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Correlation Study on User Satisfaction from Adaptive Behavior and Energy Consumption in Office Buildings

Ali Keyvanfar[a*], Arezou Shafaghat[a], Mohd Zaimi Abd Majid[a], Hasanuddin Lamit[b], Kherun Nita Ali[c]

[a]Construction Research Center (CRC), construction Research Alliance (CRA), Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[b]Center of Built Environment in the Malays World (KALAM), Faculty of Built Environment, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[c]Department of Quantity Survey, Faculty of Built Environment, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

*Corresponding author: alikeyvafar-rmc@utm.my

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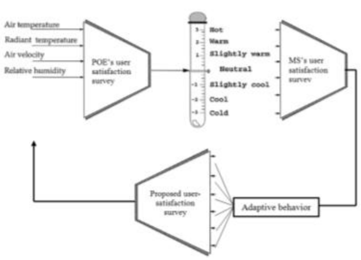
Graphical abstract



Abstract

Sustainable Building Assessment Tools have not yet measured the association between user satisfaction with adaptive behavior and energy efficiency. The current research aims to rectify this problem by testing the hypothesis that user satisfaction with adaptive behavior affects building energy consumption. To test the hypothesis, the staff's overall satisfaction with adaptive behavior in response to tenant energy-efficiency features was used as the independent variable, while office unit energy consumption was used as the dependent variable. A set of conceptual variables and measured variables were identified for both the dependent and independent variables. A total of nine possible combinations of measured variables were investigated through a survey fielded in ten office units. The survey analysis determined that the building users are not satisfied with the tenant energy efficiency features and that they may adapt the indoor environment cooling and lighting qualities. An expert input study was conducted to validate the results with respect to the hypothesis. Seven experts who had experience in building assessments were invited to participate in the input study. Grounded group decision making analysis method confirmed the hypothesis testing results. The research results indicated that user adaptive behaviors directly affect building energy performance. Sustainable Building Assessment Tool developers along with energy efficient building design consultants and contractors could make use of these research findings.

Keywords: Social sustainability; building assessment; energy efficiency; energy performance; user satisfaction; adaptive behavior, group decision making

1.0 INTRODUCTION

Researchers on 'sustainability managerial techniques in building construction practice' manage the implementation of sustainability methods and techniques in building practice. This implementation is performed with the aid of four sustainability methods and techniques, including (a) governmental status, (b) building codes, (c) private and professional associations or Non-Governmental Organizations (NGOs), and (d) marketing strategies[1]. Of these, the largest contributor to enhanced sustainability in building practices is the private and professional associations, including NGOs[1]. NGOs have mainly implemented multi-perspective 'Building assessment tools' to enhance the sustainability of building practices in specific regional areas[2,3].

In the building construction industry, assessment tools are specifically used to benchmark the enhancement of sustainability in building practices[4,5,6]. The use of assessment tools is a contribution of 'Managing Sustainability' to the building construction industry. These tools are traditionally referred to as 'Environmental building assessment tools' or 'Green building assessment tools' and are more recently referred to as 'Sustainable building assessment tools'.

Building assessment tools mainly aim to benchmark a 'Capacity Building' as a sustainable building case (i.e., social, economic, and environmental building) in a specific geographic region. This assessment includes existing buildings as well as new buildings across diverse functionalities, such as office buildings, residential buildings, commercial buildings, etc.[7] These tools involve a variety of facets of sustainability assessment, including energy efficiency, water management, waste management, land use, etc.[1] Basically, these features cover the greenery/environmental issues, along with consideration of the economically and socially sensitive approaches. To improve the usability of tools within a building lifecycle, the assessment may benchmark a building's 'sustainability' in design phase, construction phase, operational phase, and/or demolition phase[7]. According to Haapio and Viitaniemi[7], the end users of these assessment tools could be architects, engineers, facility managers, building owners, consultants, authority, contractor, and/or academic researchers. The academic researchers use the sustainable building assessment tools indirectly as decision support tools to meet the requirements of building sustainability accreditation[8].

There are some efforts being undertaken by 'Standards' to establish standardized requirements for building assessment tools. The International Organization for Standardization (ISO)[9,10] investigates features of assessments to develop a harmonized standard to measure the sustainability. The ASHRAE-55 standard[11] measures the correlation between indoor thermal environmental parameters (temperature, thermal radiation, humidity, and air speed) and user parameters (clothing insulation and metabolism rate). The use of the ASHRAE-55 standard[11] aids building energy managers in providing thermal environmental conditions acceptable to a majority of users[12]. The EN15251 standard[13] establishes environmental input parameters for the design and energy performance calculations of non-industrial buildings, such as office buildings[12]. Recently, the Temperature Limits guideline (ATG) was developed, which is an alternative to the Weighted Temperature Exceeding Hours method (GTO). The ATG has the flexibility to make recommendations for various types of buildings, including naturally ventilated buildings and mechanically conditioned buildings with sealed facades[12]. Additionally, the Construction Related Sustainability Indicators Project (CRISP) is a thematic network of sustainability indicators for construction and cities that have been developed based on a review of all the existing tools.

