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# The effects of daylighting and human behavior on luminous comfort in residential buildings: A questionnaire survey

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ABSTRACT

A questionnaire survey was conducted to investigate the effects of daylighting and human behavior patterns on subjective luminous comfort in Hong Kong housing units. The participants were recruited via mail, and included residents of both public and private housing units. 340 questionnaires were returned and analyzed by using SPSS 19.0. In analyzing the response statistics, the Cronbach's alpha coefficient, Spearman rank correlation coefficient, Chi-square test, Kruskal–Wallis test and stepwise regression were adopted to identify the effects of particular aspects of human behavior and daylighting quality. The results confirmed that luminous comfort is a function of both behavior patterns and daylighting conditions. Behavior factors have a significant influence on luminous comfort among people who grade their satisfaction with daylighting as moderate. In general, the degree of luminous comfort is most affected by satisfaction with daylighting. External obstruction is the major physical factor affecting luminous comfort, while the perception of uniformity is the major factor of residents' feelings toward daylight. The use of artificial lighting is the most relevant behavior factor affecting luminous comfort, as using artificial lighting for many hours per day indicates poor daylighting conditions and decreased luminous comfort. These results should help to raise awareness of the detailed factors that influence the luminous environment. Our findings may also assist planners and architects to implement better daylighting for housing projects and provide residents with greater luminous comfort.



## 1. Introduction

Hong Kong is one of the world's most densely populated cities, with many skyscrapers and high-rise buildings. The city ranks first in number of high-rise residential buildings, and has over half of the highest 100 residential buildings in the world. Although Hong Kong is situated just south of the Tropic of Cancer and receives a lot of sunshine, the exposure of housing units to daylight can differ sharply according to factors such as floor level, orientation or external obstruction. This actual situation of daylight exposure in residential buildings affects energy costs [1]. In many cases, the degree of exposure to daylight also determines how pleasant the atmosphere is for living and home activities.

Survey studies conducted within the last decade have shown that access to daylight prevents diseases caused by vitamin D deficiency [2], determines people's preferences for window design [3], affects their visual perception and mood [4] and enhances occupant satisfaction [5]. In both offices and homes, greater exposure to daylight improves people's psychological health [6] and their productivity [7].

In recent years there have been a number of fruitful studies concerned with providing better quality daylighting. Researchers have proposed the use of optical units [8], light-pipes [9], atriums [10], remote-source lighting systems [11] and light shelves [12] which can bring daylight into rooms more intentionally and efficiently, while improving illuminance and comfort. Increased consciousness concerning comfort has aroused people's attention to their living conditions, such as thermal comfort, acoustic comfort, as well as luminous comfort. Luminous comfort is defined as the people's satisfaction with the luminous environment, as subjectively evaluated by occupants.

In studies of luminous comfort, the level of satisfaction with daylighting should be the primary consideration. Cheung [13] surveyed 642 Hong Kong residents via mail, and found that nearly 90% of the respondents were most concerned about the daylighting performance of their living rooms. Lau et al. [14] recruited 173 participants from both public and private housing units, who mainly agreed that an unobstructed view was the most valuable advantage for living room windows. Other researchers

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have investigated various additional factors that can significantly affect daylighting performance. Li et al. [15] studied the daylighting performance of heavily obstructed residential buildings in Hong Kong, and elucidated their physical environments by testing five key variables that affect interior daylight levels. These variables were building area and orientation, glass type, external obstruction, shading, and window area. Lau et al. [16] conducted a case study of Hong Kong residential flats, and provided a set of residents' preferences for solar access in high-density tropical cities. These researchers have advocated further studies to examine the light-related behavior of residents in greater detail.

The physical environments of buildings are often described simply, and such descriptions often fail to consider personal preferences for lighting conditions. To take better account of the lighting factor, many researchers have begun to evaluate human behavior in relation to lighting. Kaplan [17] concluded that researchers need to consider not only the view from a home, but also residents' nature-based activities. Abundant documentation indicates that nature plays a remarkable role in shaping people's preferences and their sense of well-being. Haynes [18] developed a theoretical framework for the measurement of indoor productivity by using questionnaire surveys that included items to assess the behavioral environment. The results of this survey showed that the interactions of structure and behavior had a significant influence on productivity. To further optimize this type of theoretical framework, Aries et al. [5] modified a model of physical and psychological discomfort to include individual factors, namely gender, age and seasonality of mood.

As these previous studies have shown, luminous comfort involves an interaction between human behavior and the quality of daylighting. The factor of human behavior includes occupants' activities and their uses of artificial lighting. Satisfaction with daylighting involves the degree of fit among the occupants' preferences, feelings toward daylight and the actual daylighting performance. However, the objective facts of daylighting performance, including the degrees of illuminance and uniformity, are determined by the physical design of the living environment.

