ENERGY CONSUMPTION VS. USERS' PERCEPTIONS: A QUANTITATIVE STUDY OF ENERGY AND COMFORT IN UNIVERSITY CAMPUS

S.N.N.-Syed Yahya	University of Malaya	shipah79@gmail.com
Ati Rosemary-Mohd Ariffin	University of Malaya	atiarchitectureum@gmail.com
Muhammad Azzam-Ismail	University of Malaya	mazzam.ismail@gmail.com

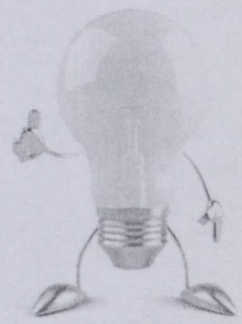

Fig 1: How much energy for a thumbs up? (image source: Pye, K. (2013))

WHICH ARE YOUR ARCHITECTURAL (R)SOLUTIONS TO THE SOCIAL, ENVIRONMENTAL AND ECONOMIC CHALLENGES OF TODAY?

Research summary

The relationship between users' perceptions of comfort and energy performance is an important integration of society with the environment which also have indirect implications to the economy. Achieving users' comfort in buildings involves the use of energy where multiple studies have associated energy use via heating and cooling as predictors of users' comfort. However, these studies have neglected the magnitude of energy needed to achieve comfort. Therefore, the current paper investigates the quantum of electricity used in a public university to achieve users' comfort. The investigation adopts the quantitative method of comparing electricity consumption and users' comfort via two different instruments namely; energy loggers and occupant survey. An energy logger was installed on three study buildings while an occupant survey was distributed to users of the same buildings. Benchmarking was used to compare energy indices of the study buildings. It was found that the study building with the highest energy index also scored the highest perception of comfort by the users. As thermal control for indoor comfort account for more than half of the total electricity consumption, the result suggested that electricity consumption predicts users' comfort positively. However, the ratio of energy consumed and comfort achieved is questionable. This study suggests that a substantial amount of electricity is needed to achieve a small measure of comfort. Additionally, the study also revealed that two of the study buildings performed poorly in terms of energy performance while one performed fairly well with the potential of becoming an energy-efficient building. By replicating the study to other buildings, the research can help identify energy-efficient potentials in buildings towards reducing the campus' energy consumption holistically.

Keywords: users' perception, user comfort, occupant survey, energy performance, academic buildings, building performance

1. Introduction

Since the initiation of sustainability movements in the late 1970s, global efforts were put into creating a sustainable environment for human activities. Following that, within the built environment expanse, more sustainable buildings were designed and built to fulfil the global vision for a sustainable environment. Among the many facets of a sustainable building, the most sought-after feature is its efficient use of energy. Regardless, the building should still perform from the users' point of view and to be especially sensitive towards their users' comfort (Berardi, 2013; Zigenfus, 2008). Recent scholars have debated the effects of users' comfort in a sustainable building on the users' productivity (Feige, Wallbaum, Janser, & Windlinger, 2013). More than ever, building effects on users' well-being have become more important. Despite of its importance, this less tangible benefit of users' comfort is often neglected when planning for sustainable buildings (Baird & Penwell, 2012).

Although numerous studies substantiated that users' well-being is closely associated with comfort (Choi, Guerin, Kim, Brigham, & Bauer, 2014; Hill & Epps, 2010; Lee et al., 2012; Yang, Becerik-Gerber, & Mino, 2013), only few have actually studied its association with building energy performance. The relationship between users' perceptions and energy performance is crucial as the process of ensuring users' comfort almost always involves the use of energy. The operations and maintenance of the users' environment, i.e. building envelope, facilities and the indoor air quality consume sizable amount of energy (Olanrewaju, 2011; Yang, Yan, & Lam, 2014). For instance, the strategies opted to cool and ventilate indoor air and to illuminate workspaces influence the bulk of energy used in the building (Bülow-Hübe & Blomsterberg, 2011; Shen & Tzempelikos, 2012). Therefore, it can be hypothesised that the users' comfort is also associated with their environment (i.e. the building) energy performance. This indirect relationship between building energy performance and users' perceptions of comfort has motivated this study to explore the relationship between the variables.

