

Building Energy Index and Student's Perceived Performance in Public University Buildings

S.N.N. Syed Yahya, A.R.M. Ariffin, M.A. Ismail

Department of Architecture, Faculty of Built Environment, University of Malaya, Kuala Lumpur, 50603, Malaysia

Abstract

Numerous studies have shown that students' learning experience is closely associated with the physical comfort level of their teaching and learning environment. The different strategies or allocation of air-conditioning, mechanical ventilation (ACMV) and lighting systems contribute greatly to the energy performances in the buildings. This study explores the relationship between electricity consumption of academic buildings of a public university in an urban context and its student's perceived performance. It seeks to find the answer patterns from unsuspected subjects; whether there is a difference from a lower energy-use building then one of a higher energy-use building. To achieve the objective, the study adopts the quantitative method of assessing student's perceived performance through questionnaire survey. The questionnaires, adopted from Building Use Studies, UK, were distributed randomly through convenience sampling to students from two academic buildings in the campus. Both buildings were selected through purposive sampling method with specific inclusion and exclusion criteria. Subsequently, power and energy logger was installed into the same buildings to monitor electricity consumption at specific intervals. For comparison, Building Energy Index (BEI) for each building was calculated. The study found that the building that scored higher in students' performance, also has higher calculated BEI. As control for indoor comfort account for more than half of the total electricity consumption, the result suggested that electricity consumption influences students' performance positively. The study also revealed that both buildings' calculated BEI were lower than recommended by many standards. This suggests that these buildings, has extremely high potential of achieving green building status. If executed properly, the university campus, which equates a size of a small city, may achieve green campus status sooner than expected and may lead others in the flagship project towards a low-carbon university campus.

Keywords: Building Energy Index (BEI), students' performance, academic buildings, public university

Introduction

Where numerous studies have shown that students' learning experience is closely associated with the physical comfort level of their teaching and learning environment [1-5], little have shown the indirect relationship between student's performance to the energy consumption. The maintenance of this teaching and learning environment, i.e. building envelope, facilities and the indoor air quality depends highly on energy supply [6, 7]. For example, the choice of strategies to cool and ventilate the air, and to illuminate the functional spaces determines the energy usage in the buildings [8, 9]. Therefore, it can be assumed that the students' performance is also associated with their environment's (i.e. the building) energy performance.

Since the initiation of the sustainability movement in the late 1970's, new buildings, particularly public buildings have been encouraged to increase energy performance and energy efficiency. For a university building, regardless of the enthusiasm to pursue energy-efficient building status, it must not compromise the quality of its core business which is teaching and learning. Reducing energy consumption should not risk reducing students' performance as well.

The indirect relationship between energy consumption and student's performance have motivated this study to explore the relationship between the two variable. More specifically, this study will compare the electricity consumption and student's perceived performance between two buildings in a renowned public university in Malaysia. The outcome of this study will answer whether the student's perceived performance in low energy-use building better or worse compared with high energy-use buildings?

Method

The paper achieved the objective of the study by collecting data from two subjects. This method is necessary to explore the relationship between two variables, which are, the energy consumption and student's performance. The first subject is the study buildings, while the second subject is the occupants of the buildings; more specifically, the students. The study buildings were selected through purposive sampling, while the students through convenience sampling.

A set of criteria were established to isolate buildings to study. The criteria restricted only multi-functioned academic buildings to be included in the study. This exclusion criteria managed to discard 310 buildings, leaving only eight to remain in the sampling frame. The research team did a one-day observation on each building shortlisted. The observation discovered that two buildings from the list were barely occupied. Aside from less than a dozen permanent occupant, the buildings intermittently received visitors who remained only for short periods. The two buildings were removed from the list of buildings to study foreseeing that the potential respondents may not be able to express their perception of the building for their lack of experience occupying the buildings. 150 questionnaires were distributed to each of the remaining six buildings.

