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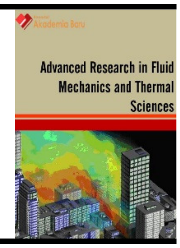

An Analysis of Occupants Response to Thermal Discomfort in Green and Conventional Buildings in Malaysia

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ABSTRACT

The aim of this study is to examine what people do when they are too hot or too cold, and whether there are significant differences in the behaviour of occupants between green and conventional buildings. Case studies of green and conventional buildings were used in this study. Questionnaires were used as the tool to gain the relevant information from the building occupants of the case studies. Results showed that in response to feeling cold, three actions were significantly different between green and conventional buildings. One of the actions were on environmental adjustments (i.e. green building occupants were less likely to adjust the temperature system) and two were on personal adjustments (i.e. green building occupants less likely to put warmer clothes & less likely to alter timing of work pattern). While in response to feeling too hot, two actions were significantly different between the building types with one action from environmental adjustment (i.e. green building occupants less likely to adjust temperature system) and personal adjustment (i.e. green building occupants less likely to consume cold drinks/food). To date, there is limited understanding on whether green buildings have any different influences on how occupants behave in response to thermal discomfort. The findings in this study will aid designers to design better buildings that encourage better behaviour adaptations.

Keywords:
Green buildings, energy saving behaviour, coping mechanism, adaptive comfort

1. Introduction

Thermal comfort is defined by the International Standard American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) as “that state of mind which expresses satisfaction with the thermal environment”. Green buildings, which are mostly mechanically and naturally ventilated buildings adopt the ASHRAE 55 andard and ISO 7730 guidelines which suggests

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a thermal comfort temperature between 20ºC to 24ºC. Studies showed that the thermal comfort at these temperatures is generally accepted by the occupants [20,35,48]. Post occupancy studies on comfort have shown that in general green buildings are more comfortable compared to conventional building [32,33].

Although the temperature of 20ºC to 24ºC is an accepted comfort range for most occupants, Nicol and Humphreys [39] argued that the temperature range advised by ASHRAE 55 2010 standard and ISO 7730 (2005) guideline is too narrow. This is supported by other studies that found high discomfort issues in green buildings where occupants find it too cold during the winter and too hot during the summer [6,33,49]. Occupants will environmentally adjust buildings when they are experiencing discomfort in thermal, daylight and natural ventilation in the buildings [10,23,24,47,51].

The adaptive thermal comfort model (i.e. International standard ASHRAE RP884 [12] and European Standard (EN 15251) proposes a wider temperature range up to 30ºC and claims that buildings should be designed in a way that provides wider opportunity for occupants to adopt behaviour adaptations [12,39]. The adaptive thermal comfort model is not widely adopted in a controlled thermal environment such as an air-conditioned building [35]. This is because there is a huge challenge in behavioural change as it requires a lifestyle change that is too onerous [35].

Scholars have categorized behaviour adaptations in response to discomfort to being cold and hot [39,24,]. There are three types of behaviour adaptations which are (i) personal adjustment- i.e. adjusting activity, adjusting posture, (ii) technological or environmental adjustment- i.e. turning on fans or heaters and (iii) psychological adjustments- i.e. just put up with it, or try to ignore the problem. However, limited studies have been conducted on the level of practice of these behaviours. By investigating the level of practice of behaviour adaptations to thermal comfort, it is possible to gain a better understanding on how buildings can encourage better behaviour adaptations.

Environmental adjustments have energy implications on the building. Among the post-occupancy issues in green buildings are lack of knowledge and skills on how to operate the environmental control systems efficiently [10,18,37] and limitation of accessibility to the control systems which caused occupants to make their own personal modifications (i.e. use personal fan, heater, and etc) to achieve optimum comfort [10,13,47]. Studies have also found that occupants' desire to achieve optimum comfort caused controls to be overridden, such as mechanical cooling and heating systems [18,47,51]. Against the need to change controls, Heewargen and Diamond [24], suggest that an adverse impact of providing good automated building control systems is the “desk couch potato” where there may be a lack of muscle movement, and an increase of social isolation.

