the responses received have been evaluated based on the sky visibility w.r.t floor level. Since external obstruction plays an important role in deciding the overall visual comfort, studying the relationship between sky visibility and floor level becomes much more important.

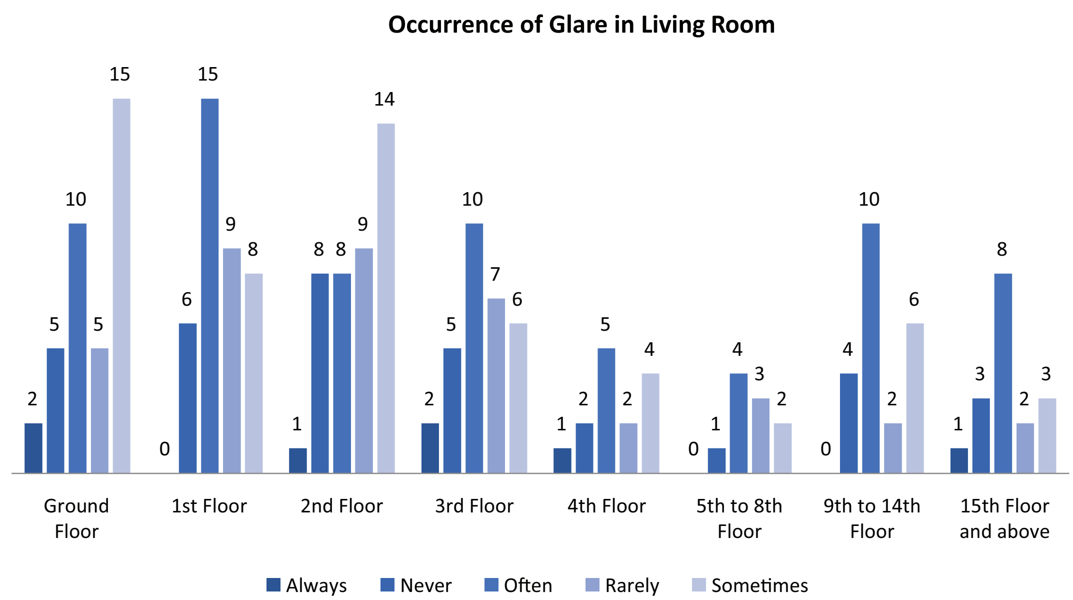


Figure 13 Occurrence of Glare in Living Room

The subject of glare has concerned researchers since the early years of the twentieth century, but even today, the causal mechanism of discomfort glare is not well understood.

However, the four factors that contribute to the perception of discomfort glare produced by an individual light source are well known and described as:

- luminance of the light source;
- position of the light source in relation to the point of fixation;
- visual size of the light source; and
- luminance of the background.

Conclusion

A questionnaire survey was conducted to study the effects of various parameters of lighting on subjective luminous comfort in low rise and high rise societies in Delhi NCR. Based on the analysis of the data, the following conclusions about the factors promoting luminous comfort can be drawn:

1. No statistical difference appears between genders concerning preferences for luminous comfort. Age, however, has some effect, as older people tend to be more satisfied with their luminous environment.
2. Glare is the major factor determining satisfaction levels for electric lighting. Other factors like Electric light hours in daytime, external obstruction and natural light hours in daytime also plays critical role in determining satisfaction levels for electric lighting.
3. Behavior factors have a significant influence on luminous comfort among people who grade their satisfaction with daylighting as moderate. People often use internal shading and artificial lighting to adjust and improve the indoor luminous environment, and these different activities influence their levels of comfort.

The results of this study may help to generate awareness of the detailed factors involved in luminous comfort. The study also shows the importance of lighting for people's overall satisfaction, and this evidence may assist policy-makers in establishing appropriate guidelines and standards. The findings would also help planners and architects implement improved lighting in their housing projects, and provide residents with better luminous environments.

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The Mahindra-TERI Centre of Excellence (MTCoE) is a joint research initiative of Mahindra Lifespaces (MLDL) and The Energy and Resources Institute (TERI). It focuses on developing science-based solutions for India's future built environment, with a view to reduce the energy footprint of the real estate industry.

The overall scope of the project includes standardization and measurement of building material, thermal and visual comfort study, development of performance standard matrices, guidelines and numerical toolkits and water related activity for sustainable water use in habitats.

The activities related to the sustainable use of water in habitats, includes both macro and micro level analysis in terms of water efficiency, conservation and management within a premise by end users in Indian cities. The study identifies potential risks associated with water sources, governance, infrastructure and demand & supply and provide recommendations to combat those risks.

MTCoE is located at TERI Gram, Gual Pahari, Gurugram, Faridabad, Haryana.

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