Since the early 1990s, approximately sixty 'Sustainable Building Assessment Tools' have been established, such as the Building Research Establishment Environmental Assessment Method (BREEAM), Leadership in Energy and Environmental Design (LEED), Sustainable Building tool (SBtool), Green Mark Scheme, and the Green Building Index (GBI). These tools aid to enhance the building construction industry in 'managing sustainability'. However, there are some shortcomings in the performance of these tools. Abdalla *et al.*[1] mentioned these tools are not accurate in the estimation of the energy consumption because they do not address the sustainability programs of end-users. Christensen[2] stated that social sustainability criteria including 'user satisfaction' and 'development impact on community' must be considered in sustainable building assessment tools.

Sustainable building assessment tools evaluate user satisfaction with diverse dimensions, including building architectural design, building value management, building asset management, real estate management, and construction management. However, user satisfaction has been analyzed independent of the Indoor Environmental Quality (IEQ) energy efficiency practices[3]. Indeed, user satisfaction criterion should be evaluated in conjunction with energy efficiency to reduce operating, occupancy, and maintenance costs for owners and tenants, while simultaneously enhancing environment preservation[4]. Indeed, enhancing energy efficiency at buildings may reduce greenhouse gas emissions and address issues related to climate change and global warming[4].

Yu *et al.*[7] stated that the behavior and activities of building occupants can affect energy consumption in a building, along with six other factors, including Climate, Building-related characteristics, User-related characteristics (excluding social and economic factors), Building services systems and operation, Social and economic factors, and Indoor Environmental Quality (IEQ). However, the 'behavior and activities of building occupants' has yet to be integrated with building assessment tool development[8]. Among the diverse behaviors and activities of occupants, 'adaptive behavior' is a measure of user satisfaction that may enhance an energy program[9,10,11,12]. Brager and de Dear[13] define user adaptive behavior as all activities to 'fit' the indoor climate to individual or collective requirements. Liu *et al.*[12] stated that adaptive behavior can be conscious or unconscious, while multiple environmental factors can affect it (e.g., climate, culture and economics). Contextual factors and the user's surroundings may have a conscious and positive impact on his/her behavior[14]. Contextual factors provide 'adaptive opportunities'[15] and 'adaptive constraints'[16]. Tabak and de Vries[17] divided staff behavior activities into skeleton activities and intermediate activities. Tabak and de Vries[17] defined skeleton activities as those that fulfill the requirements of the job descriptions of the staff (e.g., chairing meetings, giving lessons, etc.) and intermediate activities as those that fulfill the psychological and physical requirements of the staff (e.g., getting a drink). Intermediate activities are often non-scheduled activities, while skeleton are often scheduled activities.

■2.0 THE ABSENCE OF USER SATISFACTION MEASUREMENT IN SUSTAINABLE BUILDING ASSESSMENT TOOLS

There are some shortcomings with the sustainable building assessment tools described and used by the researchers in the available literature. Abdalla *et al*.[1] indicated that the building assessment tools do not accurately in estimate building energy consumption because they do not consider end-user sustainability programs. Christensen[2] stated that the social sustainability criteria such as 'user satisfaction' and 'development impact on community' need to be considered more in the tools.

Reviewing the literature in diverse disciplines indicates that the user satisfaction has been analyzed independent of the environmental and economic aspects of sustainable building practices[12]. Among the various factors that affect energy consumption in a building, the research on 'building-user behavior and activities' was not sufficiently investigated[13]. Among the diverse types of building-user behavior and activities, 'adaptive behavior' is a measure of user satisfaction that may enhance an energy program[14,15,16,17]. Dibra *et al.*[18], Eang[19], and Yun and Steemers[18] stated that building-user behavior and activities is the most common cause of fluctuation in the actual energy consumption relative to planned energy consumption. Wilkinson *et al.*[4] stated that research on 'user satisfaction from adaptive behavior' in building energy estimation was not yet mature. In fact, user satisfaction from adaptive behavior is not yet included in the index formulas of the sustainable building assessment tools. Linking energy consumption with building-user behavior and activities may potentially aid building facility managers in optimizing, and somewhat, reducing their energy usage.

Although some efforts are being undertaken by standards organizations, such as the International Organization for Standardization[9,10] and the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE)[11] to establish standardized requirements for sustainable building assessment tools, the capacity to measure user satisfaction with adaptive behavior still remains a significant issue.

To date, various methods and models have been used and/or developed for sustainable building assessment tools to measure user satisfaction in energy-efficient buildings. However, these user satisfaction index analysis methods and models cannot measure the user satisfaction with adaptive behavior.

In this regard, the current research planned to explore the correlation between user satisfaction from adaptive behavior and building energy consumption to be applied in sustainable building assessment tools. The research establishes a user satisfaction from adaptive behavior to capture the overall cognitive experience of the staff in building energy consumption. This research focuses on models and methods of data collection on user satisfaction in the design phase of the building lifecycle.

