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Investigation on Adaptation to Climate Change Impacts and Occupant Window Control in Federal Secretariat Building Asaba

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Abstract
The severity of the impacts of climate change on human comfort depends upon his indoor and outdoor environment. Climate change impacts on air quality, human comfort and health. The window is an important component for a natural ventilation cooling strategy, which can control the air flow between indoors and outdoors. Good indoor air quality is important to achieve indoor comfort and health. Opening a window is the simplest way to improve indoor air quality. It is an important environmental factor that can affect occupants satisfaction and also have great potential for energy saving. The discomfort of indoor environmental condition in occupied spaces in office building has escalated due to combined effect of high solar radiation and humidity levels which is an impact from climate change. This paper reports on the investigation using questionnaire and physical measurement to analyse the adaptation to climate change impacts by occupant through window control. The Analysis of Variance (ANOVA) test conducted at 95% confidence level showed that there was significant statistical difference between the adaptation to climate change impacts and occupant window control. The result shows that occupant windows control and adaptation is a significant adjustment method that can help occupant re-establish their comfort and reduce energy consumption especially in offices. Recommendations were made for occupants to have direct control on the indoor environment, especially by controlling the windows.

Keywords: Adaptation, Climate change, Energy consumption, Office buildings, and Window control.

1. Introduction

Climate change adaptation has been defined as "adjustment in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts" (Smit et al., 2001). Window control is one of the environmental adjustment methods for occupants to restore their personal thermal comfort in the buildings. Occupant behaviour in buildings can have large impact on building energy use. It is anticipated that window control has a key role to play in climate change adaptation through moderating impacts and improving the quality of an indoor environment. The window is an important element to link the inside and outside environment of a building; it brings view, light, solar energy and fresh air that occupants desire into interior space from outside. The opening windows can provide fresh air, which is natural ventilation. Allard (1998) pointed out that increasing the indoor air flow rate (within occupants'acceptable limit of course) can reduce the indoor pollution level. A large amount of incoming air through windows could drop the indoor temperature and increase the energy performance. Walker and White (1992) investigated the mean age of air in a single-sided naturally-ventilated office to evaluate the fresh air. The result showed that the fresh air was well distributed, but there were no more details of air velocities. The measurement of velocities and temperatures in a single-side ventilated office was taken by Eftekhari (1995). He found that high velocity (0.4m/s) and low temperature is near the floor and an opposite situation showed at head level. A computer simulation study of fresh air distribution in a single-side ventilated room (3×3×15m) was taken by Gan (2000). The external wind speed was set to 0m/s; only indoor buoyancy-driven air was considered. The size and position of the window and indoor heat gain would impact on the effective depth of air distribution, which varies between 5m and 15m in this case. The small size and low position of a window opening will reduce the effective depth, so as to lower internal heat gain. Although increasing indoor heat gain can extend the effective depth and produce better indoor air quality, it is restricted by the upper threshold of indoor comfort temperature which may cause the occupant to be uncomfortable. Controlling the opening size of the window can efficiently maintain the indoor air quality.

2. Literature Review

Climate change adaptation can be either autonomous or planned. However autonomous adaptations are likely to occur in the absence of specific policy initiatives, planned adaptation results from policies that deal with modifying the impacts or vulnerabilities of systems to climate change and its effects (Smit et al., 1999). Occupant window control offers significant potential in adapting buildings for climate change, through its important role in ameliorating the indoor climate. The window is a major element for natural ventilation, which can control the air flow between indoors and outdoors environments. Givoni (1994) indicated that the effect of a window size is related to the building's ventilation strategy. Windows have a big effect in a cross-ventilated room, but a small one in a single-side ventilated room. However, different types of windows and opening modes provide different indoor airflow patterns. Heiselberg et al (2001) indicated that the indoor air velocity is related to window type, location and opening degree. Gratia et al (2004) used computer simulation to analyse the sufficient ventilation rate as a function of size, shape and position of windows on the facade. The results in this study showed that the cooling energy can be reduced by about 40% by applying natural ventilation. Therefore, the position of the window aperture had a significant impact on natural ventilation efficiency. It is better to locate the openings at different heights in a single-sided ventilated office, the same as the inlet and outlet in a cross-ventilated office. It was found in many studies that a well-applied natural ventilation strategy had great efficiency for energy saving and also provided comfort for the indoor environment (Van der Maas and Roulet, 1991; Ding et al, 2005; Gratia and Herde, 2007; Yao et al, 2009). The energy usage in naturally ventilated buildings is 40% less than in air-conditioned buildings (Energy Consumption Guide 19, 1993).