Heerwaagen and Diamond [24] examined the three types of behaviour adjustments (i.e. personal adjustment, environmental adjustment, and psychological adjustment) in green buildings. The findings showed that the green buildings encouraged more personal adjustments than environmental adjustments. Personal adjustments were made more than environmental adjustments in spaces which occupants have limited access to the control systems such as the open plan space. While in private offices within the building, the occupants made more environmental adjustments than personal adjustments.

Advocates for personal adjustments believed it not only help reduce energy consumptions in buildings, but it is also believed to create healthier personal actions for the occupants since there is more muscle movement [24]. In order to further the debate about thermal comfort in buildings, the study in this paper examines what people do when they are too hot or too cold, and whether there are significant differences in the behaviour of occupants between green and conventional buildings.

2. Coping Mechanisms in Response to Discomfort

Reviews of the international literature showed that the three basic types of coping mechanism (i.e. personal adjustment, technological or environmental adjustment, and psychological adjustments) in response to discomfort that occupants normally take in buildings [12,24]. Table 1 provides a detailed list of adjustments considered to be personal adjustments in response to thermal discomfort.

Table 1
Personal Adjustment

Personal Adjustment	References
Clothing adjustment when felt cold and hot	[7,8,12,24,29,30,31,44]
Alter timing of their work pattern to avoid uncomfortable working conditions	[7,12,30,31,44]
Adjusting posture	[12]
Consuming hot or cold food and drinks	[7,12,24,29,30,44]
Moving to a different location	[7,8,12,24,29,30,31,44]
Taking a walk inside or outside	[24,29]
Contact building manager	[24]
Share the problem with co-workers to see if they are also experiencing discomfort	[24]

As shown in Table 1, clothing adjustment is a common personal adjustment made in response to discomfort. This behaviour has been promoted in office buildings. For example, a campaign on no neck ties in Japan in 2005 [22] and employees were encouraged to adopt casual dress code in United Nation Headquarters, New York [54]. The rationalization for this campaign was that flexibility in dress code in office buildings provides occupants more adaptive strategies to cope with thermal discomfort. O'Connor *et al.,* [41] categorised these behaviour changes as "suffer discomfort". Although discomfort is not relieved entirely by personal adjustment, these behaviours have important functions such as making people move around more and engage in social interactions [24]. The mental and social benefits generated from personal adjustments are worthwhile and create a healthier environment for the occupants [24]. Furthermore, these actions conserve energy and as a result, energy performance of green buildings can be improved [24].

Environmental adjustments are how occupants interact with the building control systems (i.e. windows, blinds, switches, and other controls). Occupants who engage in this thermal discomfort coping mechanism can impact energy usage if the building control systems are not operated efficiently [10,33].

Inefficient operation of the building control systems is described in the following studies. For example, Gabe [18] and Sawyer *et al.,* [51] discovered that occupants increased the load of the cooling and heating systems to accommodate comfort. Reiss [47] discovered that occupants routinely override switches for natural ventilation or mechanical cooling because they don't know what conditions each option is intended for. Reiss [47] also discovered that occupants did not open the window when they were supposed to which caused the heating system to consume energy five times more than predicted. Heerwagen and Wise [25] showed that occupants kept doors open for fresh air causing mechanical systems to consume more energy. Bordass *et al.,* [10] and Brown [13] reported that occupants used personal heaters or fans to relieve discomfort.

Heerwagen and Diamond [24] defined psychological coping mechanism as an attempt to adjust to a situation by managing emotions or thoughts about the situation. Occupants responded to either feeling hot/cold by just putting up with the discomfort, believing there was nothing they could or try to ignore the discomfort. Heerwargen and Diamond [24] found that almost one fifth of the occupants who experienced thermal discomfort either feeling too hot or cold chose to not do anything. Occupants engaged more in this coping mechanism when environmental adjustments are limited, and when other coping mechanisms are not effective to relieve discomfort [24].

Previous studies [10,23,24,51] describe adjustments made by occupants to relieve discomfort. These studies did not quantify the frequency of the behaviours. Quantification of the frequency of behaviours can aid building designers to make better prediction of energy usage. Current energy modelling software assume occupants schedules are similar to building operation schedules (8am to 5pm) with no absence from their offices during workdays, lunch, meetings, etc. [4]. Frequent act of occupants using additional heaters/fans, and adjust temperature are not accounted for in the energy simulation tools [26,34,56]. Often designers make inaccurate assumptions that occupants would open windows to optimize usage of natural ventilation [34]. It is important to understand better occupants' interaction with building control systems when faced with discomfort. When building control systems are operated efficiently, they may not relieve occupants discomfort entirely. Occupants have a high tolerance to discomfort. Moujalled *et al.,* [38] discovered that occupants preferred more naturally ventilated buildings as compared to air-conditioned buildings even if these buildings were colder.

