CHEMICAL ENGINEERING TRANSACTIONS

VOL. 106, 2023

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Jeng Shiun Lim, Nor Alafiza Yunus, Peck Loo Kiew, Hon Huin Chin

ISBN 979-12-81206-05-2; **ISSN** 2283-9216

DOI: 10.3303/CET23106009

Building Energy Efficiency Assessment with Integration Criteria Decision Making for Energy Reduction in Campus Building

Nur Izieadiana Abidin[a,*], Siti Mazzuana Shamsudin[b]

[a]Department of Structure and Materials, School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, Johor Bahru, Johor
[b]Kolej Pengajian Alam Bina, Universiti Teknologi Mara, Shah Alam, Selangor
izieadiana@utm.my

Issue revolving around energy in campus buildings has become a global concern upon realising the impact of its activities and operations on energy. Hence, understanding energy use in university campuses as an individual educational building is integral as a prerequisite to identifying energy efficiency (EE) conditions. Having that said, this study lists the criteria initiative for EE based on Building Energy Intensity (BEI) diagnoses in a case study building. The approach comprised three phases, namely (a) a Preliminary Survey, (b) In-situ Energy Audit, and (c) an investigation of criteria during the decision of implementing energy efficient measures. The case study was conducted in an educational building located at Universiti Teknologi Malaysia, Johor. The In-situ Energy Audit phase enabled the assessment of BEI, which was essential to identify energy-consuming equipment, machinery, and electrical appliances. The BEI value for the scheduled room was 3.24 kWh/m^2/mth while 4.97 kWh/m^2/mth for the unscheduled room with lighting and air-conditioning that served as energy-consuming equipment. The recorded BEI value was considered energy-efficient usage due to its annual use below the recommended value for the Building Energy Index (BEI) in Malaysia at 136 kWh/m^2/y based on the Malaysian Standard (MS1525). Based on this premise, the criteria identified for the implementation of energy-efficient lighting were piloted in the case study building. The findings may facilitate educational institutions and organisations in managing electricity use, reducing energy consumption, and making effective decisions.

1. Introduction

The omnipresent rise in energy demand signifies the growing pressure in light of energy use stemming from the continuous increase of the global population and standards of living. This scenario exemplifies that promoting building Energy Efficiency (EE) has turned into a major task for most countries (Yu et al., 2019). According to Duc Pham et al. (2020), the increase in population, rapid urbanisation, and escalating social demand have significantly proliferated building energy demand. As such, understanding the energy consumption pattern in a building is beneficial to enhance EE and achieve sustainability. Tian et al. (2019) asserted that determining energy use in a building is vital to improve the existing equipment, lighting, and air-conditioning system.

Both commercial and institutional buildings are the key indicators for the socio-economic development of a country, in which energy use forecast revealed that future energy consumption in commercial buildings is expected to rise and create an impact on social, environment, and economic sustainability, including better health, generate energy that has no or little emission and poisonous gases such as carbon dioxide (Ruparathna et al., 2016). Energy use in the institutional building of university campuses relies on its activities and operations, from teaching to research and other endeavors. Energy is derived from various types of space, including lecture halls, laboratories, and computer rooms (Kolokotsa et al., 2016). Due to the growing concern to reduce energy use in the building sector, campus buildings have a role in learning about the energy issue. Comprehending its building energy usage is essential as a precondition to improving EE and to establishing good energy planning (Guan et al., 2016). Numerous studies have been conducted to improve EE on campus with a retrofit implementation based on energy conditions however, there is a limited study that proposes retrofit with decision-

Paper Received: 10 April 2023; Revised: 05 August 2023; Accepted: 29 September 2023
Please cite this article as: Abidin N.I., Shamsudin S.M., 2023, Building Energy Efficiency Assessment with Integration Criteria Decision Making for Energy Reduction in Campus Building, Chemical Engineering Transactions, 106, 49-54 DOI:10.3303/CET23106009

making criteria in ensuring the implementation receives the benefits in terms of economic, technical, and comfort. With that, the objective of this study is to identify the EE measures taken in a case study building to assess Building Energy Index (BEI). A list of criteria is proposed in light of EE measures implemented to support the evaluation upon deciding on the selected technology. The criteria are established on the developed Multi Criteria Retrofit Energy Efficient Building (McREEB) tool which represents the novelty of this research that was developed for the retrofitting assessment during the decision-making process.