Occupant behaviour in buildings can have large impact on building energy use. Window control is one of the environmental adjustment methods for occupants to restore their personal thermal comfort in the buildings. Many field studies have investigated occupant window control behaviour based on different climates, regions and environmental stimuli. Robinson (2006) pointed out that the indoor temperature in a building would differ because of different environmental conditions, such as orientation, number of occupants, equipment, etc. Thus, the indoor temperature has more influence on occupant window control behaviour. According to these field studies, it can be seen that both indoor and outdoor temperatures have influence on occupant window control. Rijal et al (2007, 2008) indicated that the indoor temperature can be the main environmental stimulus. Occupants opened windows to reduce the indoor temperature and prevent the room becoming over-heated, which would cause discomfort. Except for the rain or gusts of wind, which may result in windows closing, outdoor temperature has an impact on the time the window remains open. For instance, in the dry season, a window is opened to bring fresh air into the room but kept closed most of time in order to reduce heat loss in the rainy season. In the dry season, occupants would have large windows open to promote air exchange between the indoor and outdoor environment in order to cool the indoor temperature. In addition, when the outdoor temperature is higher than the indoor, the frequency and proportion of window openings would drop, in order to reduce the hot air entering (Fritsch et al, 1990; Herkel et al 2008). Therefore, both the indoor and the outdoor temperatures have important influence on occupant window control behaviour.

The effect of facade design on window control behaviour in office building is essential in the adaptation of occupants to climate change impacts. It is known that the facade design has a close relationship with occupant window control behaviour and natural ventilation. It contributes to both embodied energy and operating energy in buildings (Amato, 1996). Natural ventilation is a passive cooling method to reduce indoor temperature and help occupants achieve comfort. Occupant behaviour of window control which can influence the indoor air flow by adjusting window and it would result in indoor convective cooling effect. Different window types provide different opening configurations, adjustable ranges of opening size, weather protection features, etc. All these different characters have various effects on air flow rate and airflow pattern. The type of window fitted in the building has a direct influence on the indoor environmental condition, and it is mainly decided by architects. A good understanding of the features of different window types can help the architect to make the right decision. The window with horizontal pivot and top/bottom hanging is relatively suitable for rainy climate conditions, as it has better protection from rain when it is open. For some places that need more ventilation for cooling the indoor temperature, the window with adjustable and large effective opening size should be considered, such as casement and vertical pivot window. On the windward side these kinds of window can be used as a wind wall, which can make the indoor air flow speed as low as 40% of the outdoor (Givoni, 1976).

2.1 Study Area: The study area is Asaba in Delta State, Nigeria. It is located in south-eastern and Nigeria lies within 4°N to 14°N latitudes and 2°E to 14.5°E longitude. Asaba lies in Latitudes 6.2°N of the Equator and longitude 6.73°E of the Greenwich Meridian. It is the state capital of Delta State and located on the banks of the lower Niger Delta. The climate of Asaba is humid sub-equatorial with long wet season lasting from March to October that alternates with a shorter dry season that last from November to February. The climate is influenced by two prevailing air masses namely the south-west monsoon wind and then North-east trade wind. Annual rainfall in the Asaba area is up to 2500mm with double peak rainfall regime which takes place both in June and September. Annual average temperature is about 27°C with no marked seasonal departure from the average. The natural vegetation of the area is rainforest with swamp forest occurring in flat-floured valleys and adjoining low lying areas that are seasonally or permanently water logged (NiMet's, 2016).

