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Energy efficiency index by considering number of occupants: a study on the lecture rooms in a university building

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ABSTRACT

The building sector is attributed to approximately 40% of the nation's energy consumption and this accounts for a significant percentage of the nation's energy consumption. For this reason, energy efficiency in buildings has now become an important subject in the national energy scenario. Energy Efficiency Index (EEI) is one of the energy consumption indicators that is widely used in the building sector for measuring energy performance. This index is generally measured based on the energy used per unit of building floor area. However, this index is not able to directly identify other factors affecting energy usage. This paper suggests an Energy Efficiency Index (EEI) for determining the performance of lecturer rooms in a university building. Unlike the conventional EEI, the proposed EEI determines the room's energy usage performance by considering the number of occupants. The study was conducted at the Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM) and the results show that the number of occupants significantly influences the energy usage performance of rooms in a university building.

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1. INTRODUCTION

Energy consumption in the commercial building sector has been gradually increasing and this affects the increase in energy production and utility bills. Based on Malaysia's Energy Statistics in 2016, approximatly 40% of the nation's energy is consumed by the building sector [1]. With such statistics on energy consumption and the fact that underdeveloped and developing countries mostly use fossil fuels as the main sources of energy, there is an urgent need to be energy efficient [2].

Commercial buildings include office buildings, shopping centres, storehouses, public administration and other commercial structures [3]. According to the Building Book Data; Council of Australian Governments, shopping mall and office buildings are the most energy demanding in many countries. In Australia, 60% of the energy consumed in commercial buildings are by the offices and shopping outlets [4].

Since university buildings are also high consumers of energy in the category of commercial buildings, many public universities in Malaysia have promoted energy management programs for better use of energy [5]. In order to promote a more sustainable way of consuming energy, energy management plays a significant role in achieving such a target. One of the public universities that implements the energy saving program is Universiti Teknologi Malaysia due to its high energy consumption and electricity bill.

The increase in the number of students as well as the number of buildings has contributed to the high energy consumption and electricity bill. In 2010, energy consumption of the university was found to decrease significantly due to the implementation of the energy saving program.

This paper proposes a new Energy Efficiency Index (EEI) to track the energy consumption performance of a university building. Unlike the conventional EEI, the proposed EEI considers the number of occupants in a building which would reflect the actual performance of the building's energy consumption. A study was carried out at the Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM) where the results and methodologies are presented in the following sections.

2. ENERGY MANAGEMENT IN BUILDINGS

2.1. Retrofitting Equipment

Renovation, retrofit and refurbishment of existing buildings are among the initiatives utilized to improve energy consumption performance in commercial buildings. Retrofitting can result in improved energy consumption and reduced energy demand [6]. This gives an opportunity to attract tenants as a result of the reduction in operational cost from energy efficiency retrofitting initiatives [3]. In addition, retrofitting could also affect the behavior of occupants concerning conserving energy. Williams et al. reported that the average energy savings that can be attributed to daylight harvesting as measured is approximately 28%. However, the savings is affected by other factors including window size, space geometry, building location, time of year, and interior finishing and geometry [7].

Retrofits can also involve electrical and mechanical appliances such as replacing lightings and air-conditioners with more energy efficient units. Erhan E. Dikel et al. reported that retrofitting lighting system with LEDs paired with sensors offer 79% energy savings [8].

2.2. Control System

A building management system (BMS), is a computer-based control system installed in buildings that control and monitor the building' mechanical and electrical equipment which consists of softwares and hardwares. Adopting the Building Automation System (BAS) for real-time monitoring and control of the building services systems has become a top trend in the building sector [9]. As reported by Waide et al., approximately 22% of the energy consumed during building operations can be saved through the use of advanced building automation technologies. The advantages of BMS systems are the possibility of individual room control, increased staff productivity and saving time and money during maintenance [10, 11]. It can also be useful for reducing energy consumption. Saeed Kamali reported that BMS allows users to control each of the sub-systems individually and it also allows integrated control. He also reported that the cost of implementation of BMS for a building is about USD40,000 and can on the average reduce 50% of energy consumption [9].

