Impacts of dynamic glazing on office workers' environmental and psychological responses

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ABSTRACT: Indoor environmental quality is a critical factor that significantly affects an occupant's work productivity, environmental health, and quality of life, especially in the workplace where a competent organization, and pleasant and healthy surroundings help assure maximum productivity. However, most building environmental design components, such as façade, are static, while the outdoor environmental condition (i.e., weather) is dynamically affecting the indoor environmental quality with significant and diverse changes. This structural limitation results in potentially compromising the environmental perceptions of a building's occupants. With the help of advanced technologies, there have been numerous efforts to implement dynamic features in modern buildings, especially dynamic structural façade components, such as electrochromic windows (called dynamic glazing). An industrial and academic research collaboration team conducted an on-site building study by collecting IEQ components in a commercial office, that was equipped with dynamic glazing. For effective comparison, an occupant environmental satisfaction study was conducted on two floors, one equipped with conventional manual blinds, and the other with dynamic glazing. The study outcomes showed that the occupants on the floor equipped with dynamic glazing reported higher environmental and psychological satisfaction/positive responses than those on the floor equipped with manual blinds. This study also revealed that environmental satisfaction and psychological perceptions could be affected by different workstation locations, such as core and perimeter zones. Therefore, these results confirmed that dynamic glazing could be effectively integrated with modern building environments to enhance individual occupants' environmental perceptions and psychological health. It follows that this would result in higher work productivity in a commercial office workplace.

KEYWORDS: Environmental comfort; Occupant well-being; Data acquisition; Dynamic glazing; Electrochromic windows; Healthy environment; Human factor

INTRODUCTION

Among the indoor environmental quality (IEQ) components in the built environment, thermal and visual quality components have been considered as major IEQ parameters that significantly affect the occupants' environmental comfort and work productivity, as well as physiological health conditions (Lan et al. 2011; J.-H. Choi, Loftness, and Aziz 2012; Loftness et al. 2009; J.-H. Choi and Moon 2017; Loftness et al. 2018; J. Choi, Aziz, and Loftness 2010). Due to the significant roles in the IEQ domain, many efforts have endeavored to accomplish better thermal and visual environmental qualities, based on the use of numerous design and technology advancements. In recent decades, with the help of advanced technologies, buildings have begun to have dynamic features in its environmental attributes for interior and exterior conditions (Bakker et al. 2014; Hammad and Abu-Hijleh 2010; Lollini, Danza, and Meroni 2010; Lee, Claybaugh, and LaFrance 2012). Among those technology-adopted building façade components, an electrochromic window, called "dynamic glazing", has emerged in the high-performance building area. Due to its advancement that enables dynamically changing visual transmittance and solar heat gain coefficients, this technology has become popular in many building typologies, especially in healthcare facilities and commercial offices. Since the dynamic pattern of such smart glazing can be controlled, as a function of solar radiation and illuminance of the outdoor condition, indoor environmental conditions, especially thermal and lighting conditions, are automatically controlled without the need for an occupants' manual control of blinds.

However, even though lab-based IEQ performance has been conducted to validate the technical function of dynamic glazing in recent studies (Lee, Claybaugh, and LaFrance 2012; Lollini, Danza, and Meroni 2010), they primarily focused on energy performance, rather than user-satisfaction centered approaches, and there is still limited, or no research effort being made to validate the IEQ performance generated by dynamic glazing in a real office environment. Therefore, this study conducted a comparison study of occupant environmental satisfaction and psychological perceptions for two different office floors; one equipped with manual horizontal blinds and the other with dynamic glazing. Since the same group of occupants stayed in both the offices before and after their move, this research was conducted in the form of a pre- and post-study.

1.0 METHODOLOGIES

One commercial office building, located in Toronto, Canada, was selected for the field study, and two office floors were selected as the testbed,. One floor (12th floor) was equipped with manual blinds, and the office on the other floor (17th) had dynamic glazing. 17 occupants worked on the 12th floor for six months and then moved to a new floor (17th floor). The survey discussed below was conducted 2 weeks before and after the move in the form of a pre-and post-study. They were conducted on April on the 12th floor and in May on the 17th floor, to minimize a seasonal variation. Fig. 1 shows an office building selected for this study, and Table 1 summarized climate conditions of the selected site in April and in May when the surveys were conducted.