3. Research Methodology

This study applied questionnaire survey research and physical measurement. These were efficient and straightforward method to investigate the adaptation to climate change impacts and occupant window control in federal secretariat building Asaba Monitored environmental factors included indoor and outdoor dry bulb air temperature, indoor and outdoor relative humidity, indoor and outdoor air flow speed and window state (open or close). The measured environmental factors were used to derive building thermal performance, natural ventilation state and window control patterns in the office building. The contents of the occupant questionnaire were developed from previous research on post-occupant evaluation and occupant behaviour by well-established researchers (Cohen et al., 2001; Yun and Steemers, 2008). The aim of the occupant survey was to establish the occupants' environmental perception that was related to indoor environmental stimulus. The measuring apparatus for field study and data documentation is shown in Table 1.

Table 1: measuring apparatus

Apparatus	Description
	**LUTRON Thermo-Anemometer (AM4201A):** it measures air velocity, air flow and air temperature respectively. Air velocity range is 0.40-45m/s, resolution of 0.001m/s and recording accuracy of ±(3%+0.20m/s). Air flow range is 0 to 9999m^3/min, resolution of 1, and recording area of (0 to 9.999m^2). Air temperature range is -10°C–60°C, resolution of 0.1°C and recording accuracy of 2.0°C respectively.

3.1 Characteristics of monitored building:

The characterizations of the monitored buildings was based on the type of windows in the building which are casement window, casement with vent, sliding window, projected window and louvre windows respectively. Understanding the characteristic of naturally ventilated office buildings can help to identify the natural ventilation type. The natural ventilation types in each office are also defined and the results of single-side ventilation and cross-ventilation type were compared. While the instruments recorded the surrounding environmental conditions, the researcher observed and kept track of the occupancy behavior or activities, such as the opening and closing of windows. The monitored buildings are shown in Plate 1.

Plate 1: Federal Secretariat Building, Asaba (Front View). Source: Field Work, 2024

Plate 2: Federal Secretariat Building, Asaba (Side View). Source: Field Work, 2024

3.3. Dsata Presentation:

This section present the data generated from the field work. The data generated from the various sources will be sorted and arranged a way that is adequately fit for statistical analysis and interpretation using tables, bar charts, graphs, frequency distributions and percentages. This measurement was carried out from February 2024 (11th to 24th) and during this period the outdoor temperature varied from a minimum of 25.5°C to a maximum of 40.1°C, with the mean daily average temperature of 36.3°C. There were large temperature fluctuations during the measuring time, which was because of high solar radiation, and the highest temperature of each day was above 38°C. However, the prevailing wind was from the south-west and the wind speed was between 0.05m/s and 5.75m/s, with an average wind speed of 1.47m/s.

The PMV model is widely used for evaluation of indoor thermal comfort and applied in many thermal comfort standards, such as American Society of Heating, Refrigerating and Air-conditioning Engineers 55 –2004 (ASHRAE, 2004), International Organization for Standardization 7730 (ISO, 2005) and Chartered Institution of Building Services Engineers thermal comfort standard (CIBSE, 2006). The seven-point PMV scale was applied in this research as shown in Table 1.

Table 1: ASHRAE seven-point PMV scale

PMV model provides sensation vote value between people and the environment.

Cold	1
Cool	2
Slightly cool	3
Neutral	4
Slightly warm	5
Warm	6
Hot	7

Source: ASHRAE (2024).

Question 1: Thermal Sensation Vote, (How do occupants feel with the indoor temperature?).