To design buildings that encourage occupants to practice energy saving behaviour, designers must understand occupants' level of interaction with the building control system. A study by Santin [19] found that energy-conscious households conserve more energy with systems that require active involvement, while less energy-conscious households conserve more energy with systems that do not require active involvement.

This paper provides a better understanding of occupants' behaviour through comparison analysis between green and conventional buildings. The findings in this paper will help designers to design better buildings that encourage green practice. This paper extends the research by Heerwagen and Diamond [24] and Azar and Menassa [5] by comparing behaviours in conventional buildings to see if green buildings have any different influences on how occupants behave in response to thermal discomfort.

3. Thermal Discomfort Adjustments in Malaysia Buildings

Three case studies building were selected to compare energy efficiency practices among occupants between a certified green building, a non-certified building with "green" features, and a conventional building.

3.1 Case study 1- Low Energy Office (LEO) Building – Green Certified

The LEO building was built as the first government energy efficient building in 2004 housing the Malaysian Ministry of Energy, Green Technology and Water. The LEO building is situated in Putrajaya, Kuala Lumpur. A city that is aiming to be a sustainable city with a master plan of theme "City in a Garden and the Intelligent City." The LEO building won the ASEAN Best Practice Energy Efficient building in 2006 and received the Platinum certificate awarded by Green Building Index in 2011. The main energy efficient features include adopting a variable air volume system which is energy efficient compared to a typical air-conditioning system. The atrium is naturally ventilated and has a large access to natural daylight through skylights. Occupancy and photo sensors are installed in the building. Solar photo-voltaic are installed at the rooftop of the building to provide renewable energy for a water wall feature in the atrium. The building has a double roof to provide additional shading. The windows incorporate low emission glazing. A spray mist system which emits water particles is installed at the sliding doors to cool natural ventilation.

The energy in the LEO building is monitored and controlled using an energy management system in which it monitors sub-meter sub-meters of energy usage in lighting, cooling, and plug load. Some of the areas have occupancy and photo sensors installed in the LEO building.

3.2 Case study 2- Perbadanan Complex, Putrajaya (PPJ) –Green (Non-Certified)

The PPJ building situated in Putrajaya built in 2008 is known for its contemporary, traditional Islamic architecture. It was also designed to incorporate energy efficiency features. The PPJ had won ASEAN Energy Award in 2008. However, it did not apply for green certification. The main energy efficient features are that it adopts variable air volume system. The building is highly glazed with double tempered green glass with no emission glaze. The building consists of floating meeting rooms which are naturally ventilated. Occupancy and photo sensors are installed where necessary in the building. A plant irrigation system controlled by an individual rain sensor is installed.

The energy in the PPJ building is also monitored using an energy management system. However, the energy management system installed does not have sufficient sub-meters or systems that enable sector assessment, which precludes thorough analysis of energy performance. In the PPJ building, some of the lighting and plug load systems are not connected to the energy management system. The architect who designed the PPJ building reported that the full system was not installed due to budget constraints during the decision at the design stage. A complete purchase of the energy management system package was claimed to be costly. Some areas in the building have occupancy and photo sensors where necessary.

3.3 Case study 3- Ministry of Health (MoH), Putrajaya – Conventional building

The MoH building was built in 2008 is adjacent to PPJ building. The building was designed to be a contemporary building which emphasises transparency and dynamism in forms. Discussion with the MoH architect and report analysis of the facade building assessment revealed that the building requires constant artificial lighting instead of optimization of daylight usage. The building has low visible light transmittance and high indoor reflectance which causes the facade to look dark and has a ‘mirror’ effect when viewed from the interior, but without sufficient green features, this building is considered as a conventional building.