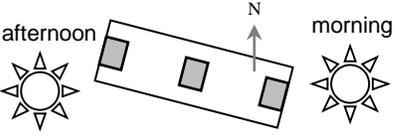
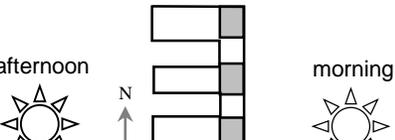
The Building Use Studies (BUS) occupant survey was found most suitable and was utilised under license from BUS Methodology 2012 for this study. The BUS occupant survey is one of two large-scale studies that have been initiated in 2002 and widely used globally to study building performance [10]. BUS Methodology has also developed a database and 'benchmarks' based on most recent fifty buildings surveyed from 17 countries [11]. Although the BUS questionnaire form is available in print and in electronic form, only the former is used for this study because as reported in previous research, print form provides higher response rate than the electronic [12].

The questionnaire asks the respondents to state their perception of how the building environment influence their performance, behaviour and health. Respondents were also encouraged to elaborate their answers in the "comments" column at the end of each section. There have been arguments that performance was a subjective variable that can be biased if not measured properly and supported by evidence [13]. Only 'perceived' performance is used as indicator for this study because it can be recorded quickly from the survey. Actual student's performance requires access to classified records and may not be achievable in the time of research.

The response rate for each building varied where the lowest response rate were 4.67%, while the highest response rate is 72.67%. Only the two buildings (Table 1, Figure 1 and Table 2) with the highest response rate were selected to be further studied due to availability of only one power and energy logger (PEL). Based on research by others, the PEL was among the best instrument to be used to measure energy consumption [14]. The availability of only one PEL forced the data to be collected consecutively instead of concurrently. Due to the short time of the research, only two buildings managed to be studied. The PEL was set to record energy consumption at the interval of ten minutes for 14 days each building. Upon completion of 14 days, the PEL was dismantled from the first study building (A1) and relocated to the second study building (A2). The installation, dismantling and reinstallation was conducted by a certified and competent charginan because the PEL needs to be installed on the main switch board (MSB). Recorded data were downloaded to the dedicated software supplied by the PEL manufacturer and then analysed.

The PEL succeeded in recording the energy consumption value for the period of 14 days and also the consumption trend, among others. For this study, only the energy consumption value is used to determine energy performance. Building energy performance were calculated for both buildings and later were analysed together with the result from the questionnaire survey.

Table 1 : Study building description and characteristics

Building	A1 (Arts Faculty Annexe Building)	A2 (Faculty of Languages and Linguistics)
Building facade		
Year Built	1999	1979
Built-up Area	8,314.01 m ²	10,532.49 m ²
Building Form & Orientation		
Building height	3 storeys (split levels)	2 storeys (split levels)
Roof Properties	pitched roof with concrete ceiling and parapet	pitched roof with plasterboard ceiling (concrete roof tiles)
Glazing Properties	float glass, tinted film casement windows	frosted jalousie windows
External Wall Properties	brickwall	brickwall
Internal Wall Properties	plaster & paint, rooms too small to have internal partitions	plaster & paint, gypsum
Ventilation Type	Mechanical Cooling -Split unit	Mechanical Cooling - Split unit and air cooled package & water cooled package