2.3. Human Behavior

Global climate change can affect many aspects in society including health, economic prospects, and food supply and water resources. Global climate change and environmental degradation are mainly caused by human behavior and can be improved through awareness and sustainable practice [12-14]. David Uzzell from the British Psychological Society, reported that energy efficiency programs, energy saving campaigns and information-based behavioral strategies rely more on the social, psychological and political dynamics that drive people's decision-making process to reduce energy usage than technology or standards [13]. The Behavioral Insights Team (BIT) [15] published a number of reports on the psychology of people's decisions when it comes to energy saving as shown in Figure1.

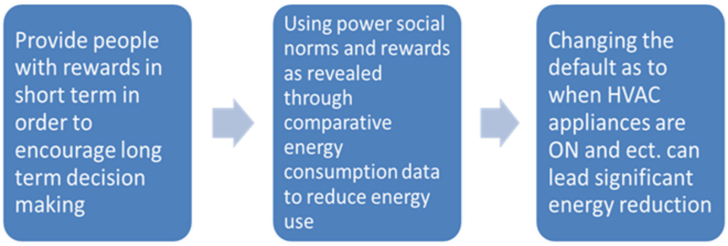

Figure 1. The psychology of people's decision [15]

3. ENERGY EFICIENCY INDEX

Energy Efficiency Index (EEI) is an indicator to record the performance of a building and act as a point of reference which provides the baseline for energy consumption of a building. The EEI is also known as the Building Energy Index (BEI) [16], Energy Performance index (EPI) [17], and Energy Cost Index [18].

EEI acts as a standard baseline or limitation that organization should follow for energy index monitoring. The EEI for commercial buildings in Malaysia according to the Malaysian Standard (MS1525:2007) is 135 kWh/m^2/year [19]. The concept of EEI is often used because it represents a global index for energy efficiency in buildings. It also provides the owners, organization, technical personnel of buildings with an understanding of the performance of energy consumption in their buildings. In general, the equation for EEI is given as the ratio of the energy input to the factor related to the energy using component [20].

$$EEI = \frac{Energy\ input}{Factor\ related\ to\ the\ energy} \tag{1}$$

There are several factors related to the energy using component that could be considered such as [21]:

a) Weight of product produced
b) Number of items produced (industrial)
c) Weight of raw material used
d) Period of production
e) Period of plant usage
f) Number of beds (hospital)
g) Number of occupied rooms (hotel)
h) Number of occupants (lecture room)

Many researchers study EEI as a building index that incorporates tracking of performance of energy consumption in buildings which controls the usage of energy without exceeding the proposed baseline [19, 21-24]. S. Moghimi et al. [19] reported that most organizations implement EEI analysis for buildings using kWh/m², where energy consumption is based on the parameter of per unit floor area.

3.1. Proposed EEI Model for Lecture Room

A study for a university building was conducted where the EEI [20] was determined from the total energy consumption, kWh per gross floor area, m^2 as shown in (2).

$$EEI = \frac{EC}{A} \tag{2}$$

EC is the total energy consumption of a building expressed in kWh and A is the gross floor area, in m^2. However, the EEI in (2) does not directly identify the effect of the occupants because it does not include the occupant density of the building in the equation. Most university buildings are designed based on the number of occupants. However, the number of students in a lecture room changes randomly and might not meet the expected capacity of the room.

In this study, the proposed EEI model for a lecture room is based on three parameters consisting of the total energy consumption, number of occupants and gross floor area as shown in (3).

$$EEI_p = \frac{EC}{A} \bullet \frac{O_{base}}{O_{actual}} \tag{3}$$

Where the energy consumption (EC) is in kWh; gross floor area (A) is in m²; O_{base} is the base number of occupants, and O_{actual} is the actual number of occupants. The unit of the proposed EEI is expressed in kWh/m².

