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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