This study primarily consisted of environmental satisfaction (Oxford Questionnaires) and psychological response surveys (Kansei Engineering Questionnaires), which are commercially available. The Oxford questionnaires include multiple questions that ask about an individual occupant's thermal, lighting, air, and acoustic satisfaction, while the Kansei Engineering questionnaires are mainly about psychological perceptions that include negative and positive emotional responses to the user's ambient environmental conditions. This study adopted the Minitab software for statistical analyses, especially for two-sample T-tests, analysis of variance, and paired T-tests for the pre- and post-analysis (Minitab 2016).

As summarized in Table 2, 12 of those 17 participants to the survey were females and five were males. Due to the significant impact of workstation location on the users' environmental satisfaction and ambient thermal and visual conditions, the workplaces were divided into two zones: core and perimeter areas depending on the distance between the building façade and individual workstations while 15 ft was adopted as a threshold to define the zones.

Table 2. Weather condition

	April 30, 2018	May 10, 2018
High temperature ('F)	64	69
Low temperature ('F)	38	50
Day average temperature ('F)	51	60
Day average humidity	48%	45%

Table 3. Demographic information

Floor	Female	Male		Office location – Perimeter	Office location – Core	Total
12th	12	5		12	5	17
17th	12	5		9	8	17

Figure 1. Facade view of the selected building

3.0 RESULTS and DISCUSSION

2.1 Improvements in user satisfaction with lighting, daylight, and window view.

The occupants were asked regarding their satisfaction with their window view to the outside, quality of daylight, and overall lighting conditions at their workstations on both of the floors. As shown in Figure 2, the occupants' were more satisfied with those environmental components in the dynamic glazing room than in the room with manual blinds. Occupants in offices with dynamic glazing have a 29.4% higher satisfaction rate with the quality of light, a 30.6% higher satisfaction rate with overall lighting conditions, and a 35.4% higher satisfaction rate with views to the outside, as compared with the opinions of occupants in identical office locations and orientation with manually controlled blinds (all p-values <0.001).

Figure 3 summarizes the comparison results of environmental satisfaction between 12th and 17th floors. The occupants in offices with dynamic glazing reported higher satisfaction with lighting and window view, quality of light, overall lighting, alertness, happiness, and perceived productivity. In a five-point scale ((1: Very poor, 2: Poor, 3: Fair, 4: Good, 5: Excellent), the average scores of those satisfactions are 2.8 and 4.2 on 12th and 17th floors, respectively, and it results in a 29% difference on the basis of a full 5 score. All these comparisons were identified with statistical significances (all p-values < 0.05)

2.2 Use of mitigation devices

This study found that occupants in offices with dynamic glazing used fewer mitigation devices to ensure visual comfort than those in offices with manually controlled blinds on the windows. To help control the ambient visual quality affected by daylight/electric light, we observed the following items: polarizing screens; visual blocks such as folders, books or plants; caps or hats; changes in desk position; and specialized eyewear (i.e. sunglasses, transition lenses, computer glasses. According to the survey data, occupants in offices with manually controlled blinds reported using on average 2.5 of 5 visual mitigation devices to cope with excess glare, while occupants in offices with dynamic glazing reported on average 0.4 visual mitigation devices, as summarized in Figure 4. The statistical significance was found at a p-value of <0.001.