The occupant perceived comfort and thermal sensation vote werebrecorded by questionnaires. In the average thermal sensation vote as shown in Figure 1. The numbers from 1 to 7 mean from very cold to very hot, while the number 4 was the neutral point, meaning neither cold nor hot. The figure shows that, during the measuring period, the thermal sensation vote was mainly around neutral. This means, generally, occupants feel slightly warm in the office. Only the vote at arriving time in office A and in the afternoon in office C, and the thermal sensation vote were close to warm (5). In office A, the thermal sensation vote at arrival time was higher than the morning and afternoon, which would be caused by the use of air-conditioning. The afternoon thermal sensation vote in office C was because of the rise of indoor air temperature caused by direct sunlight in the late afternoon.

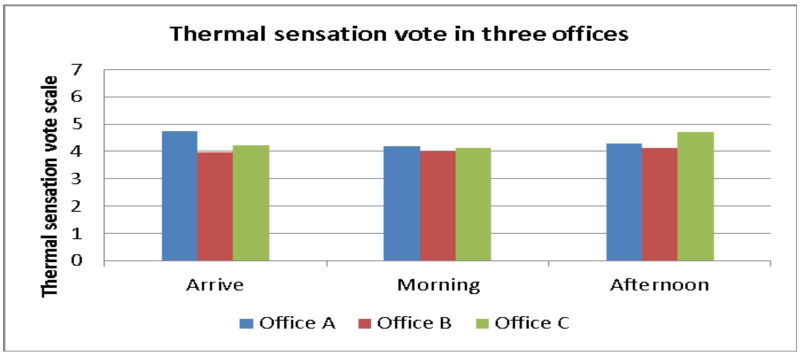

Figure 1: The average occupant thermal sensation vote results during working period.

When correlating the thermal sensation vote with related temperature in the office building in the natural ventilated time, it can be seen that in general the indoor temperature tended towards hot and the majority votes were between 3 and 5, whereby it can be considered that the temperature was still acceptable. When the indoor air temperature rises above 26°C, some occupants would feel hot, and 30°C seems to bean top thermal threshold for occupants in the office. Few votes were taken above this temperature because air-conditioning was operating, and the occupant was voting on being very hot when the office was still naturally ventilated as shown in Figure 2.

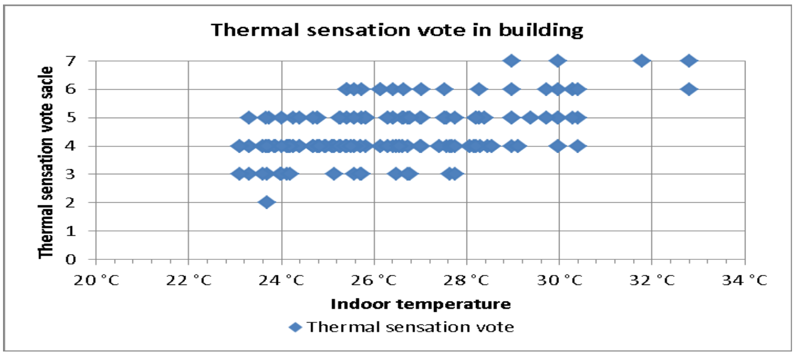

Figure 2: Thermal sensation vote with indoor dry bulb air temperature in office building during natural ventilated period.

Question 2: Perceived Comfort Vote, (Do occupants feel comfortable or uncomfortable?).

The average perceived comfort vote during the measuring time was shown in Figure 3. The scale of the numbers from 1 to 7 means from very uncomfortable to very comfortable, and the number 4 was the neutral point. Generally, according to the perceived comfort vote result, occupants were satisfied with their working environment during the monitored period. The perceived comfort vote was the lowest at arriving time and highest in the morning. Comparing all the offices, the occupants in office B provided the highest average comfort vote, meaning they were more satisfied with the indoor environmental condition than occupants in other offices. The occupant comfort votes in office C were lower than office B at a different time of the day, but the average vote was the lowest in the afternoon. For office A, the average vote was the lowest at the arriving time and it was lower than the neutral point, which means occupants were slightly uncomfortable when they had just arrived at the office. After arrival, the vote result increased gradually and reached the highest point in the afternoon, which were close to office B. The perceived comfort vote pattern was different in office A compared with other offices, which may be because of the use of air-conditioning for the majority of time. The air-conditioning was switched on when occupants arrived in the office, so occupants felt more comfortable in the afternoon than in the morning. Generally, occupants in offices B and C were more satisfied with their indoor environment than in office A, which was air-conditioned most of time.