Based on our review of the literature, we concluded that a personal questionnaire survey was the most appropriate tool for our research on luminous comfort. However, to be effective, the survey needed to include statistical analysis. Galasiu and Reinhart [19] conducted a survey via email among 177 professional participants, such as designers, engineers and researchers. The results indicated that there was no generally acknowledged method of assessing the quality or performance of a daylighting system. Clearly, personal preferences need to be coupled with statistical analysis, and researchers should choose test methods according to specific situations. Yildirim et al. [20] adopted one-way and multivariate analysis of variance to examine the effects of different variables on the perceptions of environmental conditions in two groups of people. Aries et al. [5] adopted Chi-square and path analyses to further explain the correlations between personal preferences, building designs, and perceived environmental conditions. Mak and Lui [7] added non-parametric tests such as Spearman rank correlation coefficients and Mann–Whitney *U*-tests to rate the factors affecting productivity and to identify the differences in preferences between two populations.

In developing a whole framework, the dimensions of luminous comfort, physical environment and human behavior need to be studied at the same time. Therefore, the many possible factors involved should be verified by hypothesis testing and statistical analysis. For our study, a new investigation was carried out in Hong Kong to collect data on both residents' objective living conditions and their subjective levels of luminous comfort. The specific goals of the new survey were the following: 1) to test if people of different genders and ages display significant differences in terms of their luminous comfort preferences; 2) to collect data on objective physical environment factors and to investigate the relationship between these factors and residents' satisfaction with daylighting; 3) to identify in detail how personal behavior patterns influence satisfaction with the luminous environment.

Using the data collected by our survey, we checked the reliability of the questions and analyzed the demographic characteristics of the participants using the software SPSS 19.0. This analysis was followed by an in-depth analysis using non-parametric tests to achieve the aforementioned specific goals. The results confirmed that luminous comfort is a result of the interaction between daylighting and human behavior, and that satisfaction with daylighting is the most important factor in determining the level of luminous comfort. In addition, external obstruction is the major physical environment factor that detracts from luminous comfort, and the perception of uniformity of lighting is the major factor influencing residents' levels of satisfaction with their daylighting environments. The most relevant behavioral factor affecting luminous comfort is the number of hours that residents use artificial lighting. This study will assist policy-makers in establishing appropriate guidelines and standards. The results will also help planners and architects implement more effective daylighting and provide residents with better luminous environments.

## 2. Methodology

### 2.1. Pilot study

A pilot study with a sample size of 47 people was conducted before the main study to develop our questions and check the reliability of the questionnaire. The pilot study also tested the feasibility of the statistical methods for analyzing 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. Two items were added in the modifications.

### 2.2. Sampling

The residential buildings of Hong Kong are currently categorized into either public or private housing. Public housing also has two types, namely Home Ownership Scheme (HOS) and Tenants Purchase Scheme (TPS) units. The TPS only provides rental units in buildings that were built before 1992, and the HOS offers cheap new houses for sale. The HOS, however, was halted in 2002 and only resumed in 2011. Thus, most of the recently built residential buildings have been private housing. Our survey was conducted in three residential estates in Tseung Kwan O, which is a newly developed district in Hong Kong. The estates were randomly selected among the groups and categories of housing. However, all of the buildings were over 40 stories tall, and the floor areas of the flats in these buildings were between 45 and 60 $m^2$ in size.

### 2.3. Questionnaire survey

The survey was conducted during November and December of 2013, with the participants recruited via mailed invitations. A questionnaire as shown in Fig. 1 consisted of five parts, and aimed to collect data on both the residents' objective living conditions and their subjective levels of luminous comfort. The questions were determined according to the survey objectives, the assumptions of the researchers and other references. 1782 questionnaires were sent out, and 464 completed surveys were returned to the authors

**Indoor luminous comfort questionnaire**

Part 1 – General Information

1. Age

| | | | | |
|---|---|---|---|---|
| ⩽25 | 26～35 | 36～45 | 46～55 | ⩾56 |

2. Gender

| | |
|---|---|
| Male | Female |

Part 2 – Physical Environment

3. The floor of your house is:

| | | | | |
|---|---|---|---|---|
| ⩽5 | 6～10 | 11～20 | 21～30 | >30 |

4. The area of your living room is (square foot):

| | | | | |
|---|---|---|---|---|
| <50 | 50～100 | 100～200 | 200～300 | >300 |

5. The orientation of your living room is:

| | | | |
|---|---|---|---|
| North | East | West | South |

6. The area of the window in your living room is (square foot):

| | | | | |
|---|---|---|---|---|
| <10 | 10～20 | 20～30 | 30～40 | >40 |

7. How much of the sky is obscured above the horizontal view from the window of your living room?

| | | | | |
|---|---|---|---|---|
| Almost all | Much | A half | Little | Almost none |