2.1 Effects of Building User to Energy Performances

Chung[20], Roetzel *et al.*[21], and Yun and Steemers[22] stated that the 'behavior and activities of building occupants (i.e., users)' is the most common cause of fluctuation in actual energy consumption relative to planed energy consumption. Jackson[38], in his review paper, highlighted previous studies that developed various models or simulation programs to measure and predict users' differing energy consumption behavioral patterns. Studies of the impact of user behavior and interaction with building systems on energy consumption have increased the knowledge and understanding of building performance. Eang[19] defined 'tenant' and 'land lord's energy consumption features'. The landlord's consumption includes all the energy consumption occurring in common areas for cooling, lighting, or any other purpose. The land-lord energy consumption features are less dependent on the tenancy rate, and building users commonly do not have control over these features. The energy consumption of tenants occurs mainly in the areas where energy consumption depends on the tenancy rate and the behavior of tenants. The consumption of tenants include energy consumption from:

- Lighting systems,
- Cooling systems,
- Building facilities (e.g., elevator),
- Work equipment (e.g., printers, and computers).

As a consequence, while these advances are compelling, incorporating the attitude and self-sufficiency habits of users[23] and the 'Voluntary Simplicity' approach[24], both of which potentially have large implications for energy consumption, remains as a critical challenge. Adaptive behavior might take the form of adopting an energy-saving life style; however, based on the research of Sorrell *et al.*[25], such behavior may result in poor consumption habits due to the 'rebound effect'. Jackson[26] indicated that 'green' social marketing campaigns and financial incentives can avoid such rebound effects. Azar and Menassa[27] and Allsop *et al*.[28] addressed the 'word of mouth' effect, which is considered to be a very influential channel of green communication based on the research of Harrison-Walker[29].

The above-mentioned techniques are qualitative techniques for achieving appropriate life style change through the implementation of adaptive behavior. A review of the literature in the field that discusses studies and simulations of building-user adaptive behavior confirm that this type of awareness can significantly influence building energy use[26,28].

Interaction between user behavior and building systems for energy consumption has increased the knowledge and understanding of building performance. Eang[19] stated that it is possible to save a significant amount of energy by improving building design. Cole *et al.* [30] reported a manifesto from the Passive and Low Energy Architecture–PLEA[31] conference. They stated that the building user can reduce energy consumption by

- Including 'social and ethical challenges' in building energy efficiency program.
- Considering the 'dynamic and responsible' involvement of the user and the designer in the architecture design phase of the building project.

Andersen *et al.*[32] identified 'user control' as an important factor for energy efficiency. To avoid energy-wasting behavior, Maaijen *et al.*[33] described the need to deploy energy effectively to provide comfort only in those locations where it is needed. To achieve this effective deployment conveniently, Heating, Ventilation, and Air Conditioning (HVAC) systems must adapt automatically to comfort levels of actual individuals. Maaijen *et al.*[33] proposed a method where the user is involved in the control loop, called the 'human in the loop approach'. In this approach, the human is taken as the leading factor in the design and control of HVAC systems, which can reduce energy consumption on cooling demand by 40% of the total energy demand.

In addition, several software simulation models have been created to predict user behavior and improve the performance of design. These models are designed "…to help researchers exploring relationships between building users and building performance variables"[34]. Hoes *et al.*[35] indicated that the behavior component of these models is usually based on empirical data. The users of simulation models usually attempt to simplify the occupant activities; however, it is important to consider all the complexities involved[36]. Yao *et al.*[37] stated that these models do not include a comprehensive list of the occupant activities.

Eang[19] identifies 'tenant' and 'land lord' energy consumption features. The landlord's consumption includes all the energy consumption occurring in common areas for cooling, lighting, or any other purposes. Land-lord energy consumption features are less dependent on the tenancy rate, and building users commonly do not have control over these features. The tenants' consumption is mainly in the areas where energy consumption depends on the tenancy rate and tenant's behavior. Tenants' consumption includes energy consumption in: Lighting systems, Cooling systems, Building facilities (e.g., elevators), and Work equipment (e.g., printers and computers).

2.2 Importance of Enhancing Energy Efficient Building Practices

It is a common goal of all countries to improve the Human Development Index (HDI), which measures human quality of life (Figure 1). An increase in the HDI will result in higher energy consumption and carbon dioxide emissions as well. Figure 1 shows the correlation between HDI and dioxide emission per capita within countries. As indicated in the figure, countries must foresee their future energy consumption and optimize their energy consumption in sustainable building design for a higher HDI.