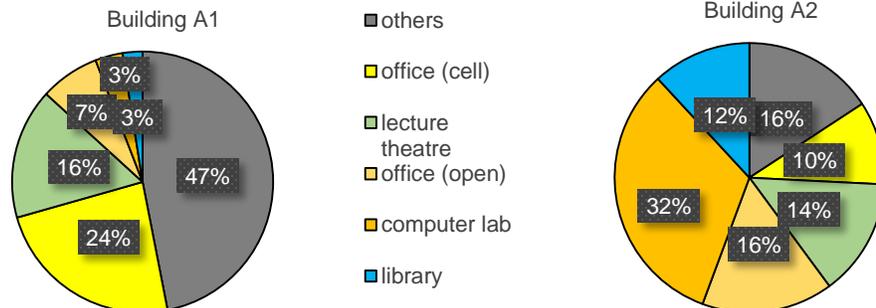


Figure 1: Space function for study buildings by area

Table 2: Position and type of ventilation for internal spaces

Building	A1	A2
Teaching and learning spaces	located along external wall with mechanical ventilation	located along external wall with mechanical ventilation
Administration	located along external wall with mechanical ventilation	located along external wall with mechanical ventilation
Lobby	open and naturally ventilated	open and naturally ventilated
Walkway/ corridor	located along interior wall. Naturally ventilated	open and naturally ventilated
Staircase	open and naturally ventilated	open and naturally ventilated
Toilet	located at external wall with natural ventilation	located at external wall with natural ventilation
Observations and comments	vernacular design, allows natural lighting. Still need mechanical ventilation because air is still	<ul style="list-style-type: none"> renovation on-going at time of observation doors and windows grilled for security room layout has advantage of natural lighting but external windows were fitted with black (almost opaque) blinds

Building Energy Performance

A building's energy performance are commonly used to determine the buildings energy consumption against its building size for the purpose of comparison [15, 16]. A look at the energy consumption alone is unable to determine whether the building over-consumes or under-consumes energy. Energy consumption has to be analysed relative to its building size. Calculating the energy consumption over building size is known as building energy index (BEI) or sometimes as energy performance index (EUI) [17-19]. BEI is calculated simply by dividing the total annual energy consumption of the building (kWh/year) with its total occupied floor area (m²) as follows:

$$BEI(kWh/m^2/year) = \frac{\sum \text{annual energy consumption (kWh/year)}}{\sum \text{net floor area}(m^2)}$$

The above BEI calculation requires the actual annual energy consumption for the building. However, given that only data for 14 days were available, the data were aggregated to obtain data for 365 days. The aggregated data were then used in the equation.

Compared to BEI, energy benchmarking is a relatively more accurate method that is widely used to compare energy performance between buildings [15]. This method adds another variable to the quantitative energy consumption and building size, which is the building function or type. This paper adopts the UK's Chartered Institution of Building Services Engineers (CIBSE) energy benchmarking system for purpose of comparison. The system has established "good standard" and "typical standard" benchmark as per Table 3:

Table 3: CIBSE benchmarking system for energy performance (adopted from [15])

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

For this paper, 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. For example, the "good standard" index for building A1 is shown below.

$$\text{Good standard index}_{A1} = \frac{\sum(\text{area for each function (m}^2\text{)} \times \text{good standard index}_{CIBSE}(\text{kWh/m}^2\text{/year}))}{\sum \text{nett area of A1(m}^2\text{)}}$$

Table 4: CIBSE good standard index calculation

	CIBSE good standard (kWh/m ² /year)		area (m ²)		A1 good standard (kWh/year)
others	54	x	2,493.79	=	134,664.66
office (cell)	33	x	1,257.30	=	41,490.90
lecture theatre	67	x	859.72	=	57,601.24
office (open)	54	x	391.21	=	21,125.34
computer lab	155	x	180.19	=	27,929.45
library	46	x	131.23	=	6,036.58
TOTAL			5,313.44		288,848.17

$$\therefore \text{Good standard index}_{A1} = \frac{288,848.17 \text{ kWh/year}}{5,313.44 \text{ m}^2} = 54.36 \text{ kWh/m}^2\text{/year}$$

For comparison, the paper uses energy index from the University of Malaya main campus (92.25 kWh/m²/year), Universiti Kebangsaan Malaysia Hospital (244.81 kWh/m²/year)[17], the recommended

Malaysian Standard for Energy Efficiency, MS1525:2001 (130 kWh/m²/year) [20] and both the CIBSE benchmarking for good (54.36 kWh/m²/year for A1 and 63.34 kWh/m²/year for A2) and typical standard (78.74 kWh/m²/year for A1 and 80.72 kWh/m²/year for A2). Apart from being compared with each other, these study buildings were also compared with other buildings.

