学位論文要旨

The Impact of Glazed Facades on Occupants' Comfort and Building Performance in Daylit Office Spaces in Tropical Regions: A Case Study in Thailand

(熱帯地域の昼光利用を取り入れた執務空間におけるガラスファサードが執務者の快適性とビル性能に及ぼす影響：タイにおけるケーススタディ)

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A strategies to enhance building performance have advanced in the forefront of building practices since the new constructed buildings are anticipated to contribute a positive effects to the buildings themselves and their occupants [1, 2]. As the trend of highly-glazed facades use continues to grow, the glazed facades results in a large amount of solar heat and daylight entering, which can translate into a critical aspects of the occupants' comfort and energy demands. To deal with these effects, the building standards with green building framework have evolved for its adoption. For the glazing selection guideline [3], however, it recommend an important features, as solar heat gain efficiency (SHGC) and visible light transmittance (VLT), based on energy perspective without any concerns on the occupants' comfort. Further, the effect of shading devices should be considerably concerned since it is generally applied in the occupied spaces.

For the glazing effects, the current criteria only refer them to the solar heat effects, with a less concerns on daylight, even though both can be experienced simultaneously. The category of comfort evaluation [2, 4] mentions thermal comfort, i.e., predicted mean vote (PMV), without any specific criteria for visual comfort. Thus, the applicable criteria, as discomfort glare index of simplified daylight glare probability (DGPs) [5], is introduced to comply with illuminace-based data in current standards [2, 4, 6], with its agreement on thermal comfort [7]. Meanwhile, for the energy assessment, as energy use [4] and overall thermal transfer value (OTTV) [8], accounts for the solar heat load, without strategies for daylight controls. Thus, the roles of daylight utilization, as the functions of daylight-dimming control and VLT feature, are discussed in this study to see how they can affect to the building energy performance.

By those gap of knowledge, this study aims to include both of the solar heat and daylight entering through the glazed facades to discuss on their profound effects on the occupants' comfort and the energy use. The results are presented alongside their corresponding references from existing building standards or guidelines, comfort indices, and energy assessments, to explore the possibilities to develop current criteria based on their regional context, with aiming at; 1) to clarify the role of glazing effects on thermal comfort and discomfort glare within green building framework, 2) to demonstrate the significance of glazing effects with daylight considerations on energy use, and 3) to suggest on how the building standards can be developed under the context of tropical regions.

The research framework was divided into 2 sections to assess a complex integration of qualitative and quantitative findings, as the impact of glazed facades on the occupants' comfort, and on the energy use. For section of the occupants' comfort, research methods were held based on the field study, which was conducted in ten offices located in Bangkok, Thailand. All reflected the generic daylit environments of an open-plan working station commonly found in the urban context of Thailand; target occupants were inside perimeter zone, with the seat-direction of facing-to-window. The survey covered an investigation on the building facades performance, the comfort indices evaluation (PMV and DGPs), and the subjective questionnaire. They were analyzed together to clarify the actual situations, and then discussed with the glazing products being used in Thai market by the computer simulations on occupants' comfort (PMV: DesignBuilder, and DGPs: product of vertical illuminance in DIALux evo) to suggest a glazing features based on the comfort factors. Meanwhile, for the section energy use, the OTTV calculation was done, and the computer simulation (energy use: H-load) was performed to highlight the functions of daylight utilization to demonstrate on how they can affect the energy performance.

For the investigation on the glazed facades performance in field study, it was important to note that the results in this study represented the shading situations since the occupants commonly applied shading devices to maintain their own comfort. The heat transferring and daylight access through the glazed facades were partially obstructed. Thus, according to the comfort evaluation in Table 1.1, most of the occupants were inside thermal comfort zone under cooling environments.

Table 1.1. *Descriptive statistics of the thermal comfort and discomfort glare variables*

Surveyed items	Max.	Min.	Mean	S.D.
Thermal sensation vote(TSV)	4	-4	-0.42	1.25
Predicted mean vote(PMV)	0.92	-3.57	-0.38	0.58
Relative humidity (%)	78.82	44.12	58.64	7.55
Air temperature (°C)	25.69	21.14	23.20	0.77
Glare sensation vote(GSV)	4	1	2.15	0.51
Simplified daylight glare probability (DGPs)	0.34	0.19	0.23	0.03
Vertical illuminance (lx)	3,731.08	144.77	571.39	106.24
Horizontal illuminance (lx)	1,983.14	318.50	608.46	129.75

Concerning on the discomfort glare evaluation, the occupants in this study supposed to achieve visual comfort since most of DGPs values were below 0.35, which denoted as imperceptible-glare. However, from the questionnaire survey, a group of discomfort occupants could be found therein. It was therefore worthwhile to determine the applicable thresholds of DGPs based on the occupants' responses following Wienolds' suggestion [5] of four sensation levels, i.e., imperceptible, perceptible, disturbing, and intolerable. As shown in Fig 1.1, the analysis of cumulative distribution function and predicted percentage of discomfort (PPD) helped mark each threshold value as: imperceptible–perceptible = 0.22; perceptible–disturbing = 0.24; and disturbing–intolerable = 0.26, which lowered than the current recommendation [5], but they agreed with other studies in tropical regions [9, 10]. This finding can be referred as a quantitative evidence to support studies on discomfort glare in tropical regions, and can act as an initial step for improving illumination criteria or standards [2, 4, 6], which currently encourage daylight utilization without any glare control strategies. However, further studies are required in terms of contrast-based glare within the lowlight-dominant environments, and studies on other lighting metrics are also needed to ensure the local preference.