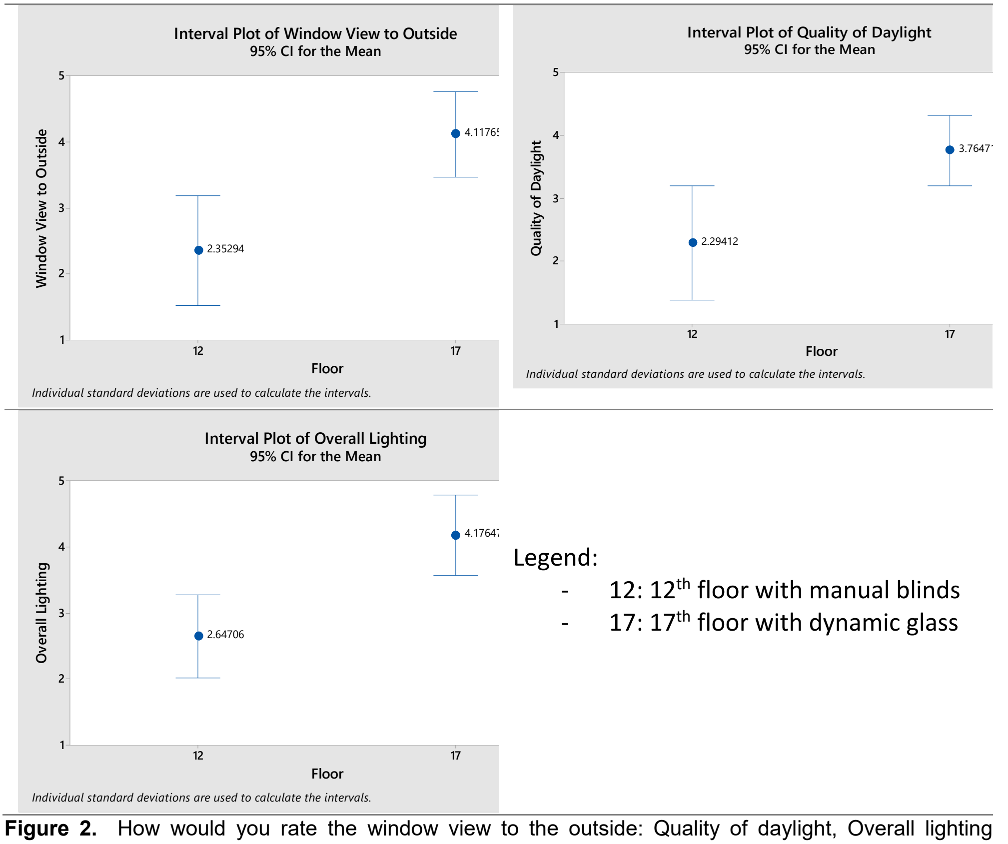

Figure 2. How would you rate the window view to the outside: Quality of daylight, Overall lighting conditions at your workstation? (1: Very poor, 2: Poor, 3: Fair, 4: Good, 5: Excellent) (all p-values <0.001).

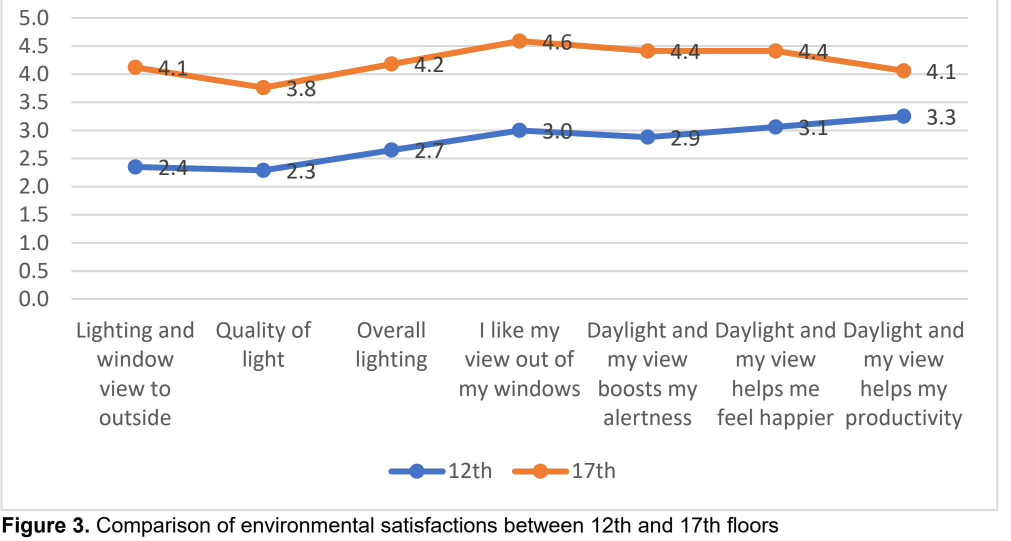

Figure 3. Comparison of environmental satisfactions between 12th and 17th floors

In addition, occupants in offices with manually-controlled blinds (12th floor) also reported on average 2.6 of 5 thermal mitigation devices: extra clothing/shoes; fan/heaters; temperature monitoring; hot/cold drinks; and refrigerators or kettles – to cope with temperature changes at the window wall, while occupants in offices with dynamic glazing (17th floor) reported on average 0.9 thermal mitigation devices with a statistical significance ($p<0.001$). Figure 5 illustrates the significant difference of heat mitigation devices between the selected two floors.