2. Research objectives

Past literature indicated that users' well-being is closely associated with building energy performance; however, there are insufficient research conducted and even less evidence available to support this hypothesis. This research fills this gap by comparing energy performance against users' comfort as part of building performance assessments. This research aims at investigating the relationship between users' perceptions and energy performance of specifically academic buildings in a Malaysia public university. The research is also designed with the vision that the public university aims to eventually retrofit its conventional buildings into energy-efficient buildings and ultimately achieve green campus status.

3. Method

To achieve the research objectives, the research investigated two subjects; the users and the buildings. Essentially, data is also collected from two sources, namely; the occupant survey to ascertain users' perception, and energy logger to record energy consumption.

From the 308 blocks of buildings in the campus building population, only three buildings were selected for the study through the purposive sampling method. Only academic buildings that are multi-functional were isolated and the final samples were selected based on their identical size and feasibility for energy logger installation. The occupant survey method was chosen to measure users' perceptions of comfort in the study buildings as they are often utilized for research involving building performance from the perceptions of the users (Baird, 2015; Baird & Penwell, 2012; Wall & Shea, 2012). For this research, the BUS Methodology was found to be the most suitable occupant survey compared to countless others mainly because it has a very large database of surveyed buildings including those in Asia.

The questionnaire is available in print and in electronic; however, only the former is used for this study. Since the research objective is to investigate users' perceptions of specific buildings, it is best to approach users in each study building personally. Moreover, the print form provides higher response rate compared to the electronic form (Baruch, 1999; Nulty, 2008).

The questionnaire required respondents to briefly provide their demographic information, and then rate their comfort level for a number of environmental parameters. Twenty Likert scale questions asked respondents about their comfort level in four sections; thermal, indoor air quality, acoustic and visual comfort. In addition to the Likert scale, a comment box was provided at the end of each section to allow respondents to elaborate on their answers. Although not all respondents took this opportunity to express their perceptions further, those who filled in their elaboration assisted the researchers to understand their perceptions better. Upon obtaining clearance from the university's Research Ethics Committee (ref: UM.TNC2/RCH/UMREC), 150 questionnaires were distributed to respondents who utilized each study buildings and were collected within one month.

Subsequent to the survey, electricity consumption was observed to determine the energy performance of each study buildings. Upon installation, the energy logger was set to record electricity consumption at the interval of ten minutes for 30 days on each building. Upon completion of the 30 days, the logger was dismantled from the first study building and relocated to the second study building. The process was repeated for the third building. Recorded data were downloaded and analysed with a software supplied by the energy logger manufacturer. Building energy performance was calculated for all three buildings which was later analysed in tandem with the results from the occupant survey.

It is worthy to point out that electricity consumption data alone is unable to determine whether the building is consuming energy proportionately. Ideally, energy consumption has to be analysed relative to its building size. Building energy performance is a method commonly used to compare one building's energy consumption against its equivalent (Abdul-Rahman, Wang, & Kho, 2011; Altan, Douglas, & Kim, 2014). Calculating energy consumption against building size is known as building energy index (BEI) or sometimes as energy-use intensity (EUI) (Bishop, 2012; GreenTech Malaysia & SEDA, 2013; Moghimi, Lim, Mat, Zaharim, & Sopian, 2011). BEI is calculated by dividing the total annual energy consumption of the building (kWh/year) with its net floor area (m^2). Since data were available for only 30 days, data obtained were aggregated to estimate the consumption for 365 days. The aggregated data is then used in the equation.

In addition to BEI, energy benchmarking is another method adopted for the study to increase reliability in benchmarking energy performance. Some scholars agree that benchmarking is a relatively more accurate method that is widely used to compare energy performance between buildings (Altan et al., 2014; Palmer, 2013). This method recognises the energy performance benchmark of different buildings according to their functions. Expectedly, a laboratory consumes more energy than a classroom of similar size. Nonetheless, this does not mean that the laboratory is not energy efficient; it merely required more energy to function. Therefore, this research adopted the UK Chartered Institution of Building Services Engineers (CIBSE) energy benchmarking system to reliably ascertain the energy performance of the study buildings. CIBSE has established 'good standard' and 'typical standard' benchmark where the standards differ according to the buildings' space function. The standards are shown in Table 1. From this table, an open office space is regarded as having good energy performance if its BEI is 54 kWh/m^2/year, while its BEI for typical performance is 85 kWh/m^2/year.

For this research, the 'good standard' and 'typical standard' for each study building is calculated by multiplying the area of each functional space with the respective benchmark and dividing it by the total floor area of the building.