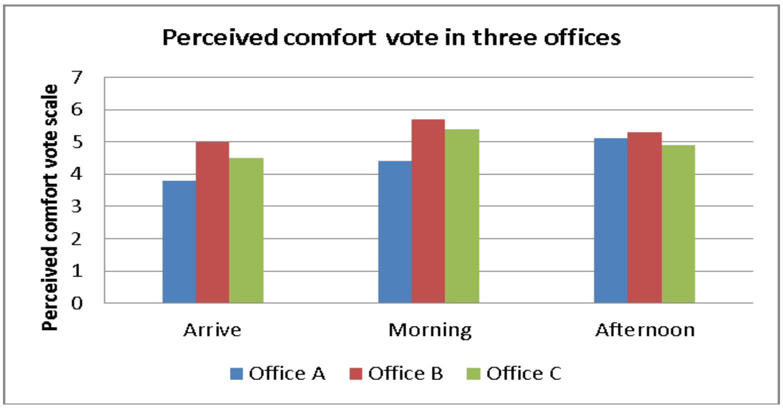

Figure 3: The average occupant perceived comfort vote during working period.

The perceived comfort vote correlates with indoor dry bulb air temperature during the natural ventilation period in three offices was shown in Figure 4. In the main time, occupants felt comfortable in the office and very few votes were below the neutral point. The vote at 7 (very comfortable) was mainly between 23°C and 26°C. When the indoor air temperature was over 30°C, none of the occupants felt comfortable.

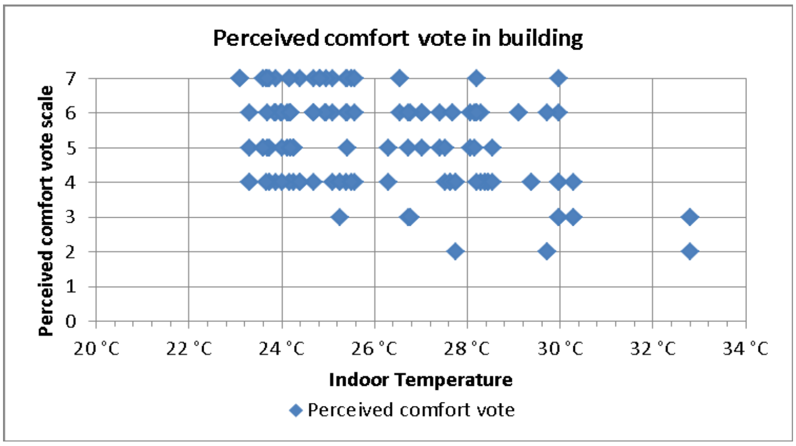

Figure 4: Perceived comfort vote with indoor dry bulb air temperature in office building during natural ventilated period.

Question 3: Perceived Air Quality Vote, (How do occupants feel with the air quality?).

It can be seen from the vote result that the perceived indoor air quality was the lowest when occupants had just arrived in the office and it was better in the morning than in the afternoon in offices B and C, but the other way round in office A, which gradually increased from arrival time to the afternoon. However, some relationship between the occupants' perceived thermal sensation and the indoor air quality can be seen from the comparison, in offices A, B, and C. Taking A as an example was shown in Figure 5, when occupant thermal sensation vote was at neutral (neither cold nor hot) or cool, the vote of air quality was shown as generally higher. As the indoor temperature gradually increased, the vote on air quality became gradually lower. This phenomenon shows that occupants' perceived indoor air quality was fresher when they were in an indoor environment of neutral or cool than hot. Therefore, the average vote of perceived indoor air quality and the average vote of perceived comfort were quite similar. So, in hot and sticky air conditions, occupants may confound the perceived comfort and perceived air quality. It may be because the heat loss from the respiratory system decreased and caused an uncomfortable sensation in this environmental condition.