Part 3 – Feelings towards Daylight

8. In general, how many abundant daylight hours last in a day without using artificial light?

| | | | | |
|---|---|---|---|---|
| <1 | 1～3 | 3～5 | 5～7 | >7 |

9. Do you agree that your living room has a good uniformity distribution of illuminance?

| | | | | |
|---|---|---|---|---|
| Strongly disagree | Disagree | Just right | Agree | Strongly agree |

10. How many hours will the sunlight shine into the living room in summer?

| | | | | |
|---|---|---|---|---|
| <1 | 1～2 | 2～3 | 3～4 | >4 |

11. How many hours do you prefer that the sunlight shine into the living room in summer?

| | | | | |
|---|---|---|---|---|
| <1 | 1～2 | 2～3 | 3～4 | >4 |

12. How many hours will the sunlight shine into the living room in winter?

| | | | | |
|---|---|---|---|---|
| <1 | 1～2 | 2～3 | 3～4 | >4 |

13. How many hours do you prefer that the sunlight shine into the living room in winter?

| | | | | |
|---|---|---|---|---|
| <1 | 1～2 | 2～3 | 3～4 | >4 |

14. How often do you think does the sunlight bring you the following troubles?

（1）*Thermal discomfort*

| | | | | |
|---|---|---|---|---|
| Always | Often | Sometimes | Rarely | Never |

（2）*Glare*

| | | | | |
|---|---|---|---|---|
| Always | Often | Sometimes | Rarely | Never |

（3）*Fading object*

| | | | | |
|---|---|---|---|---|
| Always | Often | Sometimes | Rarely | Never |

15. Do you agree that the overall daylighting effect in your living room is satisfactory?

| | | | | |
|---|---|---|---|---|
| Strongly disagree | Disagree | Just right | Agree | Strongly agree |

Part 4 – Human Behaviors

16. What is your main activity in your living room at daytime?

| | | | | |
|---|---|---|---|---|
| relaxing | Watching | Eating | Chatting | Reading |

17. The internal shading in your living room is usually:

| | | | | |
|---|---|---|---|---|
| All drawn | Drawn more than a half | Drawn a half | Drawn less than a half | Not drawn |

18. What is the main purpose of using the internal shading?

| | | | | |
|---|---|---|---|---|
| No shading | Prevent direct light | Prevent reflect light | Prevent private | Prevent heat |

19. How many hours do you turn on the artificial light in daytime when at home?

| | | | | |
|---|---|---|---|---|
| <1 | 1～3 | 3～5 | 5～7 | >7 |

20. Which kind of artificial lighting is mainly used in your living room?

| | | | |
|---|---|---|---|
| Incandescent lamp | Energy saving lamp | Fluorescent lamp | LED |

Part 5 –Luminous Comfort

21. Do you agree that the luminous environment of your living room is satisfactory?

| | | | | |
|---|---|---|---|---|
| Strongly disagree | Disagree | Just right | Agree | Strongly agree |

**Fig. 1.** The questionnaire used in this study.

through collection boxes, out of which 340 were valid for further analysis.

The rationale of the questionnaire is shown in Fig. 2. The first part included the participants' gender and age as background information. Part 2 involved objective questions about their physical living environments, such as floor level, orientation, window area, living room area, shading devices and external obstructions. Among these items, four factors were based on the study of Li et al. [15], and another two factors were added for basic information. Part 3 concerned the residents' feelings toward their daylighting environment, including the factors of skylight, sunlight and the perception of uniformity. We asked the residents to assess their abundance of daylight time as an indication of the relationship between their physical environment and their feelings. We asked about their sunlight access time compared with their expectations (both in summer and winter). A question about sunlight problems helped us to check the residents' preferences for sunlight. These questions concerning access to sunlight were based on the study of Lau et al. [16]. We then collected information on residents' subjective feelings toward daylight to investigate the factors affecting