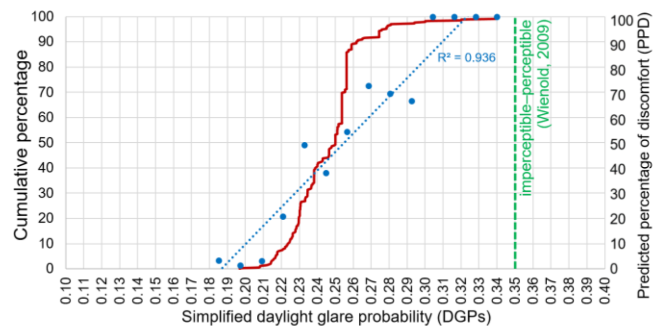

Figure 1.1 *Plot of cumulative histograms and predicted percentage of discomfort with various values of DGPs.*

For the cross analysis model, the occupants' responses were classify by simplifying to a nominal form based on their answering scale from the questionnaire. They were tested in multiple regression analysis, and plotted in the linear model, as shown in Fig 1.2 and 1.3. Achieving both was a consistent experience; their interaction could be highlighted for a thorough understanding of the occupants' comfort. There is a possibility to address both thermal comfort and discomfort glare together as a more comprehensive model for comfort evaluation in building assessments or standards [2, 4], which currently focus on thermal comfort without measure for discomfort glare control.

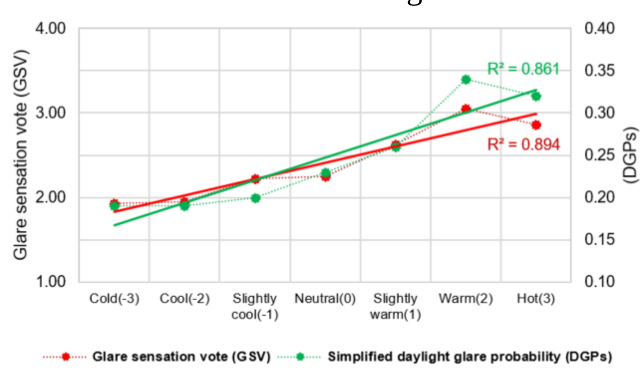

Figure 1.2 *Cross analysis plotting of the effect of thermal sensation level on glare sensation vote (GSV) and simplified daylight glare probability (DGPs)*

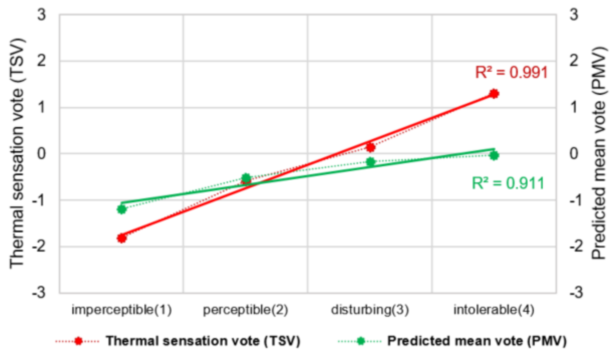

Figure 1.3 *Cross analysis plotting of the effect of glare sensation level on thermal sensation vote (TSV) and predicted mean vote (PMV)*

The correlation tests between the occupants' comfort and the glazing features with shading devices usage indicated that SHGC and VLT must be carefully concerned. But not only the glass itself, must the shading devices be concerned as well, since it was required by the occupants. The logistic model of comfort and discomfort occupants in Fig 1.4 marked the shading occlusion level at 66.14% for achieving comfort. This shading condition was put into the computer simulation of mockup office under the venetian blind with slat angle at 30º and 45º [11, 12] applying with several glazing products. The outputs of PMV (as thermal comfort) and DGPs (refer to vertical eye illuminance as discomfort glare) were generated. The occupants were divided into 3 zone based on the distance from the window; zone1=sitting close to the window, zone2=mid-perimeter zone, and zone3=perimeter zone edge. Then, the results were presented by the linear model of PPD method to determine the threshold values of SHGC and VLT of the glazing products that could meet up with the occupants' comfort.

The current thresholds of SHGC and VLT [3] are suggested to be 0.55 and 0.88, respectively, based on energy perspective. Meanwhile, to apply the glazed facades that can balance between energy efficiency and occupants' comfort, the shading devices is required into the facades systems. Under this shading condition, the simulated results showed that thresholds of glazing features could be marked lower than that current recommendation; and their implications could be discussed with seat positions and orientations, as shown in Fig 1.5. The threshold value of SHGC was suggested as a lessen values at 0.45. For the VLT, the threshold value at 0.85 was recommended to utilize daylight. However, the occupants sitting close to the windows seemed to be considered with their lower values.