The energy management system in MoH building does not separate lighting and plug load energy use. Hence, an assessment of where energy is consumed, and energy waste is difficult to identify. Although the design of MoH building incorporated some energy efficient measures, the architect indicated it was not the focus of the design. The budget allocation to install an effective energy management system was not prioritized. The MoH building do not have any occupancy nor photo sensors installed in the building.

4. Energy Consumption of Case Study Buildings

Figure 1 shows that all three case studies consumed energy less than 200kWh/m^2/year (ASEAN region Energy Index) and 150 kWh/m^2/year (MS1525 Energy Efficiency code). This shows that all three case studies are performing efficiently. The energy consumption in the LEO building has the least with 118 kWh/m²/year, followed by the MoH building in second position (127 kWh/m²/year), and lastly the PPJ building with the highest energy consumption (138 kWh/m2/year). The green certified (LEO) building uses less energy compared to the conventional (MoH) building. While the non-certified green (PPJ) building uses more energy compared to the conventional (MoH) building.

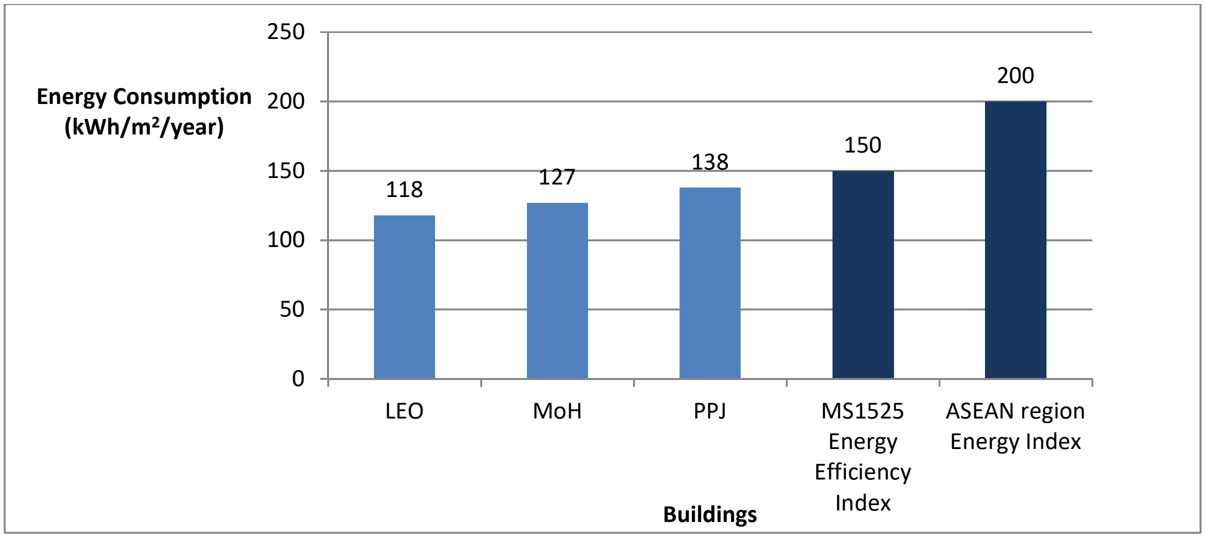


Fig. 1. Energy consumption index

In all three cases, a detailed energy scheduling is practiced. Air- conditioning temperatures are at 24ºC and are regularly reviewed according to occupancy density in the building. Lighting is scheduled to switch off after office hours. All three buildings have a building maintenance office that is fully equipped with facilities. The energy management system showing the track of energy usage is accessible online in all three case study buildings. An active facility management team whereby there is a pro-active help desk to deal with complaints are in all three buildings. The building managers in all three case study buildings claimed to resolve any complaints by the occupants immediately. The facility management team in the LEO building aimed to reduce energy consumption through clear direction on energy conservation goal. The LEO building has an energy policy committing to an energy consumption target of 100kWh/m2/year.

5. Research Method

A survey was conducted to understand how occupants in the building behave to achieve comfort. Invitations to participate in this study were sent through an e-mail and a follow up call to the building managers was made. The building managers in each of three case study buildings then distributed an online survey uploaded onto the building website to the occupants in the buildings. The researcher conducted a follow up e-mail requesting the building manager to circulate the website link to the occupants in the building after two weeks. Hardcopies were also provided to the building manager for occupants who wished to fill in the questionnaire manually. In order to increase the response rate, the researcher was given access to the case study buildings to invite participants in the research face to face. Hardcopies as well as the website link were given to interested participants.