Study Building A1

The result section will be reported according to the study building so that comparisons can be discussed in the discussion section. The distribution of questionnaire survey was done randomly through convenience sampling and were not restricted to just students. Therefore, there was a mix of staff, students and visitors who responds to the survey. Thirty three out of 102 respondents for building A1 were students. Thirty of them were aged under 30 years old and 23 have occupied the building for at least one year. Only responses from students were used for this paper. The respondents mean score for perceived performance was 5.67 compared to 4.13 of the BUS benchmark. Fourteen respondents (42.4%) perceived that the building environment increases their performance by at least 10% while the majority of 16 respondents believed that their performance are not affected by the building environment.

The trend for energy consumption of building A1 showed a maximum consumption of 18.72kWh and was recorded on a Wednesday, 12.40 noon. At the end of the 14 days, the PEL recorded that building A1 has consumed 12.71 MWh or 12,710.00 kWh of energy. Using the BEI equation, the calculated BEI for building A1 is 39.83 kWh/m²/year. Figure 2 shows the BEI for building A1 against other standards.

Study building A2

As with building A1, the respondents for building A2 came from different backgrounds where only 49 out of 109 respondents were students. 36 students have been occupants of the building for at least a year and 41 aged under 30. Responses from other respondents were discarded and only responses from students were analysed from hereon. The mean score obtained from the responses for perceived performance were 5.73 compared with 4.13 for BUS benchmark. Twenty eight respondents, equivalent to 58.3% reported that their productivity were increased by at least 10% due to their building environment, while only 12 respondents perceived that their productivity is not affected by their building environment.

The PEL recorded maximum energy consumption of 52.88kWh on a Monday at 10.50am. The 14th day of the equipment installation on building A2, the PEL recorded that 31.75 MWh (31,750.00 kWh) of energy has been used. The calculated BEI for building A2 is 78.59. BEI for building A2 and other standards are plotted in Figure 2: BEI for building A1 and other standards Figure 3.

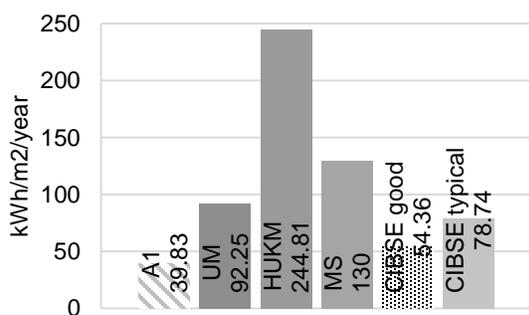


Figure 2: BEI for building A1 and other standards

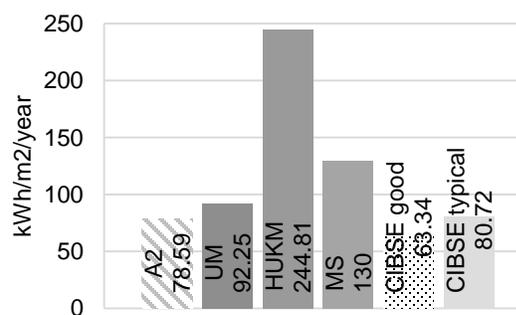


Figure 3: BEI for building A2 and other standards

Discussion

The demographic profile of the respondents shows that more than 60% of student respondents have been occupying the building for more than one year. It can be assumed that they occupy the building permanently and are not transient occupants. This signifies that their responses are genuine and reliable. Mean score for perceived performance show that the occupants for both buildings perceived that their building

environment increases their performance by at least 10%. These scores are comparatively better than the BUS benchmark score.