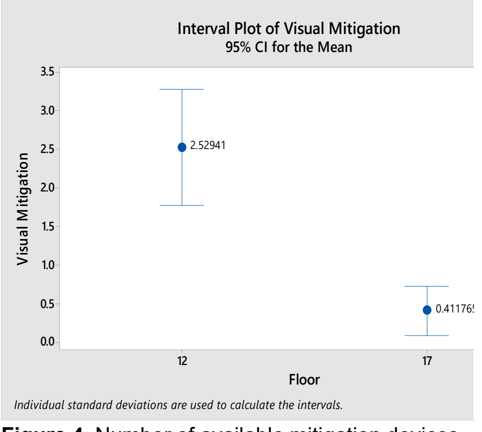

Figure 4. Number of available mitigation devices for visual environmental control

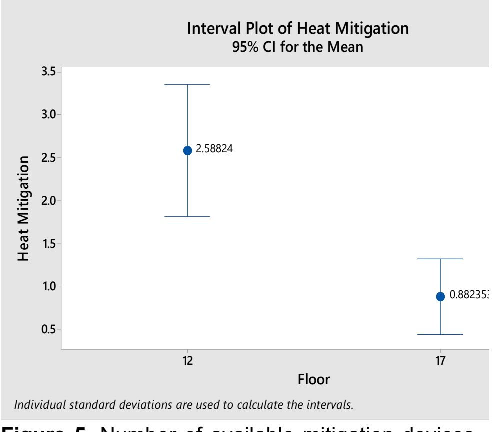

Figure 5. Number of available mitigation devices for thermal environmental control

In term of the frequency of the use of mitigation methods, occupants with dynamic glazing reported 71% less use of thermal and 59% less use of visual mitigation methods, as compared to the condition when they stayed in the workplace on 12th floor with manual blinds. Also 41% those in offices with dynamic glazing reported fewer breaks to take a walk than when they were in offices with manually controlled blinds (Figure 6).

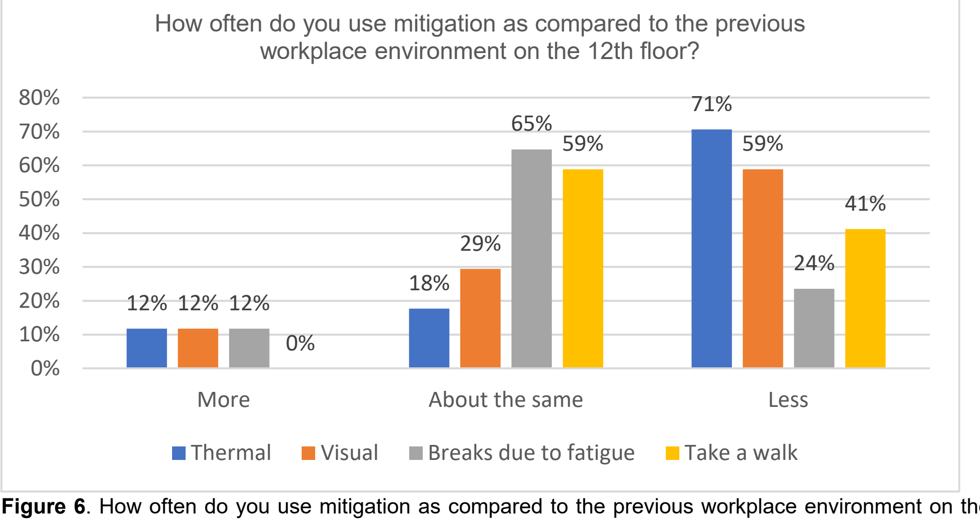

Figure 6. How often do you use mitigation as compared to the previous workplace environment on the 12th floor?

2.3 Physiological symptoms by the glare

One of the significant technical features of dynamic glazing is the glare mitigation by changing visual transmittance of the glazing. Considering the direct sunlight to the office throughout the daytime and the multi-orientation that each workstation faces, the potential visual stress caused by glare is significant. This study asked six glare-relevant questions associated with physiological symptoms. As summarized in Figure 7, there is a significant drop in the number of occupants who reported their physiological response/symptoms, such as annoyance, glare on the computer screen, drowsiness, eye fatigue, concentration, and thermal stress. On the average, 9 to 12 among the 17 occupants reported their physiological stress and discomfort on the 12th floor, but there were only 2 to 4 occupants who stated sustained physiological conditions. On the other hand, the number of occupants who reported headaches did not change for the new office floor (i.e., 17th).