The aim of the questionnaire was to understand how occupants use the building to adjust their thermal comfort. Questions about coping mechanism for each environmental condition were asked. Occupants were asked to rate their actions to achieve comfort using a Lickert scale to (5: I always do to 1: I never do). Option N/A was also provided for actions that are not relevant to them. Occupants were also asked to tick whether they had access to the building control systems such as being able to adjust temperature or open/close windows and doors.

Analysis was undertaken using SPSS Statistic 22. The Man U Whitney test was used to identify which of the coping mechanisms were significantly different between the building types. The coping mechanisms identified as significantly different via Man U Whitney test were further analysed using frequency description and crosstab analysis to ascertain which building types practiced the most coping mechanisms.

Occupants were also asked whether if working in a green building meant they would sacrifice comfort level to save energy using "a my comfort level and change my lifestyle to save energy" using a Lickert scale (5-Strongly Agree to 1-Strongly Disagree). Frequency analysis was used to identify the highest percentage of response for each factor.

6. Results

The building managers estimated that there were 1640 people in the three buildings. A total of 267 responses were received. It is difficult to definitely know the response rate, as some of the occupants may never have received the information about the survey, or known of the study. However, if the actual numbers are taken as correct, then the calculated sample size of the population is 311 with mean a response rate of 86%. Table 2 shows the breakdown response rate in each building.

Table 2
Response Rate

Type of Building	Population	Sample Size	Respondents Received	Response rate
Conventional Building	500	217	61	28%
Green Buildings	1140	288	206	72%
TOTAL	1640	311	267	86%

Name of Building	Population	Sample Size	Respondents received	Response rate
MoH	500	217	61	28%
PPJ	800	260	110	42%
LEO	340	181	96	53%
TOTAL	1640	311	267	86%

6.1 The Significant Differences in How Occupants' in Green and Conventional Buildings Respond When They Feel Cold

Statistical analysis using Man-U Whitney test showed that there are three actions significantly different between the green (LEO and PPJ) and conventional (MoH) buildings for occupants responses when they feel cold. These actions are on environmental adjustment (i.e. "adjust temperature on the air-conditioning system") and two actions on personal adjustment ("put on warmer clothes" & "alter timing of their work pattern").

Under environmental adjustment, Figure 2 shows that the occupants in green (LEO and PPJ) buildings are less likely to adjust the temperature on the cooling system when they feel cold ($p = 0.001$). As for personal adjustment, Figure 2 shows that the occupants in the green (LEO and PPJ) buildings are significantly less likely to put on warmer clothes ($p = 0.000$) and alter timing of their work pattern to avoid uncomfortable working conditions ($p = 0.021$).