4. CASE STUDY

This case study was conducted in a selected building in the Faculty of Electrical Engineering (FKE), UTM. FKE is one of the sixteen (16) faculties on campus and has the highest energy consumption among the other faculties. FKE has 13 blocks which consists of lecture rooms, offices and laboratories. The electricity use in the buildings are mainly for lighting, air-conditioning and appliances such as computers and other appliances. Normal working days are from Sunday to Thursday.

The obtained data were analyzed based on the work conducted in lecture rooms at the P16 building. Several parameters were considered in the analysis, such as load usage, space area, operation hours and occupant capacity. The lecture rooms are mainly used during the semester period. Six lecture rooms in the P16 building were selected for this case study using the criteria of occupant density, gross floor area and energy consumption.

Table 1 presents the P16 building details of lecture room. The load analysis for each room showed that the highest power consumption of 11.19 kW was for air- conditioning. Each room was installed with 3 (three) split air-conditioning units with a total of 15 hp capacity. Besides air-conditioning, lighting is also a major energy consumer. The average power consumption in each room in the P16 building was determined to be 13.203 kW.

Table 2 shows the lecture rooms schedule showed that the rooms are frequently used on Wednesday. The usage time for the rooms was assumed to be 7 hours [25]. Each lecture room was designed to accommodate 120 people. However, the number of occupants is normally less than the design value.

Table 1. P16 Building Details

Room	Function	Gross Floor Area (m²)	Room Capacity (Person)
Demo 1	Lecture room	204.35	120
Demo 2	Lecture room	204.35	120
BKT 1	Lecture room	204.35	120
BKT 2	Lecture room	204.35	120
BKT 3	Lecture room	204.35	120
BKT 4	Lecture room	204.35	120

Table 2. Students Occupancy during Lecture Hour on Wednesday [25]

Time/Day	0800-0900	0900-1000	1000-1100	1100-1200	1200-1300	1300-1400	1400-1500	1500-1600	1600-1700	1700-1800	1800-1900
BKT 1	15	80	80	25	25					32	32
BKT 2	31	31	52	30	30						
BKT 3	27	27		28	28						
BKT 4	41	41									
DEMO 1		11	11	59	58						
DEMO 2	23	29	29		33						

5. RESULTS AND ANALYSIS

The data from the lecture rooms in the P16 building were used to evaluate the proposed EEI in terms of energy consumption, gross floor area and number of occupants. An observation of a lecture room for two different scenarios in which the number of occupants is different. In this case, the design number of occupants for each lecture room is 120 people. However, it can be seen that the actual number of people is much lesser than the design value during most of the lecture sessions. In the worst case scenario, there were less than 20 people in the lecture room which could lead to energy wastage.

The conventional EEI is unable to directly identify the effect of occupant density in the building because it considers the energy consumption and gross floor area only. The resulting EEI does not include other factors in the calculation but every lecture room in university buildings are mostly design based on the number of occupants. Reduction in the number of occupants can lead to inefficient use of electricity.

Figure 2 shows the result of the proposed EEI for six lecture rooms evaluated on a Wednesday. It can be seen that the highest EEI is 0.7047 kWh/m², during lecture session held in DEMO 1 at 9 am to 11 am due to the low occupancy in the room.

Figure 3 shows the comparison between the conventional EEI and the proposed EEI for a period of one week. The data were analyzed based on the number of highest occupants in the lecture room. It can be seen that the conventional EEI (blue bar) remains constant regardless of the number of occupants. Meanwhile, the proposed EEI (red bar) successfully shows the effectiveness of the additional factor of occupants in indicating the energy wastage in each room. The figure shows that the BKT 2 room has the highest EEI of 0.1463 kWh/m² compared to other rooms. It can be concluded that higher value of EEIs demonstrates opportunity for improvement in terms of energy savings. Lower EEI indicates better performance in terms of energy consumption especially when the EEI is less than 0.0646 kWh/m².