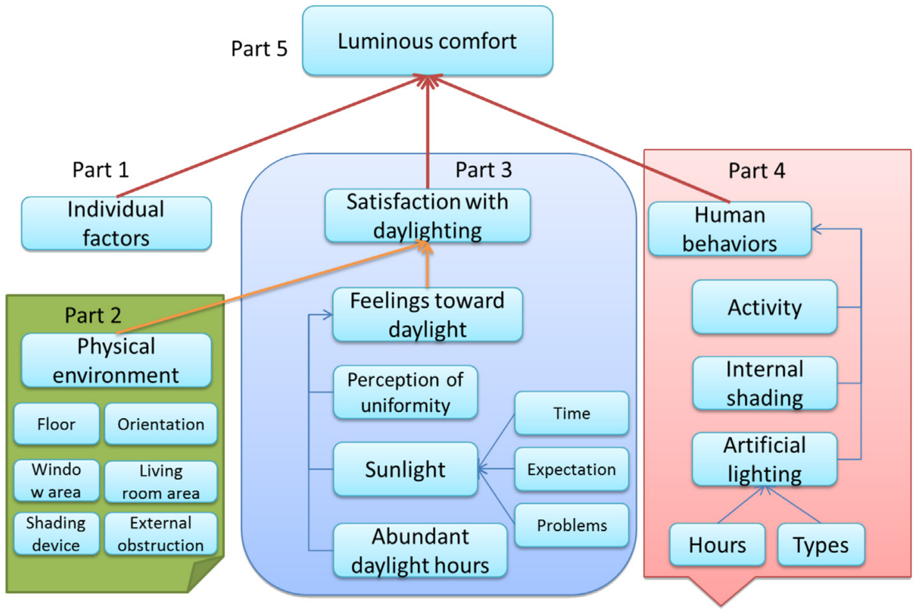


**Fig. 2.** Rationale and content of the questionnaire.

their levels of satisfaction. The residents answered these questions on a five-point scale. Part 4 comprised questions regarding the residents' light-related behavior, namely the kinds of activities they performed in their living rooms, their use of internal shading, and the times and types of artificial lighting they used. These behavioral questions were based on those used in a dissertation by Cheung [13]. In part 5 of the questionnaire, the participants were invited to answer the question regarding the residents' overall satisfaction with their whole luminous environment, including both daylighting and artificial lighting.

### 2.4. Statistical analysis

The data were accurately coded and analyzed using SPSS 19.0. The statistical reliability was first tested to assess the overall consistency of the psychometric questions. The Cronbach's alpha coefficient was used to estimate the internal consistency of the two scales, the level of satisfaction with daylighting and human behavior 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. The Spearman rank correlation coefficient is a non-parametric measure of statistical dependence between two variables that assesses how well a relationship can be described using a monotonic function. This correlation coefficient was applied to investigate the relationship between the residents' satisfaction with daylighting and the other factors measured. Stepwise regression is a step-by-step selection model that involves automatic selection of independent variables. This analysis was further used to find the most parsimonious set of predictors for satisfaction with daylighting. The Kruskal–Wallis test is another non-parametric test of the null hypothesis that three populations are the same (as opposed to an alternative hypothesis). This type of test has greater efficiency than the *t*-test for non-normal distributions. The Kruskal–Wallis test was therefore adopted to identify differences in degree of luminous comfort and in light-related behavior as graded by the participants.

## 3. Results

### 3.1. Reliability of the questions

In statistical analysis, Cronbach's alpha is commonly used to estimate the reliability of a psychometric test. The questions involving perceptual evaluations were tested by this coefficient (omitting those regarding the objective physical environment). The reliability of the questions concerning feelings toward daylight (nine items) and human behavior (four items) are shown in Table 1.

The Cronbach's alpha coefficient estimated the internal consistency of the scales, and the values concerning feelings toward daylight and human behavior were 0.753 and 0.673, respectively. Both the number of test items and the item dimensionality affected the values of the alpha. A low alpha value could be due to a low number of questions or to poor interrelatedness between items. The acceptable value of the alpha has been announced in different studies as ranging from 0.60 to 0.95 [20,21]. The coefficients in our study were both above 0.60, representing good reliability. The scales can thus be considered reliable.

### 3.2. Demographic characteristics of the participants

Bivariate associations between luminous comfort, gender and age were tested by a Chi-square test, and the results of frequency

**Table 1**
Reliability of the dependent variables.

| Feelings toward daylight | Cronbach's alpha | Human behavior | Cronbach's alpha |
|---|---|---|---|
| Abundance of daylight hours<br>Perception of uniformity<br>Problems sunlight brings (3 items)<br>Sunlight access hours (summer and winter)<br>Expectation of sunlight hours (summer and winter) | 0.753 | Kinds of activities<br>Internal shading<br>Artificial lighting hours<br>Artificial lighting types | 0.673 |

distributions in the participants' demographic characteristics are presented in Table 2.

Fifty-one percent of the participants were female. The number of participants in each age band is shown in Table 2. No statistical difference in gender occurred for feelings of luminous comfort according to the Chi-square test ($P > 0.05$). However, there was a significant difference in satisfaction between different age groups ($P < 0.05$). The result generally suggests that older people tends to be more satisfied with the luminous environment. It is a known fact that people's visual ability degrades as they age because their lenses become thicker and absorb more light. Older people may need a higher lighting level for their visual activities. However this fact doesn't imply that they are more likely to be dissatisfied with the luminous environment as reflected from the result of the questionnaire survey. In the contrast, the result suggests that older people tends to give higher ratings for luminous comfort. It may be because older people are milder towards dissatisfaction to their living environment compared to younger people who would express their discontent more actively.

### 3.3. Rank order of the factors affecting the satisfaction with daylighting

Satisfaction with daylighting was a main element in luminous comfort, and this element involved two primary aspects: the actual physical environment and the resident's feelings toward daylight. Both physical and emotional factors have great influence on levels of satisfaction with daylighting. Tables 3 and 4 show how well these elements affect satisfaction by applying a Spearman rank correlation coefficient, which tests the monotonic function. The larger the coefficient values, the closer the relationship between elements.