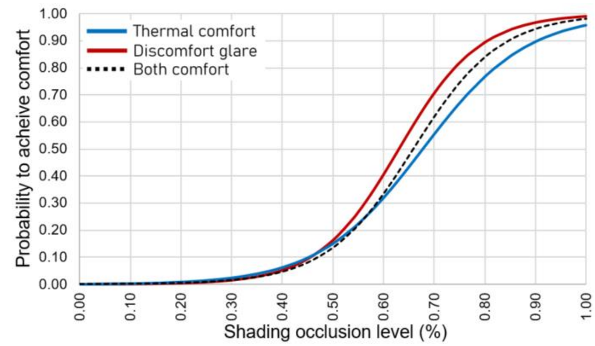

Figure 1.4 *Logistic model of achieving occupants' comfort as a function of shading devices occlusion level*

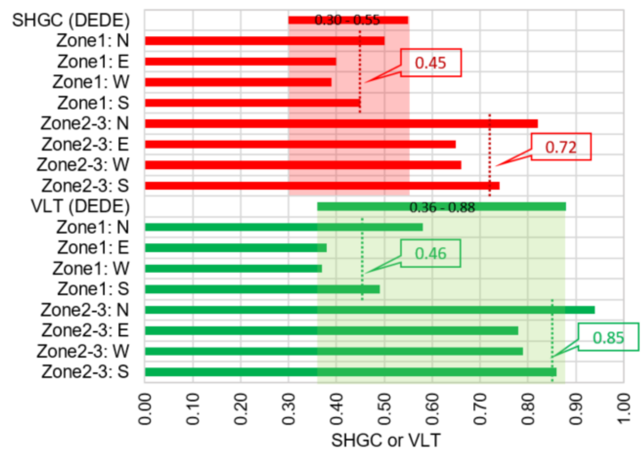

Figure 1.5 *Suggestion of SHGC and VLT plotted with their current reference (DEDE), and their mean (dash line), based on seat positions and orientations*

For the highlight of daylight utilization on energy use, the computer simulation of mock up office were performed with several glazing products providing various values of VLT, alongside the function of lighting systems with and without daylight-dimming control. The results showed that daylight utilization resulted in energy-saving potential; the daylight-dimming control with the high VLT usage helped reduce energy demand around 5.65 % compared to the current reference [4]. For OTTV consideration, the low rate of SHGC and VLT was practically recommended for building facades designs since it could fulfill the required OTTV at 50 w/m^2 [8] in the early design stage.

However, concerning on the post-occupancy stage, OTTV could be lowered for 11.17% when the impact of shading devices was taken with a lower heat transferring rate through the glazed facades. Conversely, when energy units of simulated-cases with daylight-dimming control were plotted against OTTV and VLT, as shown in Fig 1.6, the OTTV above its limit was possible to apply by concern on energy efficiency since the function of daylight utilization helped reduce electrical loads, based on the above-mentioned. Thus, the OTTV limit can be widened when the actual energy performance is taken, and the high VLT glass is recommended to be used but its adoption should be applied with shading devices for achieving occupants' comfort following the suggestion in Fig 1.5.

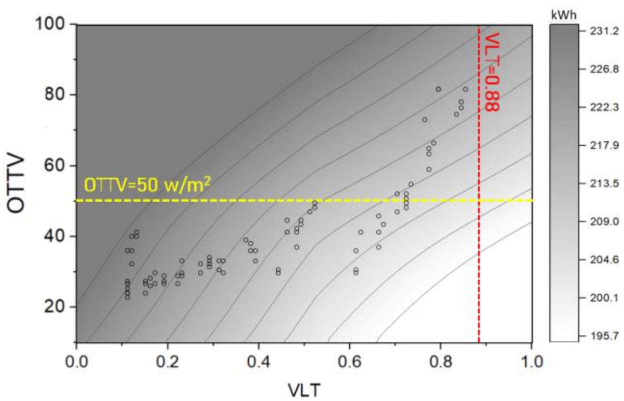

Figure 1.6 *Example of energy use contour (South) with daylight-dimming control plotted against OTTV and VLT*

In conclusion, the findings from this study can act as an initial step for improving the building standards based on their regional context. Both of solar heat and daylight entering through the glazed facades are discussed with their impacts on the occupants' comfort and the energy use. For glazing features, the shading devices should be incorporated as an effective layer into the buildings' facades systems, and their selection guideline can be discussed with concerns on occupants' comfort. For occupants' perspective, the comfort category mentioning in terms of thermal comfort can be updated by addressing the discomfort glare along the line for enhancing the comfort evaluation; the applicable discomfort glare criteria as DGPs is marked with its thresholds determination by local occupants' responses in this study. For energy perspective, not only solar heat load, but daylight utilization should also be considered for the energy assessment as an energy saver. Furthermore, the OTTV limit can be expanded with a proper daylight controls to compensate a balance on energy demands. With an appropriate controlled-strategies, these development of building standards can be expected to take a step toward reducing the building load and improving occupants' comfort.

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