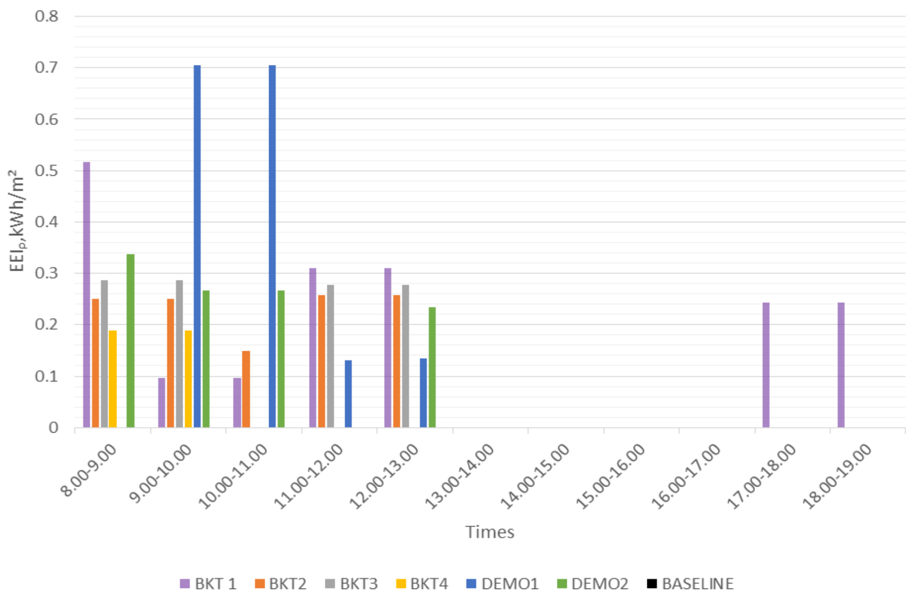

Figure 2. Results using proposed EEI on wednesday

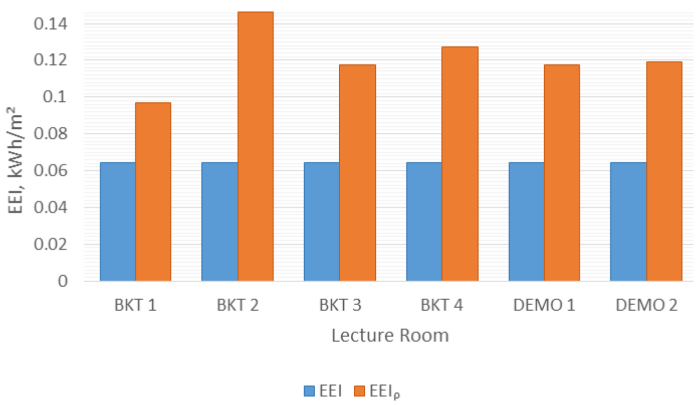

Figure 3. Comparison between conventional EEI and proposed EEI

The proposed EEI definition has shown that including the number of occupants in determining a building's EEI will represent a clearer picture of energy wastage in evaluating a building's energy performance. Apart from occupancy factor, other factors may also contribute to energy consumption such as the use of electrical devices, air-conditioning and lighting. With the inclusion of the occupancy factor in the calculation of the EEI, the energy consumption in a lecture room can be represented to indicate how the occupant density in a building space affects the energy usage.

6. CONCLUSION

This paper has presented a study for lecture rooms in a faculty building in UTM. The approach used in determining the Energy Efficiency Index (EEI) includes the effect of occupant density in a room. It can be seen that occupant density is a significant factor in determining EEI for lecture rooms in university buildings. Thus, the proposed calculation for EEI is expected to be a useful tool in evaluating university buildings' energy performance towards achieving energy efficiency.

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