As seen in Table 3, external obstruction had a strong and significantly positive correlation ($P$-value $< 0.01$) with satisfaction with daylighting. The correlations between satisfaction with daylighting and the physical factors of floor level, orientation and window area were also significant, with a $P$-value of less than 0.05. The coefficients of shading device and floor area were 0.082 and 0.102, respectively, but the $P$-values were greater than 0.05, which means that these factors were not significant. As correlations were found between the satisfaction with daylight and these significant physical environment factors, more detailed information as to these correlations was shown in Fig. 3.

As seen from Fig. 3, generally, less external obstruction, higher floor and bigger window area could increase the residents' daylighting satisfaction level. The residents with windows facing south were more satisfied than those with other window orientations.

Table 4 shows that the perception of uniformity, abundance of daylight hours, thermal discomfort, and solar access hours in both summer and winter all had significantly positive correlations

**Table 3**
Spearman rank correlation coefficients of satisfaction with daylighting and the physical environment.

| | Floor level | Shading device | Floor area | Orientation | Window area | External obstruction |
|---|---|---|---|---|---|---|
| Satisfaction with daylighting | .137[a] | 0.082 | 0.102 | .132[a] | .122[a] | .354[b] |

[a] Correlation significant at the 0.05 level (two-tailed).
[b] Correlation significant at the 0.01 level (two-tailed).

($P$-value $< 0.01$) with satisfaction with daylighting. Expectations of sunlight time in summer and winter had a correlation coefficient with a $P$-value of less than 0.05. The other factors had lower coefficients with poor $P$-values, which indicated they were not significant.

After the simple correlation analysis, stepwise regression was further used to find a set of predictors that would be effective in predicting satisfaction with daylighting. Satisfaction with daylighting was set as the dependent variable, and the 11 relevant factors tested by the significance level from Tables 3 and 4 were chosen as independent variables. A statistically significant model was then selected ($R = 0.94$, $F = 44.172$, $P < 0.001$) from the six obtained models. Table 5 shows the results of the analysis.

As can be seen from Table 5, the perception of uniformity, thermal discomfort, obstruction, solar access hours in summer, expected sunlight hours in winter and orientation all had significant $P$-values. The standardized beta reveals the relative influence of the six factors. Basically, the degree of perception of uniformity had a principal influence on daylight comfort, and the other factors had a secondary influence.

### 3.4. Human behavior

People often use internal shading and artificial lighting to adjust or improve their indoor luminous environment. However, different activities need different kinds of illumination, and different lamps provide different color temperatures. Therefore human behavior, including the use of artificial lighting, should also be included in assessments of luminous comfort. From the collected data, as shown in Fig. 4, 30.9% of the participants felt more comfortable with their whole luminous environment than satisfied with their daylighting environment. Only 8.5% of the participants felt that their level of satisfaction decreased after considering their own light-related behavior. Some 60.6% of the participants reported the same level of satisfaction with their overall luminous comfort as they did with their daylighting situation. In general, it can be concluded that the level of satisfaction with daylighting had the greatest influence on level of overall luminous comfort.

For further analysis of how behavioral factors affect luminous comfort, we selected the group of people who graded their degree

**Table 2**
Cross-tabulation of luminous comfort with gender and age.

| | | Luminous comfort | | | | | Total | Pearson Chi-square |
|---|---|---|---|---|---|---|---|---|
| | | Strongly disagree | Disagree | Just right | Agree | Strongly agree | | |
| Gender | Male | 1 | 14 | 67 | 67 | 17 | 166 | 0.725 |
| | Female | 2 | 10 | 64 | 80 | 18 | 174 | |
| Total | | 3 | 24 | 131 | 147 | 35 | 340 | |
| Age | ≤25 | 0 | 6 | 13 | 25 | 1 | 45 | 0.031 |
| | 26–35 | 2 | 6 | 28 | 21 | 5 | 62 | |
| | 36–45 | 0 | 5 | 37 | 34 | 9 | 85 | |
| | 45–55 | 0 | 5 | 30 | 23 | 10 | 68 | |
| | ≥56 | 1 | 2 | 23 | 44 | 10 | 80 | |
| Total | | 3 | 24 | 131 | 147 | 35 | 340 | |

**Table 4**
Spearman rank correlation coefficients of satisfaction with daylighting and feelings toward daylight.

| | Perception of uniformity | Abundance of daylight hours | Solar access hours | | Expected hours | | Sunlight problems | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Summer | Winter | Summer | Winter | Thermal discomfort | Glare | Fading |
| Satisfaction with daylighting | .607[b] | .382[b] | .267[b] | .208[b] | .217[a] | .136[a] | .184[b] | 0.087 | 0.105 |

[a] Correlation significant at the 0.05 level (two-tailed).
[b] Correlation significant at the 0.01 level (two-tailed).