Table 1: CIBSE benchmarking system for energy performance (adapted from (Altan et al., 2014))

Function	CIBSE good standard (kWh/m^2/year)	CIBSE typical standard (kWh/m^2/year)
others	54	85
office (cell)	33	54
lecture theatre	67	76
office (open)	54	85
computer lab	155	175
library	46	64

4. Results and design potential

The respondents' demographic profile suggested that the survey had achieved homogeneity in the respondents' status. There was a marginal difference on the percentage of students and employees who responded to the survey while visitors' count was the smallest, as predicted. The respondents' demographic profile also revealed that more than 80% of the respondents have been occupying the building for at least one year which signified that their responses were genuine and reliable.

Fig 2 compares the calculated BEI for the study buildings against other known standards. The figure shows that building A3 has the highest BEI while building A2 has the lowest. The difference between the three buildings is quite substantial as BEI for building A1 is almost 80% more than BEI for building A2. Meanwhile, BEI for building A3 is approximately 30% more than building A1 and substantially 130% more than building A2.

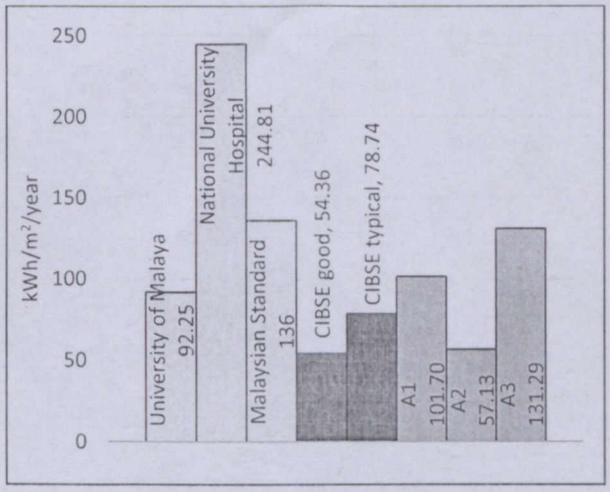

Fig 2: BEI comparison between studied buildings and other standards

Fig 3 shows that by being the highest energy consumer, building A3 used energy least efficiently compared to the other study buildings. The figure also shows that although

BEI for building A3 is almost three times building A2, the reported perceived comfort for building A3 is comparatively small. The figure also depicts that in average, for every 1kWh/m^2/year building A3 only contributes to 0.67% of users who are comfortable with the indoor temperature, 0.71% for indoor air comfort and 0.67% for indoor lighting comfort. Building A2 charted to be the most energy efficient in terms of comfort.

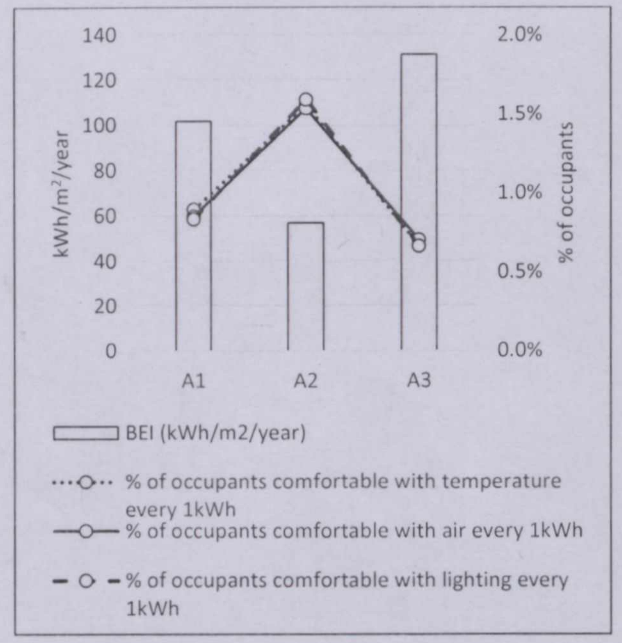

Fig 3: Percentage of comfortable users every 1kWh/m^2/year against BEI

The comfort index provided by the BUS Methodology for the three study buildings revealed that the building with the highest energy consumption was also surveyed to have the most comfortable users. This finding corroborated with a review by Yang et al. (2014), which found that control for indoor comfort account for more than half of the total electricity consumption and a research by Yahya, Ariffin, and Ismail (2014b) that suggested more energy is needed to adjust the building's environment to suit the users' comfort. Unfortunately, this does not apply to building A1 which was the second highest energy consumer but scored the lowest index for comfort.