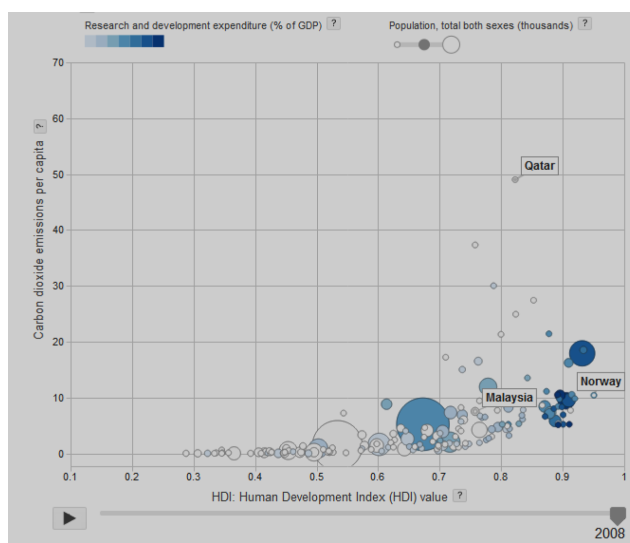


Figure 1 HDI versus Carbon Dioxide emission (Adopted from Human Development Report 2013, United Nations Development Programme-UNDP[23])

In summary, the reviewed literature indicated that user satisfaction was not dependently incorporated with energy efficiency in sustainable building assessment tools. In particular, effects of 'user satisfaction with adaptive behavior' on building energy consumption were not yet established[7]. Zhang and Barrett[39] stated that "there are no published studies that test if the design of a sustainable building can have a positive influence on pro-environmental behavior of a transient population within that space".

In this regard, this research investigates the correlation between building-user satisfaction with adaptive behavior and energy efficiency. Based on established definitions of adaptive behavior in an energy efficient building, this study defines adaptive behavior as behavior that expresses the personal or environmental adjustment of users in response to the following conditions of the indoor environment:

- Off-time running of energy consuming systems.
- Slightly uncomfortable indoor environmental conditions that are not considered unacceptable by users.

In this study, 'adaptive behavior' refers only to the technological and personal aspects of adaptation. Psychological and physiological adaptation are not covered. Because psychological adaptation is dynamic, it cannot be forecast accurately in design phase of project life cycle. It is obvious from laws of causality that 'physiological' adaptation is a prime mover (i.e., cause) of 'Technological' and 'Personal' adaptation (i.e., effect). Indeed, measuring dissatisfaction with 'Technological' and 'Personal' adaptation eliminates dissatisfaction from 'Physiological' adaptation[13].

Based on the issues discussed, this research defined a 'null hypothesis' and 'alternative hypothesis' to investigate the observed problem. The null hypothesis is:

H0, *'Building-user satisfaction with adaptive behavior does not have an effect on building energy consumption' (r =0).*
While the alternative hypothesis is:
H1, *'Building-user satisfaction with adaptive behavior affects building energy consumption' (r0).*

3.0 HYPOTHESIS TESTING

The research conducted hypothesis testing through a survey to determine if it is appropriate to reject the null hypothesis because of the validity of the alternative hypothesis. In this study, the Type I error 'α' is set at 0.05; correspondingly, the p-value of less than 0.05 is considered as an acceptable result to reject the null hypothesis.

A structured fixed format questionnaire was designed to collect data, within which, the conceptual variables, independent variables, dependent variables, and control variables were been indicated. The staff's overall satisfaction with adaptive behavior in response to tenant energy efficiency features was the independent variable. Office unit energy consumption was the dependent variable. The conceptual variables corresponding to the dependent variable and the independent variables are as follows:

1) Independent variables in the survey instrument:
The conceptual variables of the independent variable are as follows:

- The staff's overall satisfaction with adaptive behavior in response to an energy efficient cooling system,
- The staff's overall satisfaction with adaptive behavior in response to an energy efficient lighting system,
- The staff's overall satisfaction with adaptive behavior in response to an energy efficient building facility (e.g., an elevator),
- The staff's overall satisfaction with adaptive behavior in response to energy efficient work equipment.

The measurement of the independent variable used the following categories:

- 'DS' for Dissatisfied,
- 'N' for neutral, and
- 'S' for satisfied.

The control variables are described in the below.

ISO 1525[10] requirements and GBI's[40] POE requirements were used as control variables in the survey. These control variables confirm that building users are satisfied with the overall performance of the tenant energy efficiency features in POE as well as IEQ. In this regard, Figure 2 shows a thermal satisfaction cycle, including the physical factors included in POE (i.e., air temperature, radiant temperature, air velocity, and humidity). Figure 2 also shows the thermal satisfaction based on human sensation, which is a focus of the Malaysian Standards (MS)[41], and thermal satisfaction based on adaptive behavior. In fact, the null hypothesis can be proven or rejected when POE's thermal satisfaction and ISO thermal satisfaction are simultaneously achieved.