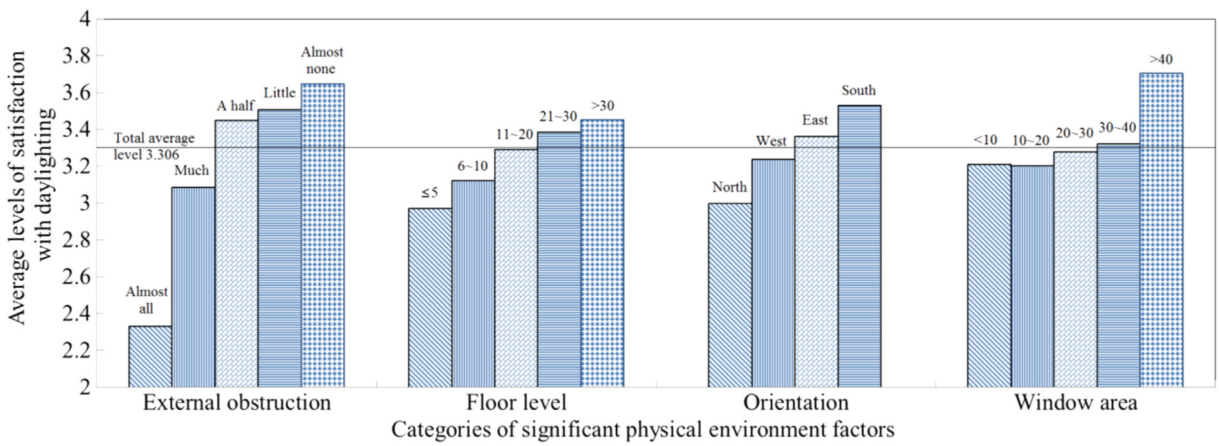


**Fig. 3.** Satisfaction with daylighting across the categories of significant physical environment factors.

of comfort with daylighting as “just right”, and treated their degree of luminous comfort as the dependent variable. The Kruskal–Wallis test was adopted to study how different patterns of behavior improved the participants' satisfaction. In each test of behavior, 149 participants were grouped according to their own survey question answers, and the degree of overall satisfaction they indicated was set as the result. The distribution of satisfaction levels was the same across behavior patterns when their *P*-values were above 0.05. The smaller the *P*-value for a given type of behavior, the more important the role that the type of behavior played. The third column (where the degree of satisfaction with daylighting is 3) in Table 6 shows the results of these tests.

As the third column in Table 6 indicates, the distributions of kinds of living room activity, internal shading area and artificial lighting type were the same across the categories of luminous comfort. In other words, these activities made little contribution to overall luminous comfort. Artificial lighting hours, however, had a significant influence on luminous comfort levels. To provide a comprehensive analysis, a Kruskal–Wallis test was applied to investigate how these kinds of behavior influenced luminous comfort and the degree of satisfaction with daylighting. Table 6 shows the summary of the hypothesis testing results.

As can be seen from Table 6, behavior factors had great influences on the participants' who graded their level of satisfaction with daylighting as moderate. However, in the cases in which participants were strongly dissatisfied or strongly satisfied with their daylighting performance, no particular behavior factors appeared to have a significant influence. Lateral comparison showed that artificial lighting hours and kinds of activity had the most significant *P*-values among the four behavior factors. On average, the increased use of artificial lighting was the most relevant and efficient behavior affecting the luminous environment and people's luminous comfort.

By comparing the average degrees of satisfaction shown in Fig. 5, it can easily be seen that longer periods of artificial lighting decreased the level of luminous comfort in relation to degrees 2 (disagree) and 3 (just right) of satisfaction with daylighting. This finding suggests that people tend to feel more uncomfortable in situations in which artificial lighting is overused. Using interior illumination for long periods can indicate that the room lacks good quality daylighting. This result also provides the evidence that daylighting is a key factor in luminous comfort.

**Table 5**
Coefficients of regression.

| Model 6 | Standardized Beta | $t$ | Sig. |
|---|---|---|---|
| Perception of uniformity | 0.453 | 9.231 | 0.000 |
| Thermal discomfort | 0.267 | 5.803 | 0.000 |
| External obstruction | 0.183 | 3.890 | 0.000 |
| Solar access in summer | 0.209 | 4.255 | 0.000 |
| Expected hours in winter | −0.134 | −2.936 | 0.004 |
| Orientation | 0.115 | 2.646 | 0.009 |

## 4. Discussion

The 340 valid responses to the survey allowed this study to provide a set of rational results concerning residents' feelings about luminous comfort in high-rise residential buildings. This result confirms that the questionnaire survey is a practicable way to obtain data from residents living in different kinds of estates. The reasonable results also show that the residents have their own preferences for and feelings about luminous comfort. The whole study concentrated on solving the complex causal relationship between luminous comfort and a range of physical and behavioral conditions. However, there are still two aspects of the issue that need to be addressed. The first aspect involves the effect of artificial lighting in decreasing the degree of luminous comfort. The second aspect relates to the other factors that showed some influence on luminous comfort.