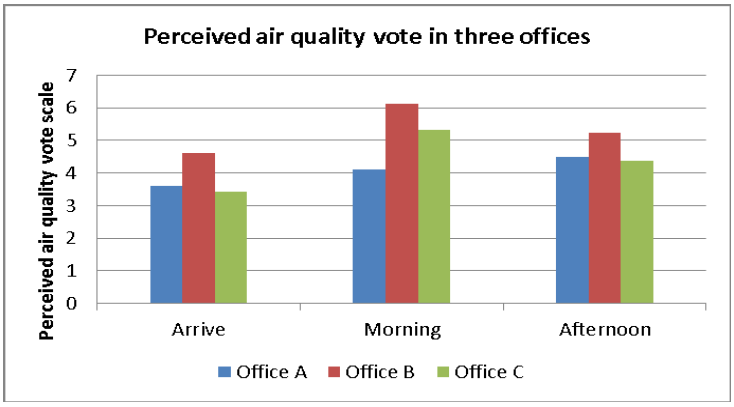

Figure 5: The average occupant perceived air quality vote during whole working period.

The window control results were divided into three parts with the window states being at arrival time, during the working period, and at the leaving time, to find out occupant window use patterns as shown in Figure 6. Most of the window states would not be changed during the working hours; it seems changing window state would not impact on occupant comfort sensation. Window type and opening size would influence occupant window control behaviour in three offices. The small opening size restricts the air flow rate in the office and the hot air cannot be successfully moved out of the office, so changing the opening size in the office cannot effectively influence the indoor temperature. High indoor air velocity would disturb occupants' working and cause discomfort, but the air flow passing through the open window would go up to the top of the office and have little impact on occupants. Thus, changing the window state was more likely to be for fresh air rather than to adjust the indoor temperature.

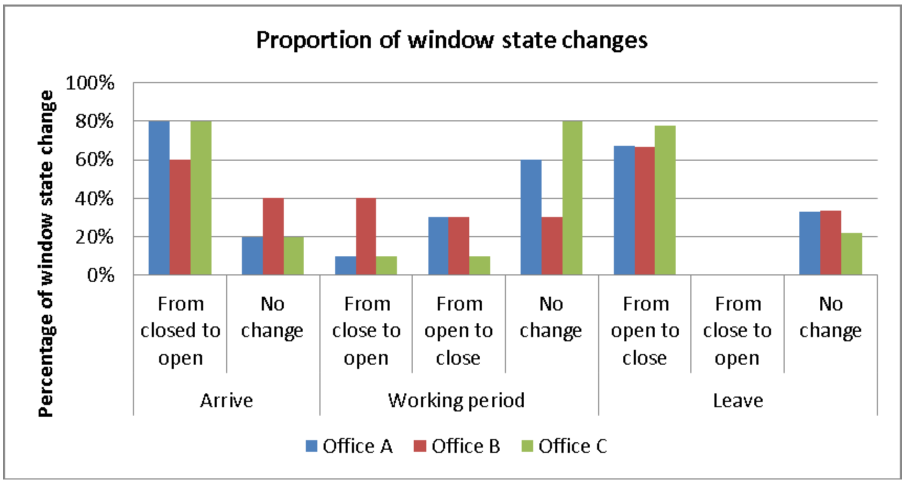

Figure 6: The proportion of window state changes in three offices.

3.4 Result analysis:

H01: The adaptations to climate change impacts do not significantly affect occupant window control.