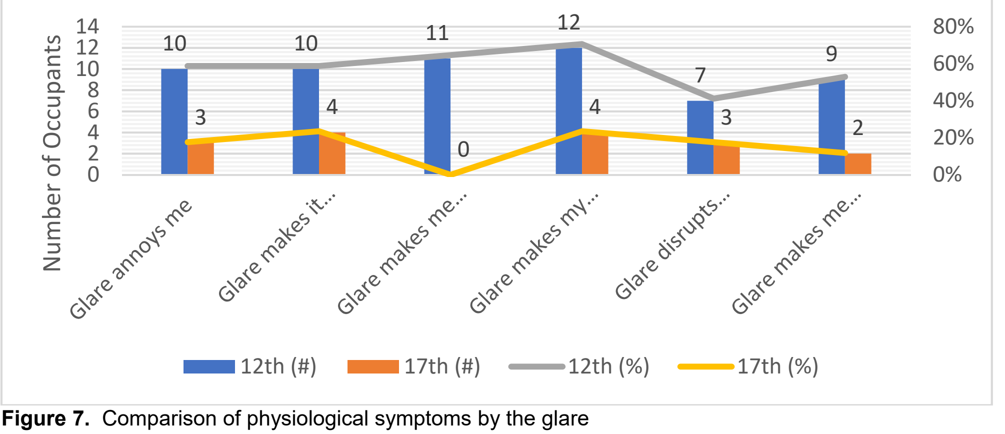

Figure 7. Comparison of physiological symptoms by the glare

2.4 Improvements in emotional responses

To investigate the emotional responses, this study adopted a survey in a five-point scale (ranging from Not at all (1) to Very much (5)). As illustrated in Figure 8, overall, occupants in offices with dynamic glazing reported 24% greater positive emotional responses and 21% lower negative emotional response than occupants in offices with manual Venetian blinds. Occupants with dynamic glazing had substantially greater positive emotional responses of energized, awake, delighted, excited and happy when compared to occupants with manual blinds. Occupants with dynamic glazing also had substantially lower negative responses of tired, boring, dark and gloomy when compared to occupants with dynamic glazing. However, the levels of upset, annoyed, distressed, frustrated, bothersome, and miserable perceptions showed limited or almost no differences between both the floors.