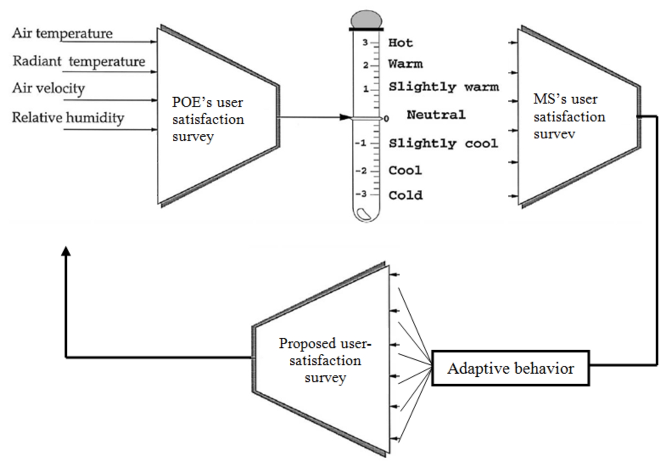


Figure 2 Human thermal satisfaction assessment cycle

In this research, the cultural and social characteristics of users and the attitude and beliefs of users were also used as control variables. According to previous studies, the cultural and social characteristics of users are common control variables in research on the satisfaction with environmental conditions in response to a cooling system[13,14]. Additionally, the attitudes and beliefs of users are common control variables in research on 'satisfaction from environmental conditions in response to the cooling system'[42,43,44].

2) Dependent variables in the survey instrument:
The conceptual variables of the dependent variable are as follows:

- Energy consumption of the cooling system,
- Energy consumption of the lighting system,
- Energy consumption of the building facility (e.g., elevator),
- Energy consumption of the work equipment

The measurement of the variables of the dependent variables was as follows:

- 'E+' for an increase in energy consumption from the expected energy consumption,
- 'E' for the same energy consumption as expected,
- 'E-' for a decrease in energy consumption from the expected energy consumption

Control variables related to the dependent variable are as follows: The validity of observation, as a control variable, was confirmed using the Building Energy Management System (BEMS).

In the developing user satisfaction adaptive behavior criteria based on the reviewed literature, two additional control variables have been considered: users' cultural and social characteristics and users' attitude and beliefs. This research used these variables as the control variables in the investigation into the relationship between user satisfaction with adaptive behavior and the energy consumption of a building.

Users' Cultural and Social Dimensions: According to the literature, one of the control variables used in the research on satisfaction with environmental conditions in response to a cooling system is the cultural and social contextual dimension of the users[13,39,43,44]. To date, there is no definitive evidence on the effect of the 'cultural and social dimension'. Researchers using the term 'cultural and social dimension' referred to the dress code and clothing habits/behaviors of the occupants of a particular building, or workplace culture, such as taking a siesta in the heat of the day, the local and vernacular architecture, the traditional means of construction and the demographics of building users. However, none of these factors have been investigated as a special subject.

Users' Attitude and Beliefs: Another control variable used in research on satisfaction with environmental condition in response to cooling system is building users' attitudes and beliefs. de Dea[42] argued that occupants' attitudes and beliefs towards the environment may boost the 'forgiveness' factor in the assessment of conditions created by building systems. However, according to Jensen *et al*.[42], people generally tend to distance themselves from behavior that might be considered too different and troublesome. In addition, as Edwards[43] indicated, environmental attitudes are not always translated into action and may negatively impact people's productivity. Lan *et al.*[44] reported that the loss of productivity has already been detected in slightly unsatisfactorily cool conditions.

Based on the conceptual and measurable variables, the researcher identified nine (9) possible observations for survey on hypothesis testing: 'DS&E+' observation, 'DS&E' observation, 'DS&E-' observation, 'N&E+' observation, 'N&E' observation, 'N&E-' observation, 'S&E+' observation, 'S&E' observation, and 'S&E-' observation.

3.1 Selection of the Case Study for the Survey

To conduct the survey to test the hypothesis, the research study identified three possible energy efficient buildings using on the Malaysia Green Building Index (GBI) 2010 report: the Ministry of Energy and Water Resource Management building (known as the Low Energy Office (LEO)), the Green Energy Office (GEO), and the Energy Commission office building (known as ST-Diamond).

Through an expert input study, the three potential case study subjects were validated on the following criteria: accessibility of framework users to researchers, validity of ISO 1525:2007 ISO 1525[10] requirements for Indoor Environmental Quality (IEQ), standard Post Occupancy Evaluation (POE) track records, eagerness of BEMS to support the study, availability of the POE result, and having been under operation for more than 5 years. The expert input study resulted in the selection of the Low Energy Office (LEO) Building of the Ministry of Energy, Water and Communications located at the city of Putrajaya, Malaysia.

The LEO building is equipped with energy saving design features, a building control system and energy recovery system, daylight and shading, energy management system and an energy manager. The LEO building achieved a 50% energy savings, equal to 114 kWh/m2 per year. The LEO building has the temperatures set to 24ºC for the offices and 26ºC for the corridors. The relatively low energy consumption is due to a higher population density, approximately 60 m^2/person, compared to that of conventional office buildings (normally at 14–20 m^2/person) along with a good infiltration of outside air into the building. The CO2 level in the building ranges within 280–450 ppm despite the set-point concentration of 1,000 ppm in the ASHRAE recommendation. The distribution of energy consumption is: 45% cooling system, 21% lighting systems, and 34% equipment.