The result in table 4, below has reported the p-value result for the ANOVA analysis on the effect of opening methods of the window types on room temperature.The result is said to be significant if p-value is less than 0.05 significant level. The result reports a p-value of 0.000 with an F-value of 65.555. We therefore reject the null hypothesis and accept the alternate hypothesis stating that the adaptation to climate change impacts significantly affect occupant window control.

Table 4: The ANOVA analysis result on the adaptation to climate change impacts and occupant window control.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	322.570	4	80.643	65.555	.000
Within Groups	141.468	115	1.230		
Total	464.038	119			

Source: ANOVA analysis output, SPSS 25

4. Discussion of Results

The investigation was carried out by physical measurement. The data loggers were used to obtain data. The result shows the small opening size would limit indoor air flow rate which would restrict indoor heat from moving out in a naturally-ventilated office. This would result in indoor temperature being much higher than outdoor temperature and cause occupants to be uncomfortable. The air flow passing through a top-hung window can move up to the top of the room and the air flow speed around occupants was much lower than the opening area. Even under high wind speed the occupant who was doing office working near the window would not be disturbed by high air flow speed. Also, the low air flow speed at the occupied area has limited effects on extending the occupant thermal comfort area. So, in these three offices occupant opening window behaviour was more for fresh indoor air purposes rather than adjusting indoor temperature and air flow speed.

The occupant perception of indoor air quality vote result would lead to occupants changing the window state, but the occupant air quality sensation vote cannot evaluate actual indoor air quality, and it was related to thermal sensation vote. Based on the results of occupant perceived comfort vote and thermal sensation vote during naturally ventilated working hours, the indoor temperature was tending towards hot, but occupants were still satisfied by the indoor environmental condition and in most of the time when occupants felt uncomfortable the air-conditioning was operated. Thus, the top indoor air temperature threshold can be defined as 30°C; it was close to Givoni‘s (1998) comfort zone which can be identified on the psychrometric chart. During the working hours, it was proved that relatively few windows would change state, while most of the windows remained in their state (open/closed) for a long time. The reason probably is that occupants have adapted to the indoor environmental condition since they arrived at the office, so that changing window state is not important to occupants‘ comfort sensation (Fritsch et al, 1990). Yun and Steemers (2008) found that the frequency of window state changes in a shared office with a single window was lower than in a single occupant office. When there are two or more occupants in a room, the behaviour of changing window state as appeared to be a group decision, so the window state remains during most of the time. However, this study shows that occupant window control can achieve a cooling purpose and remedy the risk of high temperature impact from climate change within the warm humid climate.

5. Conclusions

At the arrival period, the majority window state was from closed to open; none of the windows were closed at arrival time in the office. In office building B, the percentage of window state change from closed to opened was much lower than in other office buildings and about 30% of occupants changed the opening area when they arrived at the office. This was caused by the way occupants used the window lock, which kept the window on a small open state rather than fully closed. Although the window was not fully closed, the effective opening area was too small to have impact on indoor air temperature during the night time. When occupants left the other offices, they tended to close the windows in order to prevent rainfall and gusty wind. During the working hours, a small number of occupants would close the windows. According to the records, this was mainly because of rainfall. Most of the windows were closed and rarely there was a small open area left when it was raining. The effective opening size change accounted for the highest proportion during the working period. The percentage in office building B was higher than in the other two office buildings. This was mainly related to the window control frequency in the single-side ventilation office in the building; because in office buildings A and C the opening area change percentage in a single-side ventilation office was much lower than the percentage in single-side ventilation offices in building B. In cross ventilated offices in each building the opening area change was the main behaviour in window control frequency in working hours which was around 90%. When the window control frequency between the single-side ventilation office and the cross ventilated office was compared (Figure 7.5), the result showed that in the cross ventilated offices the window control frequency was 27% higher than that in single-side ventilated offices. Thus, the occupants in the cross ventilated offices adjusted the window opening area more frequently than in single-side ventilated offices. The windows seem to be an important factor often used by the occupants in the cross ventilated offices to control the indoor environment.

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