2. Building Energy Efficiency (EE)

Energy Efficiency Index (EEI), also known as Building Energy Intensity (BEI), is commonly used as a baseline or benchmark to monitor and compare energy consumption performance in buildings. This index has been widely applied since it is a universal index that is beneficial to practice EE in buildings (Ahmad et al., 2012). Basically, the BEI of a building is dictated based on building size since the consideration of energy used depends on the building floor area (Ahmad et al., 2012). With the increasing awareness of building energy-saving, many have taken the initiative to use the building index. It refers to a model that can significantly improve the energy consumption of a building, especially in the implementation of an energy management program. The BEI is expressed in kWh/m^2 by dividing energy input (total energy consumption, kWh) by gross floor area (m^2), as shown in Eq(1) (Ahmad et al., 2012):

$$BEI = \frac{Energy\ Input}{Gross\ Floor\ Area} \quad (1)$$

3. Decision making for Energy Efficiency (EE)

The selection of EE measures is a complex decision and heterogeneous that requires various variable conditions as the integration of specialties in the EE approach (He et al., 2019). According to Kumar et al. (2017), Multi-Criteria Decision Making has been widely used for energy planning since it allows decision-makers to focus on all the criteria available and to make an appropriate prioritisation of decisions. A good design for decision in energy planning is when it contains multiple dimensions, the decision makers may look into several parameters such as economic and technical. It helps the decision makers to quantify the criteria based on their importance. Diakaki et al. (2018) opined that with EE implementation with innovative technology, there might be an issue encountered to achieve reliability and long-term effectiveness. With every EE measure proposed, the decision makers require consideration of many factors such as environmental, economic, social, and many others to maximize EE's achievement. It also helps to deliver the best possible solution to satisfy the building occupants and owners. This paper introduced significant criteria for the implementation of EE, which is then tested in the case study to see the criteria considered during the decision of EE in a building.

4. Case study development

4.1 Building description

The case study building at the Universiti Teknologi Malaysia (UTM) Johor Bahru campus was built on 30 December 2008 and fully completed on 4th June 2013. It occupies 5 floors with an area of 11,903 m^{2}. This building is part of the 9th Malaysia Plan cluster development which is made up of an academic office, café, lecture hall, centre of excellence, laboratories, and space for teaching and learning. The faculty has a capacity for approximately 2,000 undergraduate students and 400 postgraduate. It has all rooms connected to the open central courtyard which is designed as a circulation of the internal space. This building also features special natural lights which are elevated to the North and South to allow the inner space to fully utilise the daylight. However, to filter the unwanted glare and excessive solar heat gain, the sun is controlled by the perforated panels on the building’s parameters on the east and west sides. Besides, the design of cross-ventilation that optimised natural ventilation is another feature of this building to ultimately maximise the use of natural light and ventilation (Idiana, 2014). This building also uses energy-efficient lighting through the installation of the fluorescent T5 system. This is in line with the UTM energy conservation initiative. The sensor timer was also installed in the hallway of the building. The timer is set for operation at night and switched off at 5 a.m.