3.2 Conducting the Survey at Leo

Using the POE method, over 20% of the total occupants should be calculated as sample size. Thus, the researchers conducted the survey with ten (10) office units that are representative of the total population of office users. One respondent in each office unit represented of the entire unit staff. Each respondent was identified based on the recommendation of the building manager. Within the survey, the researcher asked personal information of the respondents. Subsequently, the researcher described different nine possible observations to the respondents. Next, the researcher recorded the observation of each office unit based on the answers of respondent(s) on following queries: "Which option describes your staff's satisfaction level from their adaptive behavior in response to 'Tenant energy efficiency features'?", and, "What is the effect of this satisfaction level on the energy consumption of the considered 'Tenant energy efficiency features'?"

In the last part of the questionnaire, the researcher asked the respondents if the recorded result is subject to the specific composition of staff, including 1) Proportion of male to female, 2) Proportion of Malays to Chinese or Indian races, 3) Proportions of single, shared, and open working spaces, 4) Proportion of staff within a specific age group of 25-45 or 45-above. The researcher double checked the information to confirm of the answers with respondents at the end of each interview.

■4.0 RESULTS OF HYPOTHESIS

To test the hypothesis, the collected data from the survey was integrated with the following questions (Q). This action was conducted to enable the ease of importing the data into SPSS (Statistical Package for the Social Sciences) for analysis.

Q1- Energy consumption of the cooling system,
Q2- The staff's overall satisfaction with adaptive behavior in response to the energy efficient cooling system,
Q3- Energy consumption of the lighting system,
Q4- The staff's overall satisfaction with adaptive behavior in response to the energy efficient lighting system,
Q5- Energy consumption of the building facility (elevator, etc.),
Q6- The staff's overall satisfaction with adaptive behavior in response to energy efficient building facility (elevator, etc.),
Q7- Energy consumption of the work equipment,
Q8- The staff's overall satisfaction with adaptive behavior in response to energy efficient work equipment

According to the first section of the questionnaire (i.e., personal information about the respondents), it was observed that within all ten (10) office units, the ratio of male staff to female staff was in the range of 30 to 70 percent; in addition, over 90% of the office staff was Chinese. Only 10% of the total staff work in the 'single working spaces', and the rest work at the 'shared working spaces'. Sixty percent (60%) of the staff was 25-45 years old, and forty percent (40%) was above 45 years old. A summary of the data collected in response to survey questions Q1 to Q8 is presented in Table 1.

Table 1 Summary of data collected in the survey

		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
N	Valid	10	10	10	10	10	10	10	10
	Missing	0	0	0	0	0	0	0	0
Mean		.8000	-.8000	-.8000	.8000	-.1000	.9000	-.1000	.8000
Median		1.0000	-1.0000	-1.0000	1.0000	.0000	1.0000	.0000	1.0000
Mode		1.00	-1.00	-1.00	1.00	.00	1.00	.00	1.00
Std. Deviation		.42164	.42164	.42164	.42164	.31623	.31623	.31623	.42164

Table 2 presents the variables used in the analysis of the data collected in the survey.

Table 2 Summary of variables values appointed for survey interview

Question No.	Value	Label
	-1.00	Energy -
Q1, Q3, Q5, Q7	0.00	Energy
	1.00	Energy +
	-1.00	Dissatisfaction
Q2, Q4, Q6, Q8	0.00	Neutral
	1.00	Satisfaction

In response to the cooling system operation, the data analysis shows DS&E+ and N&E types of responses that were observed by the researcher. Overall, 'Dissatisfaction of staff' (DS) was recorded in eight (8) out of ten (10) office units (80%), which is a very high rate. In those eight office units, a private cooling system was installed inside the office unit to meet the comfort requirements of the staff, which caused an increase in the electricity consumption (E+). The main cause of the DS response that led to E+ was found to be the dissatisfaction of the staff with the expected high 'Clo' (Clothing level). Furthermore, in the survey, two (2) of the office units were recorded as N&E, which refers to recording an overall neutral level of staff satisfaction in the unit, where there is no energy consumption difference from the expected energy consumption.

- In response to the lighting system control, the data analysis indicates that N&E and S&E- types of responses were observed. The N&E was recorded in two (2) office units. N&E refers to recording an overall neutral level of staff satisfaction in a unit where there is no energy consumption difference from the expected energy consumption. As in the cooling system data analysis, the overall satisfaction of the staff (S) was recorded in eight (8) out of ten (10) office units (80%), which is a very high rate.

- In response to the building facilities, the researcher observed the S&E type of response among eight (8) cases. The overall satisfaction of the staff (S) was recorded based on observations from the interviews and the BEMS report. The BEMS confirms that the energy consumption of the building facilities was equal to the expected energy consumption (E). Furthermore, in one unit, N&E, which refers to recording an overall neutral level of staff satisfaction in a unit where there is no energy consumption difference from the expected energy consumption, was observed. Another observation was S&E, which refers to recording an overall neutral level of staff satisfaction in unit where there is a decrease in the energy consumption from the expected energy consumption. From the correlation analysis, presented in Table 3, the observed relationship is not significant; the correlation coefficient is very small, the significance level is less than 95%, and Cronbach's Alpha is less than 0.7. The study failed to support the hypothesis corresponding to building facilities.