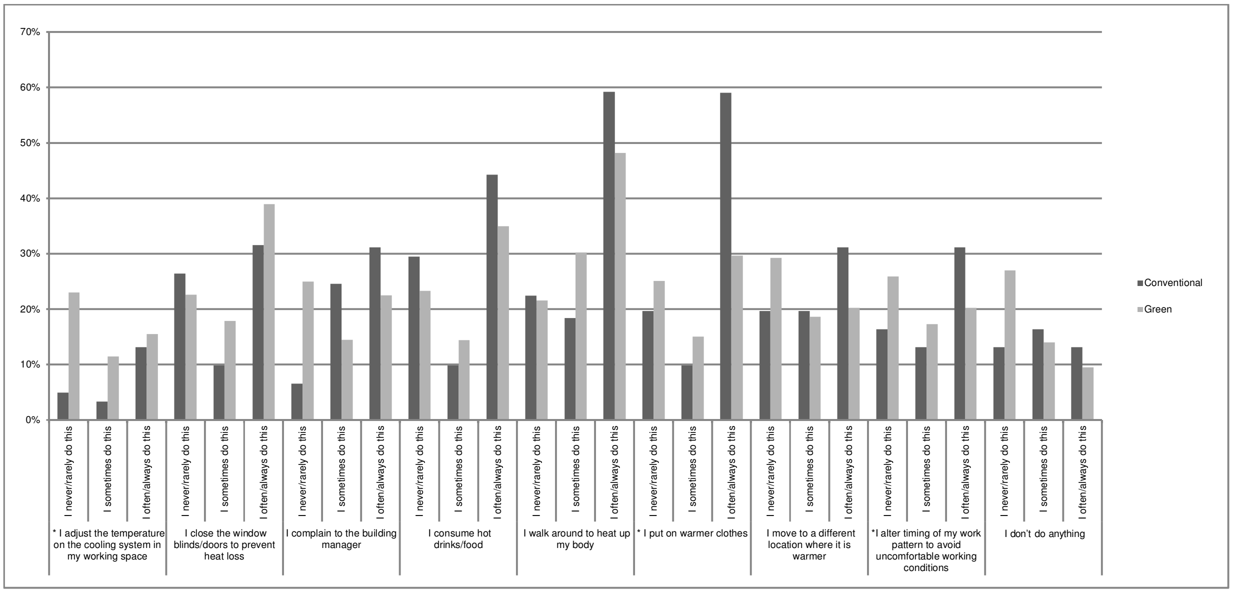


Fig. 2. Occupant's response when feeling cold in their working space. Note: energy saving behaviours that are significant different through Man-U Whitney test (p values <0.05)

6.2 The Significant Differences in How Occupants' in Green and Conventional Buildings Respond When They Feel Hot

As for thermal condition of the building being too hot, Figure 3 shows two actions statistically significant different between the two building types. These actions are on environmental adjustment (i.e. less likely to adjust the temperature; $p = 0.021$), and on personal adjustment (i.e. less likely to consume cold drinks/food; $p = 0.007$).

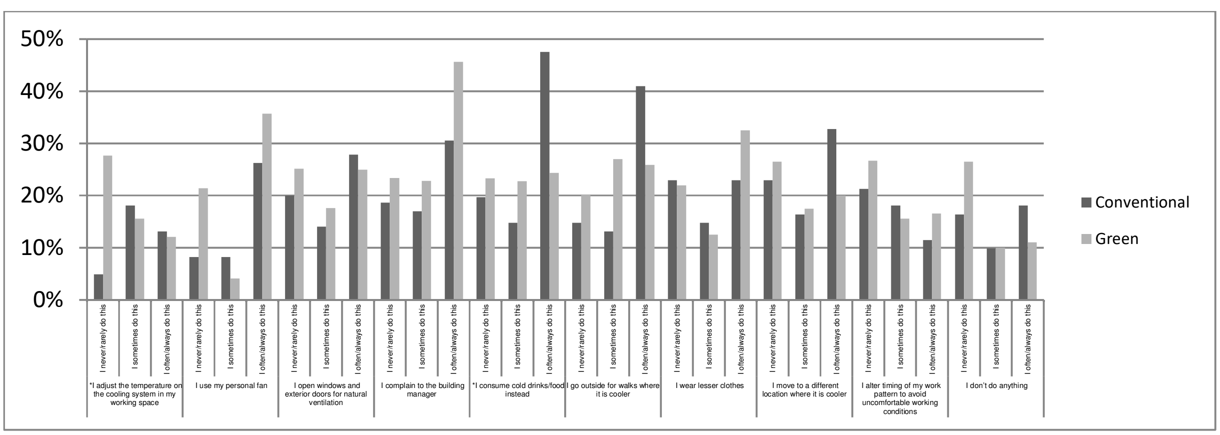


Fig. 3. Occupant's response when feeling hot in their working space. Note: energy saving behaviours that are significant different through Man-U Whitney test (p values <0.05)

6.3 What Access Do Occupants Have to Adjust Building Controls?

Figure 4 shows the accessibility to the building control systems. The results show that the occupants in green (LEO and PPJ) buildings (15%) have more access to adjust temperature system as compared to the conventional (MoH) building (5%). Similarly, accessibility to windows are also seen higher in green (LEO and PPJ) buildings (56%) than in the conventional (MoH) buildings (17%). The occupants in green buildings (69%) also had higher access to the doors than in conventional buildings (54%).