Similarly, when plotted against BEI from other standards, both study buildings' energy performances are considerably better. Building A1's energy performance is substantially less than CIBSE good standard index, while building A2 has a very high potential of meeting the CIBSE good standard benchmark. By combining the data from the two subjects, they answered the research question that, the building with higher electricity consumption scores higher mean score for perceived performance. As reviewed by Yang, Yan [7], control for indoor comfort account for more than half of the total electricity consumption, the result suggested that electricity consumption influences students' performance positively. In other words, more energy is needed to adjust the building environment to suit the occupants' comfort so they can perform better.

Although building A2 scores higher in terms of student's perceived performance and energy index, a further analysis revealed that building A1 uses energy more efficiently in terms of student's performance. This is shown in Table 5 below. The table shows that although BEI for building A2 is doubled from building A1, the reported perceived performance is small comparatively. The table also calculates that on average, every 1 kWh/m²/year only contributes to 0.74% of performance for building A2, while 1 kWh/m²/year only contribute to 1.07% of student's performance.

Table 5: Percentage of performance increase every 1 kWh/m²/year

Code	mean score for perceived performance (a)	reports increase 10% or more (b)	BEI (kWh/m ² /year) (c)	perceived performance every 1 kWh/m ² /year (b) ÷ (c)
A1	5.67	42.4%	39.83	+1.07%
A2	5.73	58.3%	78.59	+0.74%

Looking at the possible causes of the large difference in electricity consumption for buildings A1 and A2, there is a considerable difference in space usage; where building A2 comprised of more computer labs and lecture theatres and building A1 is made up of offices and other spaces that consumes less energy. As established by CIBSE, computer labs and lecture theatres contribute to higher energy indices.

Another factor that are known to cause the difference in energy usage and performance is the passive designs observed on the two buildings. Building A2 permits natural light and ventilation while the other does not. Although it is usual that passive features reduce energy usage, it is not the case for building A2. Natural light that penetrates the building permits high heat indoor while the natural vents causes air-conditioner leakages and makes them less effective.

Limitations

The original design for this study was to concurrently measure the electricity consumption for both buildings and conduct the questionnaire survey. Unfortunately, funding received was only able to accommodate one power logger, therefore measurement cannot be done concurrently. In addition, although originally, two similar buildings in size were finalized to be studied, it was discovered that one building were operated by two separate Main Switch Boards (MSB) and there were only one energy logger. Therefore, building A2 were chosen to replace the originally shortlisted building. Another limitation faced by the researchers are the short research period. Therefore, actual electricity usage for 365 days is impossible to record. In fact, only 14 days were allocated for each building. Recorded data had to be aggregated to estimate consumption for 365 days. It would also be less difficult for the researchers if occupancy profile for both buildings were available. Although student enrollment records are available, the records do not reflect the actual occupancy of the buildings. The only occupancy profile available for these buildings are for administration offices.

Recommendations and conclusion

The results of the study have answered the research question that, the building with higher electricity consumption scores higher mean score for perceived performance. Although it has been discussed that

students perform better in buildings with higher electricity usage, the significance of the difference should be further looked into. Is a 10% increase in student's performance worth double the energy usage and electricity bill? The next phase for the study is the potential to pursue green building status for the buildings studied. From the study, it is evident that both building has very high potential in being energy efficient. The low BEI of both buildings compared to other standards should be an encouragement towards a greener campus. If executed properly, the university campus, which equates a size of a small city [21, 22], may achieve green campus status sooner than expected and may lead others in the flagship project towards a low-carbon university campus.