- In response to the work equipment, the researcher observed an S&E type of responses among seven (7) cases. In two units, N&E, which refers to recording overall neutral level of staff satisfaction in a unit where there is no energy consumption difference from the expected energy consumption, was observed. Another observation was S&E-, which refers to recording an overall neutral level of staff satisfaction in a unit where there is a decrease in the energy consumption from the expected energy consumption. From the correlation analysis, presented in Table 3, the observed relationship is not significant; the correlation coefficient is very small, the significance level is less than 95%, and Cronbach's Alpha is less than 0.7. The data analysis failed to support the hypothesis corresponding to work equipment. The calculated correlation between 'Q1' and 'Q2' is '-1', with a significance level of over 99% and with high reliability (Cronbach's Alpha=1). The 'Y= -X' equation is identified based on the linear regression analysis between the dependent and the independent variable. Table 4 shows the result of the coefficient calculation. This correlation was the same between 'Q3' and 'Q4'.

Table 3 presents the result of the correlation analysis hypothesis test on responses to 'cooling system', 'lighting system', 'building facilities', and 'work equipment'.

Table 3 Correlations analysis in response to 'cooling system', 'lighting system', 'building facilities', and 'working equipment'

		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Q1	Pearson Correlation	1	-1.000**						
	Sig. (2-tailed)		.000						
	N	10	10						
	Cronbach's Alpha	1	1						
Q2	Pearson Correlation	-1.000**	1						
	Sig. (2-tailed)	.000							
	N	10	10						
	Cronbach's Alpha	1	1						
Q3	Pearson Correlation			1	-1.000**				
	Sig. (2-tailed)				.000				
	N			10	10				
	Cronbach's Alpha			1	1				
Q4	Pearson Correlation			-1.000**	1				
	Sig. (2-tailed)			.000					
	N			10	10				
	Cronbach's Alpha			1	1				
Q5	Pearson Correlation					1	-.111		
	Sig. (2-tailed)						.760		
	N					10	10		
	Cronbach's Alpha					1	.250		
Q6	Pearson Correlation					-.111	1		
	Sig. (2-tailed)					.760			
	N					10	10		
	Cronbach's Alpha					.250	1		
Q7	Pearson Correlation							1	-.167
	Sig. (2-tailed)								.645
	N							10	10
	Cronbach's Alpha							1	.381
Q8	Pearson Correlation							-.167	1
	Sig. (2-tailed)							.645	
	N							10	10
	Cronbach's Alpha							.381	1

Note. **. Correlation is significant at the 0.01 level (2-tailed).

Based on the analysis results, the null hypothesis was proved for the cooling and lighting systems. Consequently, building user dissatisfaction with adaptive behavior contributes to increasing energy consumption, specifically from the cooling systems and lighting systems. This result confirms the hypothesis that "building users are not satisfied with the tenant energy efficiency features and they may adapt the building's design and technologies according to their satisfaction level, which causes higher energy consumption". However, the hypothesis was confirmed using a small sample size of 10, which may not be sufficient to support the hypothesis at a high level confidence. Thus, an extra stage was added in the study, an 'expert input study', to validate the results of the hypothesis testing.

■5.0 EXPERT INPUTS ON THE VALIDATION OF THE RESULTS OF THE HYPOTHESIS TEST

The researcher conducted an expert input study to validate the results of the test of the hypothesis. The field expert Delphi structured Close Group Discussion (CGD) method was used to collect inputs from the experts. Delphi was chosen as the most applicable group decision method because it can cover 'non-alternative selection' decisions in the CGDs. Based on the sampling method, seven (7) experts with expertise in building energy efficiency assessment and building facility management were selected. A structured, fixed-format, self-reporting questionnaire was designed based on a five-point Likert rating scale, within which, 1 referred to Weak and 5 refers to Excellent.

The experts were asked to report their perception for each following four questions; 'Is the hypothesis acceptable for office building cooling energy consumption?', 'Is the hypothesis acceptable for office building lighting energy consumption?', 'Is the hypothesis acceptable for office building facility energy consumption?', and 'Is the hypothesis acceptable for work equipment energy consumption in the office building?'

The data collection process was performed in four group decision making sessions. Each session lasted approximately one hour. At the end of each session, the researcher asked if an interview should be conducted with other respondent(s) or expert as 'resource(s) relevant to the issue'.

The collected data was analyzed using the Grounded Group Decision Making (GGDM) method. Lamit *et al.*[45] stated that the GGDM is suitable if decision makers in a closed group discussion ask for another closed group discussion round with other 'resource(s) relevant to the issue'.