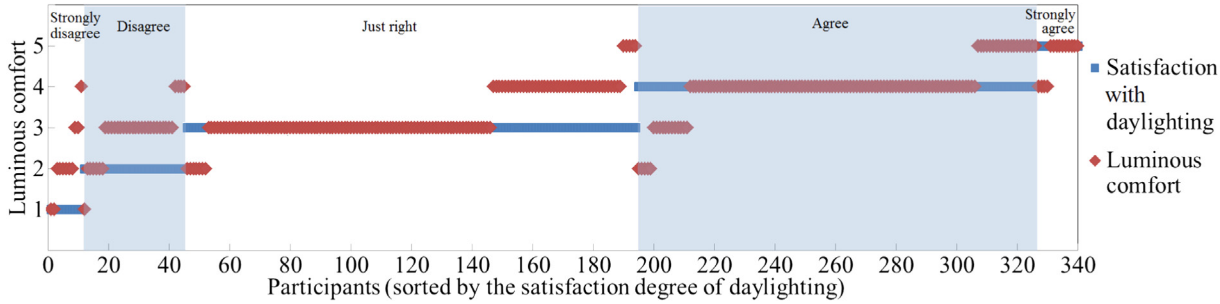


**Fig. 4.** Comparison of satisfaction with daylighting and level of luminous comfort.

### 4.1. *Increases in artificial lighting hours decrease luminous comfort*

We posed an artificial lighting question to see if this type of lighting increased people's satisfaction with their luminous environment compared with their satisfaction with daylighting. In fact, the unexpected result is very reasonable and constitutes a real contribution. As can be seen in Fig. 5, the level of satisfaction with the luminous environment declined with increasing hours of artificial lighting. Nevertheless, there was an exception to this pattern in cases in which residents felt that their overall lighting comfort and their quality of daylighting were both just right, yet their use of interior lighting went beyond seven hours. This result could indicate that these particular residents had grown used to having strong illumination all day long. In general, seven hours of artificial light indicates that a household lacks sufficient natural light, or that the illuminance is not adequate for the whole day. We used the Pearson coefficient to further test the relationship between artificial lighting hours and luminous comfort, and the result is shown in Table 7.

**Table 6**
Hypothesis test summary with different degrees of satisfaction with daylighting.

| Degree of satisfaction with daylighting | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Kinds of living room activity | 0.713 | 0.025[a] | 0.351 | 0.019[a] | 0.539 |
| Internal shading area | 0.382 | 0.155 | 0.099 | 0.055 | 0.833 |
| Artificial lighting hours | 0.655 | 0.021[a] | 0.000[a] | 0.702 | 0.736 |
| Artificial lighting types | 0.141 | 0.234 | 0.245 | *0.025*[a] | 0.219 |

[a] The significance level is 0.05. Reject the null hypothesis

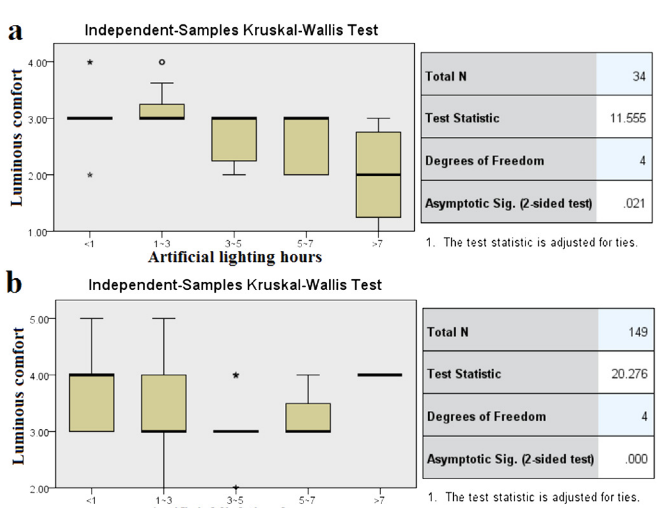


**Fig. 5.** Luminous comfort across the categories of artificial lighting hours with different degrees of satisfaction with daylighting (a) Degree 2; (b) Degree 3.

The coefficient shown in Table 7 is −0.455, which means that the correlation between luminous comfort and artificial lighting was negative and linear, with the degree being significant at the 0.01 level. This result indicates that increased use of interior lighting reflected a lower satisfaction with luminous conditions. People prefer daylight where it is available. When daylight is restricted, artificial lighting needs to be used. In this case, the level of satisfaction for residents will be reduced. An earlier survey [22] also suggested another reasonable explanation for our result, namely that the diverse luminous conditions created by comfortable daylighting allow residents to choose the ambience they feel most appropriate to their own definition of comfort. In contrast, artificial lighting can only increase the illuminance and provide certain lighting effects.