4.2 Phases of case study

In the case study, there are three (3) phases adopted which are a preliminary survey, an in-situ energy audit, and the identification of criteria for the installation of energy-efficient projects. Phase 1 (preliminary survey) involves a plan review to identify areas with similar or different equipment and appliances. It also helps to identify the total number of rooms/spaces and to measure the gross floor area. A plan review helps to set out the forms that will be used to fill during the audit phase which are divided on the basis of the room location (level), room type, room number, room area, type and quantity of electrical equipment or appliances used together with hour usage to make it easier to record the data. Phase 2 (In situ energy audit) is an opportunity to gather information about the actual use of energy (kW) towards each type of equipment and machinery used in the building to survey the energy-consuming equipment. This included lighting, air-conditioning, refrigerator, etc. The period of operation (hours) under typical operation was observed through walk thorough audit with the building engineer and technician. Phase 3 is for the assessment of the Criteria for Implementing Energy Efficient. The BEI results help to interpret energy consumption and indicate how efficient the current implementation of energy-efficient equipment in a building. When the energy used is efficient, it provides further justification for the important criteria considered during the decision to implement energy-efficient equipment. The selection of the important criteria was performed by the Electrical Engineers through the distribution of a questionnaire survey. The list of respondents is obtained from The Institution of Engineers Malaysia (IEM). A total of 459 populations with 210 of the required sample size to be distributed with the successful response received is 115. The selection of respondents is based on their experience in the installation of equipment to retrofit buildings. The results were analysed with Weightage Factor (WF) to perform for the criteria to generate its own weightage. The WF enables the comparison or the determination of the influence of the variables in deciding EE measures. All the weightage values should be added and the sum will be equal to 1 with a percentage of 100 % (Maletta and Aires, 2007). The Eq(2) below denotes the basic formula for WF. The stratum denotes the score for both criteria and sub-criteria, FSsc is the Factor Score for sub criteria and Fsc is the Factor Score for criteria.

$$\pi\ subcriteria = \frac{\%\ Stratum\ in\ Variables\ (sub-criteria), FSsc}{\%\ Stratum\ in\ Criteria, FSc} \qquad (2)$$

Results from WF were transferred into an automated system which is in Microsoft Excel 2010 developed by the researcher. It is a decision-making tool known as Multi-Criteria Energy Efficient Building (MCREEB) which acts as a calculator with a drop-down list of criteria(s) and the weightage. The result of the selection is capable of generating the categorisation of Practice and Preferences. Practice is influenced by the weightage achieved from the criteria selected. The higher the weightage and the best their practice for achieving optimal retrofitting. There are four (4) types of Practice: Best Practice, Good Practice, Moderate Practice and Basic Practice. Best Practice implies decision-makers achieve a high weightage (100-81), whereas Good Practice is when the weightage is above the average point (80-54) at which it is below Best Practice. Following this, Moderate Practice is at an intermediate level (53-27) where the weightage is much lower compared to the above Practices. Lastly, Basic Practice (26-0) showed that it is at the lowest weightage for the criteria selected. Every practice has its preference level consisting of Exemplary, Proficient, Apprentice and Novice, which is determined by the total number of sub-criteria chosen. Exemplary arises when decision makers choose the criteria selected at a maximum number. Whereas Proficient, Apprentice and Novice happen when there is a reduction of the criteria selected after exemplary. This tool was piloted into the case study building to test the criteria using a real case. This suggests the final weightage based on the criteria selected from the EE implementation.