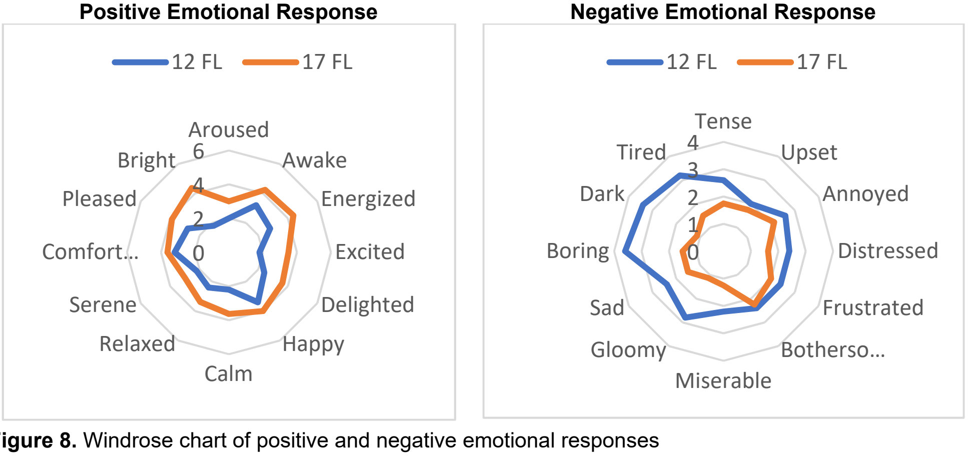

Figure 8. Windrose chart of positive and negative emotional responses

2.5 Environmental satisfaction enhanced in core zones

In general, core zones in offices have been frequently reported as a relatively humble space as compared to perimeter zones primarily because of limited access to nature, such as light and natural ventilation (J.-H. Choi and Moon 2017; J.-H. Choi, Aziz, and Loftness 2009; J. Choi, Loftness, and Aziz 2009). In this study, the collected dataset was grouped per workstation location, i.e., perimeter and core zones depending on the distance between building façade and a workstation. 15 ft was selected as a threshold to define the selected two zone based on the team's previous study (J.-H. Choi and Moon 2017). As summarized in Figure 9, the occupants in core offices with dynamic glazing reported higher satisfaction with lighting and window view, quality of light, overall lighting, alertness, happiness, and perceived productivity. In a five-point scale (1: Very poor, 2: Poor, 3: Fair, 4: Good, 5: Excellent), the average scores of those satisfactions are 0.9 and 4.2 on 12th and 17th floors, respectively, and it results in 66% increase on the basis of a full 5 scale. Also, considering the significance of productivity in office facilities, the increase of perceived productivity by 2.5 scores on 17th as compared to 12th is noteworthy. All these comparisons were identified with statistical significances (all p-values < 0.05)

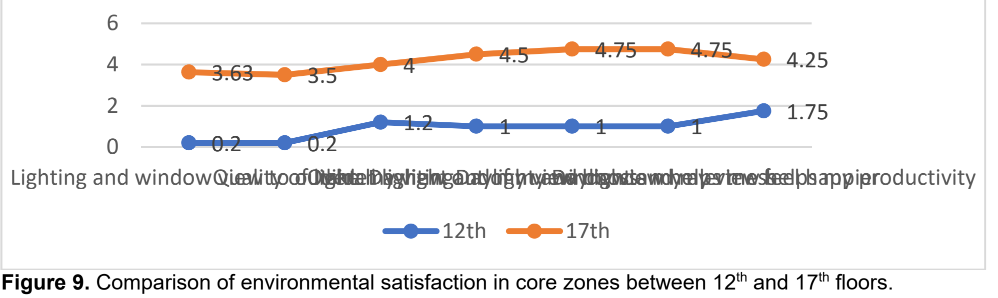

Figure 9. Comparison of environmental satisfaction in core zones between 12th and 17th floors.

CONCLUSION

In this pre- and post- study of 17 office workers moving from offices equipped with manual venetian blinds to a different office floor with dynamic glazing statistically significant improvements were identified in user-satisfaction with lighting, daylighting and view' perceived productivity; and improved emotional responses. Occupants with dynamic glazing have significantly higher environmental satisfactions and perceived productivity than those with manual blinds by an average of 29%. On the other hand, those environmental satisfaction and perceived productivity of occupants in core zones with dynamic glazing, which have been frequently reported as humble places, were significantly higher than those with manual blinds by an average of 66%. In addition, the pre- and post-survey about emotional responses revealed 24% higher in positive emotional responses and 21% lower in negative emotional conditions in the dynamic glazing condition as compared to the manual blinds. In the physiological symptom survey, only 2 to 4 occupants in offices with dynamic glazing reported annoyance, glare on a computer screen, drowsiness, eye fatigue, concentration, and thermal stress while there were 9 to 12 occupants reporting those symptoms.

As such, this study revealed a significant impact of dynamic glazing on human physiological and emotional perceptions in workplace environments. As modern people spend a significant amount of their time indoor and their productivity becomes a key parameter in a workplace environment, the role of such technology-applied environmental control as a passive strategy is critical. In consideration of these facts, an electrochromic window, as dynamic glazing could be one of the critical candidates to be considered for modern office environments where workers' productivity and environmental health are critical. For this purpose, this study provides intellectual values by investigating the impacts of dynamic glazing on environmental and physiological parameters of office workers.

However, despite the significant findings above, there is still a limitation to this study. First, additional samples sizes with environmental parameters to measure should be considered to support the research findings. There were only 17 occupants available per floor in this study. Also, a future study should consider ambient environmental quality such as thermal and lighting environmental elements, including temperature, humidity, illuminance, luminance, contrast and ratio, and glare that are significantly affected by dynamic glazing performance. Also, since dynamic glazing performance vary depending on seasons and times of measurement, additional field studies are required with consideration of seasonal and daily/hourly climate conditions.

ACKNOWLEDGMENT

The authors thanks to the office workers of the Canada Lands Property who participated in the survey, and also thanks to Dr. Dongwoo Yeom at Lawrence Technological University for his technical assistance.

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