With the exclusion of the results for building A1, it can be concluded that comfort relates positively with energy consumption. Fig 4 further reinforces the notion that building A2 consumes energy more efficiently than the other study buildings. The notion is demonstrated by the steep gradient for BEI between building A2 and building A3 compared with the gradient for comfort for the same two buildings.

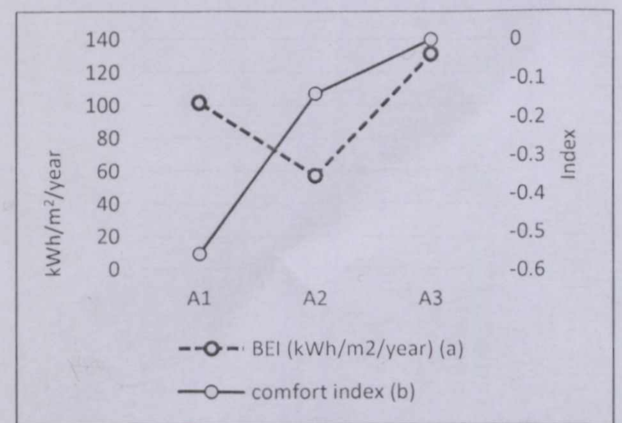

Fig 4: Comfort index against BEI

With the nonconforming result obtained for building A1, further investigation would be appropriate to justify its condition of high BEI but poor users' comfort. For now, it can be assumed that poor comfort may be influenced by the conditions of longstanding building as suggested by Yahya, Ariffin, and Ismail (2014a). The high BEI recorded in building A1 may be caused by the poor state of the cooling systems (Tang & Chin, 2012). It can also be assumed that since the building was built prior to the existence of air-conditioner where all rooms were fitted with *jalousie* windows to allow natural ventilation, air-conditioners which were installed in later years may be inefficient with the occurrences of draught and leakage. Another assumption could be that energy was used inefficiently due to users' indiscretion. Day and Gunderson (2015) and Nguyen and Aiello (2013) put forth that energy consumption in buildings are significantly influenced by users' behaviour.

Findings of the study also suggested that comfort may also be initiated from other environmental parameters that do not require the use of energy. Remarkably, user comfort can also be increased merely by upgrading non-energy dependant fittings and fixtures such as modifying the room finishes and subscribing to efficient pest control. Even so, some increase in energy-use is hard to avoid when putting increased efforts for comfort such as installing additional artificial lighting to amplify visual comfort which simultaneously provide security; or installing elevators for upturn accessibility and overall comfort.

6. Conclusions and future implementation

The relationship between users' perceptions of comfort and energy performance is a crucial process of integrating society and the environment which also has an indirect implication on the economy. Despite the abundance of research available, none so far have studied the relationship of energy consumption with the comfort of the users. This research has addressed this need by exploring the relationship of energy consumption and users' perceptions of comfort through the monitoring of electricity consumption as predictors of users' perceived comfort. This study has achieved the aim of the research by collecting data from two sources and found that the building studied with high energy index also scored high perception of comfort by the users. Since energy is directly affected for achieving temperature and lighting comfort, it can be assumed that energy consumption predicts user comfort positively. Regardless of this assumption, the ratio of energy performance as predictor and users' perception as the outcome is questionable. If the control for indoor comfort through heating and cooling accounted for more than half of the total electricity consumption, the result suggested that user comfort should increase in parallel to energy consumption. Although building A3 scored highest in terms of comfort and energy consumption, a further analysis revealed that building A2 uses energy more efficiently. When ratio of user comfort was calculated against energy consumed, building A2 scored twice better compared with building A1 and A3. In other words, to achieve the same level of comfort, building A2 only required half the amount of energy as building A1 and A3. This study suggests that the substantial increased use of electricity to achieve small comfort may not be worthwhile.

It is foreseeable that the research can be expanded to study the potential of retrofitting each building to be energy-efficient by reducing their BEIs. From this study, it is evident that at least one study building has a very high potential of being energy efficient while the rest performed poorly. The low BEI of building A2 compared to the benchmark and other standards should be a motivation for the management towards becoming an energy-efficient campus. Other than merely answering the research objective, the research can also be a stepping stone towards prioritising energy-efficient potentials in existing conventional buildings. If properly executed, the university campus which equates the size of a small township may achieve energy-efficient campus status sooner than expected and may lead others towards a low-carbon university campus.

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