### 4.2. *Other factors affecting luminous comfort*

The findings of this study clearly present the key factors involved in satisfaction with daylighting. Among these factors, external obstruction is the main physical impediment, and perception of uniformity of light is the main factor influencing residents' feelings toward daylight.

External obstructions block much of the sky in heavily developed zones of residential buildings, and increasing obstruction decreases the degree of satisfaction with daylighting. A similar phenomenon was also reported by Chang and Chen [23], who explained that having a good view of the outside area has a major effect on human physiological and psychological well-being. This finding is understandable, because the suggestions given by residents indicated that some of the participants also thought that the reflected luminance from the surrounding buildings was another obstruction problem. These results confirm the findings of Li et al. [15], and show that the level of external obstruction influences satisfaction with daylighting, regardless of whether the obstruction causes shade or reflected light.

The perception of uniformity has always been a big issue when studying daylighting performance. This factor is also one of the four key values in advocating for daylighting systems, and improvement in the uniformity of light is considered highly valuable [24]. Galasiu and Reinhart [19] proposed a pertinent question concerning what indicator they should use to assess the quality of daylighting

**Table 7**
Pearson coefficient between luminous comfort and artificial lighting hours.

| Luminous comfort | Artificial lighting hours |
|---|---|
| Pearson Correlation | −.455[a] |
| Sig. (2-tailed) | 0.000 |
| N | 340 |

[a] Correlation significant at the 0.01 level (two-tailed).

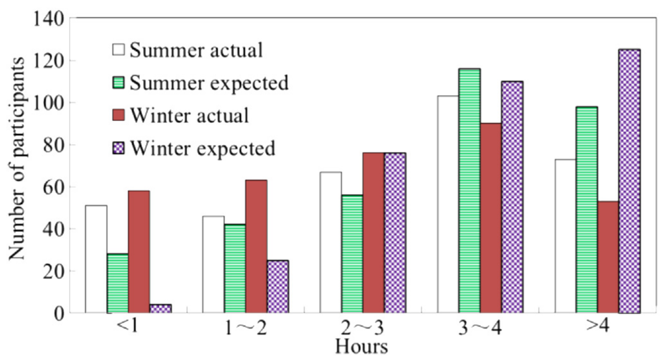


**Fig. 6.** Sunlight hours on a normal day.

performance. More than 60% of 28 professional researchers gave the answer of the perception of uniformity, with this value ranking third in importance behind energy saving and avoidance of glare. Surprisingly, the glare problem had a low correlation with satisfaction with daylighting in our residential survey. Galasiu and Veitch [25] found that the actual discomfort glare from windows in an office environment is less problematic than the one predicted by daylighting glare index models, and the perceived degree of discomfort glare is mostly associated with the task being performed. In residential environments people may be more tolerant of glare than in office settings, where glare may impede the task performance. At home, people have a greater freedom of movement than at work and also have other means to control glare that may not be available at work. As energy saving is not a factor in luminous comfort, it is understandable that our survey participants rated the perception of uniformity of light as more important than other factors affecting luminous comfort.

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, as indicated in Section 3.3. In actuality, the duration of sunlight hours decreases from summer to winter, and the participants would have had fewer sunlight hours in winter (see Fig. 6). 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 three to four hours of sunlight on a summer day. However, the amounts of sunlight time that they hoped for in winter were considerably different. We confirm that our participants preferred as much sunlight time as possible in the winter. This result may be due to the way that winter sunlight serves as an efficient heating source for living rooms.

## 5. Conclusion

A questionnaire survey was conducted to study the effects of daylighting and human behavior on subjective luminous comfort in both public and private housing estates in Hong Kong. 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) The perception of uniformity, thermal discomfort, external obstruction, solar access hours in summer, expected sunlight hours in winter and orientation are the six key factors that determine people's levels of satisfaction with daylighting. External obstruction is the major physical factor affecting luminous comfort, while the perception of uniformity is the major factor of residents' feelings toward daylight.
3) Satisfaction with the quality of daylighting determines the level of luminous comfort more than behavior-related factors such as the use of artificial lighting. Some 60.6% of the survey participants reported that their level of luminous comfort was the same as their level of satisfaction with daylighting.
4) 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.
5) The use of artificial lighting (by number of hours) is the most relevant behavior for influencing levels of luminous comfort. Use of artificial lighting for many hours a day indicates poor conditions of daylighting and decreased luminous 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 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 luminous environments. In further studies, daylighting performance will be tested with computer simulations or on-site measurements. A combination of objective measurements and subjective evaluations will result in a more precise study, especially in terms of the interaction between people's behavior patterns and their experiences of luminous comfort.

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