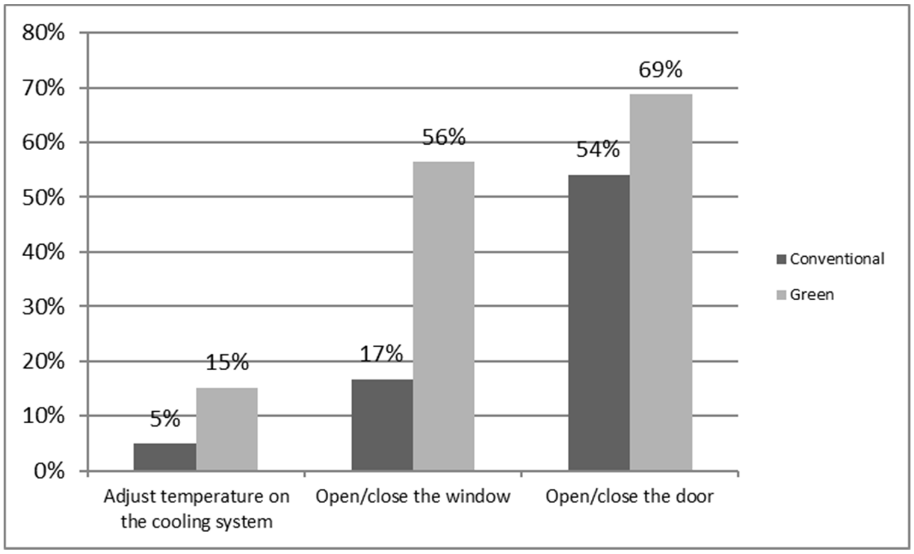


Fig. 4. Accessibility to the building control system

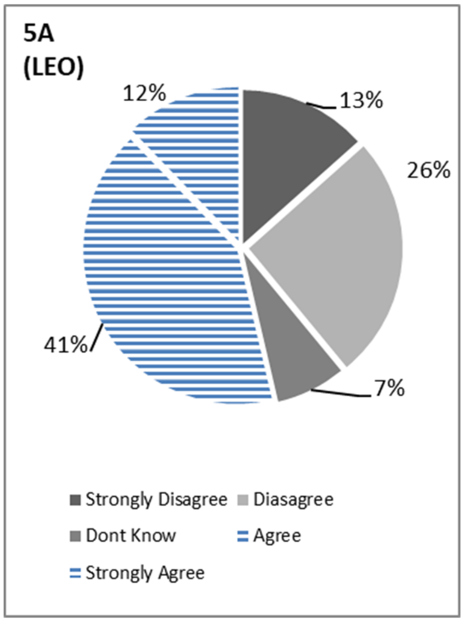
6.4 The Effects of Working in A Green Building on Building Changes

Occupants in the green (LEO and PPJ) buildings were asked whether they perceived the building they work in as a green building. Only 38% of the green (PPJ) building occupants perceived their building as green, while 75% of the green (LEO) building occupants perceived their buildings as green. Occupants who were aware on the green building status were asked whether working in a green building meant that they sacrifice comfort to save energy. The highest percentage of occupants in both of the green (LEO and PPJ) buildings agreed to this behavioural adaptation. As shown in Figure 5A, 53% of the green (LEO) building occupants and Figure 5B shows 43% of the green (PPJ) building occupants had selected agree and strongly agree. These results demonstrate that they have a higher level of awareness on energy efficiency.

7. Discussion

7.1 Environmental Adjustment

Although earlier studies reported that occupants in green buildings adjust the temperature systems in response to discomfort [10,40] the current study found that these practices are significantly lesser for occupants in green building than those occupants in the conventional building. The findings in the present study showed that although occupants in the green (LEO and PPJ) buildings have greater access to adjust the temperature than occupants in the conventional (MoH) building (see Figure 4), they were significantly less likely to adjust the temperature when feeling cold and hot (see Figure 2 and 3). These findings are in contrast with earlier studies which showed that occupants with higher accessibility to adjust the temperature systems were more likely to adjust the temperature systems [24,18,51].