References

1. Yang, Z., B. Becerik-Gerber, and L. Mino, *A Study on Student Perceptions of Higher Education Classrooms: Impact of Classroom Attributes on Student Satisfaction and Performance*. Building and Environment, 2013. **70**(0): p. 171-188.
2. Plympton, P., S. Conway, and K. Epstein. *Daylighting in Schools: Improving Student Performance and Health at a Price Schools Can Afford*. in *Proceedings of the Solar Conference*. 2000. American Solar Energy Society; American Institute of Architects.
3. Lee, M.C., et al., *Student Learning Performance and Indoor Environmental Quality (IEQ) in Air-Conditioned University Teaching Rooms*. Building and Environment, 2012. **49**(0): p. 238-244.
4. Hill, M.C. and K.K. Epps, *The Impact of Physical Classroom Environment on Student Satisfaction and Student Evaluation of Teaching in the University Environment*. Academy of Educational Leadership Journal, 2010. **14**(4): p. 65-79.
5. Choi, S., et al., *Indoor Environmental Quality of Classrooms and Student Outcomes: A Path Analysis Approach*. Journal of Learning Spaces, 2014. **2**(2).
6. Olanrewaju, A.A., *Green Maintenance Management Initiative for University Buildings*. Built Environmental Journal, 2011. **8**(1): p. 17-24.
7. Yang, L., H. Yan, and J.C. Lam, *Thermal Comfort and Building Energy Consumption Implications – A review*. Applied Energy, 2014. **115**(0): p. 164-173.
8. Bülow-Hübe, H. and Å. Blomsterberg, *Important Design Aspects of a Very Low - Energy Building*. 2011, Intelligent Energy Europe - NorthPass: Promotion of the Very Low-Energy House Concept to the North European Building Market.
9. Shen, H. and A. Tzempelikos, *Daylighting and Energy Analysis of Private Offices with Automated Interior Roller Shades*. Solar Energy, 2012. **86**(2): p. 681-704.
10. Gou, Z., D. Prasad, and S. Siu-Yu Lau, *Are Green Buildings More Satisfactory and Comfortable?* Habitat International, 2013. **39**(0): p. 156-161.
11. Building Use Studies, *The Building Use Studies (BUS) Occupant Survey: Origins and Approach Q&A*, Building Use Studies, Editor. 2011.
12. Nulty, D.D., *The Adequacy of Response Rates to Online and Paper Surveys: What Can Be Done*. Assessment & Evaluation in Higher Education, 2008. **33**(3).
13. Palmer, J., *Post-Occupancy Evaluation of Buildings*, in *A Handbook of Sustainable Building Design and Engineering: "An Integrated Approach to Energy, Health and Operational Performance"*. 2013, Routledge: London, UK. p. 347-354.
14. Alajmi, A., *Energy Audit of an Educational Building in a Hot Summer Climate*. Energy and Buildings, 2012. **47**: p. 122-130.
15. Altan, H., J. Douglas, and Y. Kim, *Energy Performance Analysis of University Buildings: Case Studies at Sheffield University, UK*. J Architectural Engineering Technology, 2014. **3**(129): p. 2.
16. Abdul-Rahman, H., C. Wang, and M.Y. Kho, *Potentials for Sustainable Improvement in Building Energy Efficiency: Case Studies in Tropical Zone*. International Journal of the Physical Sciences, 2011. **6**(2): p. 325-339.
17. Moghimi, S., et al. *Building Energy Index (BEI) in Large Scale Hospital: Case Study of Malaysia*. in *4th WSEAS International Conference on Recent Reseaches in Geography Geology, Energy, Environment and Biomedicine*. 2011. Corfu Island, Greece.
18. GreenTech Malaysia and SEDA, *Method to Identify BEI, Net BEI, GFA, NFA, ACA*. 2013, Seminar by Building Consumption Input System.
19. Bishop, R., *Why Some Buildings Have Very High or Low EUIs*. 2012, BEES Seminar by BRANZ Ltd.
20. Aun, C.S., *Energy Efficiency: Designing Low Energy Buildings Using Energy 10*. 2004, CPD Seminar 2004 by Pertubuhan Arkitek Malaysia.
21. Hoe, Y.K., *Achieving Sustainable Campus in Malaysia University*, in *Department of Civil Engineering*. 2011, University Teknologi Malaysia.
22. Mat, S., et al., *Managing Sustainable Campus in Malaysia - Organisational Approach and Measures*. European Journal of Social Sciences, 2009. **8**(2): p. 201-214.