Adapted from Lamit *et al.*[45], formula 1 of the GGDM is denoted as $FW(a_i)$. This formula is used to calculate the final weight (FW) of sub-issue number 'i', (a_i) of the discussion.

$$(1)\quad FW(a_i) = (\textstyle\sum_{j=1}^{n}(\min\{WP_j, W\Pr_j\} \times SV_j)) \times a_i,$$

$$for\, i = 1,2,3,\ldots,m$$

Where,

WP_j refers to the assigned weight by the participants number 'j' in a closed group discussion on sub-issue' a_i ',

$W\Pr_j$ refers to the assigned weight by the resource(s) relevant to the issue, whom were introduced by participant number 'j' in the closed group discussion for sub-issue ' a_i ',

' a_i ', refers to the sub-issue under discussion,

$FW(a_i)_{\max}$ refers to the maximum possible weight that can be given for sub-issue ' a_i ',

SV_j refers to the CGD sessions value (SV) used by the decision researcher for the CGD session included participant number 'j'.

In the cases where the participant(s) did not introduce other resource(s) relevant to the issue, $\max\{WP_j, W\Pr_j\}$ was taken as WP_j .

Furthermore, the participant(s) in the cases where participant(s) did not vote and did not provide an absolute decision for the introduced resource(s) relevant to the issue, $\min\{WP_j, W\Pr_j\}$ was taken as $W\Pr_j$. Formula (2) indicates the consensus calculation of the GGDM for sub-issue '' a_i ', based on percentage (%). If the final consensus calculated is over 70%, then the issue is approved.

6.0 DISCUSSION ON FINDINGS

It is obvious that a study on user satisfaction with adaptive behavior requirements will enhance the sustainability of a building in terms of functionality, serviceability, adoptability, human comfort requirements, well-being, risk reduction of investment and a have negative impact on the environment[13]. Focusing on the energy efficient building, user satisfaction evaluation has been traditionally considered in the operation and maintenance phase of building life cycle. However, a literature review indicates that the majority of building assessment tools lack a focus on the energy, environmental, and/or economic aspects in the design phase of the building life cycle. As a result, the current research established a comprehensive list of user-satisfaction adaptive behaviors for the evaluation of an energy efficient building in the 'Design' phase. The research findings help to enhance the sustainability assessment techniques for buildings. Indeed, such an assessment will assist building design and construction teams to have a quantitative assessment on the downstream requirements of the satisfaction of end-users.

A critical literature review on previous studies indicates that building user satisfaction is correlated to energy consumption. However, there is no evidence demonstrating the effect of 'building user satisfaction with adaptive behavior' on 'building energy consumption'. To address this, a survey with expert input was performed to clarify the issue. The research defined a null hypothesis based on a content analysis of the reviewed literature. The hypothesis testing survey found that building user dissatisfaction from the adaptive behavior contributes to increasing the building energy consumption, specifically for the cooling and lighting systems, i.e., building users are not satisfied with the tenant energy efficiency features and they may adapt the building indoor environment design according to their satisfaction level, which causes higher energy consumption.

An expert input study to support the results of the survey to test the hypothesis with a higher confidence level. The expert input study used Delphi structured close group discussions. The expert(s) justifications were collected based on four (4) questions that investigated the acceptability of the hypothesis on the cooling system, the lighting system, the building facilities, and the work equipment. The expert input data was analyzed using GGDM, which resulted with 70% saturation in the acceptance of the hypothesis for the 'cooling system' and the 'lighting system'.

6.0 CONCLUSION AND RECOMMENDATIONS

Based on the research results, we conclude that social issues and social behavior effects on the energy efficiency should be considered by sustainable building assessment tool developers in the design phase of the building life cycle. In particular, user satisfaction with adaptive behavior is an inter-connected criterion in compliance with energy efficiency in the development of a sustainable building assessment tool, and also, in sustainable urban assessment[46,47].

In conclusion, the study was successful in investigating the effect of 'building user satisfaction from adaptive behavior' on 'building energy consumption'. The findings indicated the importance of this study and confirmed that previous efforts were not sufficient in this area. Conducting a survey and obtaining expert input resulted in accepting 'cooling system' and 'lighting system' as the main factors in tenant energy consumption.

Managing the adaptive behavior of the building users will assist investors, developers, tenants, and government bodies to make informed decisions on the energy management of buildings. The research findings can be used by Sustainable Building Assessment Tool developers. Moreover, 'energy-efficient building design consultants' and 'design and build contractors' are also possible direct users of the research findings. The findings indicate that both professionals and practitioners must consider user satisfaction in the design to achieve social sustainability in the energy-efficient building.

In addition, considering the adaptive behavior of the building user reduces the risk of volatile investment as well as future competitiveness of the building asset in the market. The results of this study will assist professionals in benchmarking previously completed and future projects.

The practical approaches of energy efficient building design will be investigated in further studies. In particular, the physical and structural aspects of sustainable building need to be studies which have been recommended in previous construction researches, such as, Talebi *et al.*[48], and Abdulrahman *et al.*[49].

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