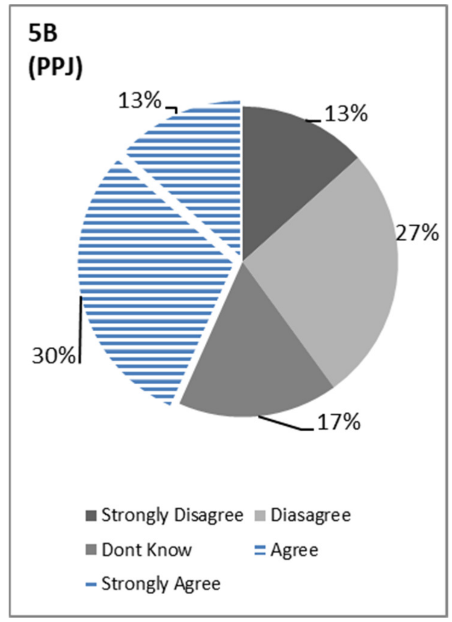


Fig. 5. Percentage of occupants who sacrifice comfort to save energy

The present findings do not provide evidence to support the hypothesis made by Heerwagen and Diamond [24] whereby higher accessibility to control systems creates the "desk couch potato" social phenomena nor does it support the notion by Sorrel et al., (2001) in which occupants adopt poor energy saving behaviours in energy efficient design buildings. With reference to studies that found occupants in the green buildings were more environmental concerned and more tolerant of discomfort than those in the conventional building [33], the findings in this study agrees that occupants in the green buildings are more aware on the impact of changing the temperatures on energy use in the building and therefore do not change their building controls. This can be supported from the results in Figure 5A where the green (LEO) building occupants (53%) and Figure 5B where the green (PPJ) building occupants (43%) agreed that working in a green building meant that they have to sacrifice their comfort to save energy. Even though occupants in the conventional building have less access to adjust the temperature system, they are still significantly more likely to adjust their temperature when feeling hot or cold.

7.2 Personal Adjustments

Overall, occupants in green buildings engaged in less personal adjustments for both cold and hot conditions. When cold, they are less likely to put warmer clothes and less likely to alter their work pattern. When hot, they are less likely to consume cold drinks/food. These findings support the study by Heerwagen and Diamond [24] that showed occupants with high access to the building control systems are less likely to engage in personal adjustments.

Given that the green building occupants engage in less personal adjustments as well as less environmental adjustments, therefore suggesting that these occupants can cope with discomfort more than the occupants in the conventional building. These findings in the current study reinforces the findings in earlier studies [1,14,33] which found that occupants in green buildings are more tolerant with discomfort than occupants in the conventional buildings.

Heerwargen and Diamond [24] found that occupants in green buildings walk around in the building when they feel cold; the present findings showed that this practice was the same even in a conventional building. Heerwagen and Diamond [24] explained that occupants are likely to walk around in the building in response to feeling cold when they have limited ability to adjust the building control systems. However, the results in this study showed that either occupants have limited or high access to the building control system (i.e. temperature systems) approximately 50% of the occupants from both building types chose to walk around in the building to heat up their body (see Figure 2). One explanation for this is perhaps due to the similar layout design that the green and conventional buildings studied have. Both of the building types are highly glazed buildings which provide wide access to view the natural environment outside the building. Prior studies have indicated that views of the natural environment can make occupants feel less stressed.

Previous studies reported that green buildings are more spacious which make occupants feel more productive at work [21,36] the findings in the present study found that even a conventional building studied have common room spaces that provides opportunity for occupants to exercise healthy adjustments.

7.3 Psychological Adjustments

Heerwagen and Diamond [24] suggested that psychological adjustments are more likely chosen when occupants have limited access to the building control systems. Unlike Heerwagen and Diamond [24], the findings in the current study found that occupants with high and limited access to the building systems were both less likely to engage in psychological adjustments when feeling cold or hot. As shown in Figure 2 and 3, a small percentage of 10% claimed that they do not do anything when they feel cold and hot.

8. Conclusion

In conclusion, the study found that occupants' response to thermal discomfort is different between green and conventional buildings. Occupants in the green buildings appeared to demonstrate that they cope with discomfort more than the occupants' in the conventional building by engaging in less environmental adjustments as well as less personal adjustments. The findings in the current study suspect that a reason is because occupants in green buildings have a greater awareness of energy efficiency. Being too hot, or too cold, resulted in significant differences between occupants behaviour and building types. The results in this study will assist designers of green and conventional buildings to understand how to moderate comfort design for the benefit of the occupants.

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