5. Results and discussion

5.1 Building Energy Intensity (BEI) analysis

The interpretation of the findings for BEI was categorised into scheduled and unscheduled rooms. Scheduled room is when the operation hour of electrical appliances, machinery, and equipment is based on a specific time or according to 8 h of building operation period. Under the scheduled room, the energy audit revealed that the main energy sources in this building are air conditioning and lighting. It is often found in the office-space type, such as control room, work area, general office area, and graduate office area. The highest amount of BEI consumed by this building is 12.44 kWh/m^2/mth located in the General Office area on the first floor with 40 h of use per week. The General Office area consists of technicians, management, and administrative staff of the faculty. Besides, this area is also utilised by students and academicians to deal with administrative staff to manage their affairs and activities. It is the busiest place in the faculty and it involves maximum use of air-conditioning throughout the business operation. For lighting, the majority of the lighting systems used are T5 fluorescent fixtures, which are energy-saving technologies that have been widely used in many buildings. The highest contribution of energy is located in the postgraduate work area on the fourth-floor level with the BEI is only at 1.68 kWh/m^2/mth. The postgraduate work area is fully used by the research students throughout the working hour period. While the second highest BEI contributed by lighting is at the quality room located at the ground floor level with a value of 1.61 kWh/m^2/mth with 40 h of usage per week. It was followed by Postgraduate Lab with a BEI of 1.44 kWh/ m^2/mth. The overall BEI value under the category for the scheduled room is 3.24 kWh/m^2/mth. Figure 1a shows the summary of the illustration for the scheduled room. The unscheduled room is where the period of energy use for machinery, equipment, and electrical appliances did not exactly specify. These include the lobby, corridor, prayer room, academic staff room, viva room and toilets. Through the in-situ energy audit, the highest energy consuming is coming from air-conditioning and lighting. The highest BEI value for air-conditioning is only at 22.24 kWh/m²/mth, located at the main pantry of the building at the second-floor level with 40h usage per week. For lighting, the highest BEI is only 3.36 kWh/ m²/mth, which consumes 40 h per week located at the training corridor on the second-floor level. The second highest BEI for lighting is 2.62 kWh/m²/mth located in the photocopy room which also consumes 40 h/week. Besides, the third-highest lighting BEI is 2.24 kWh/m²/mth at the waste storeroom and organic synthesis lab. The overall BEI value under the category for the unscheduled room is 4.97 kWh/m²/mth. Figure 1b shows the summary of the illustration for the scheduled room.

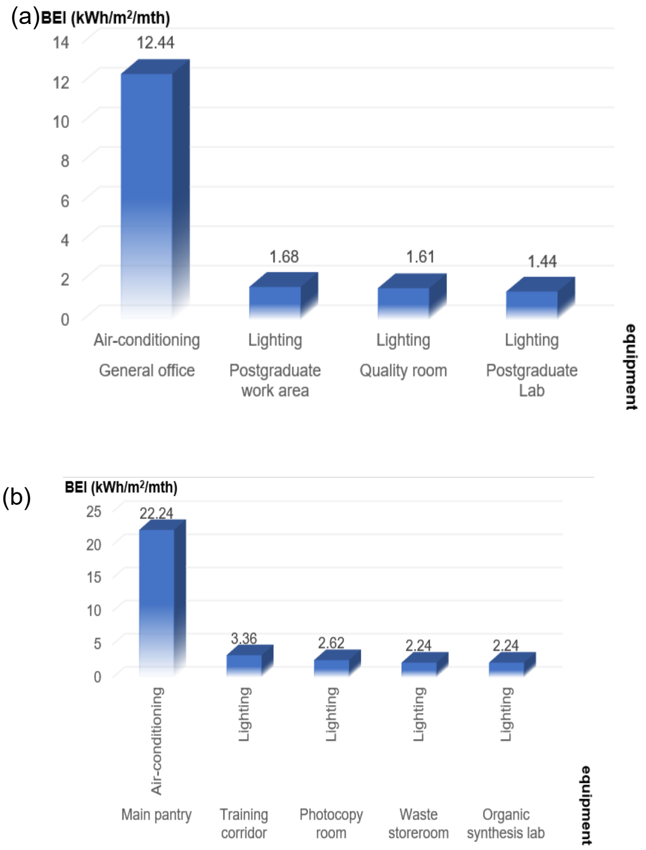

Figure 1: Illustration (a) energy utilisation for the scheduled room (b) unscheduled room

6. Assessment of criteria for energy efficient equipment in a case study building

The measurement of actual BEI found that the lighting used in this building was efficiently utilized due to the use of an energy-efficient T5 fluorescent lamp and the installation of the motion sensor. The criteria considered during the decision on energy-efficient lighting installation with T5 fluorescent lamps and motion sensors were identified. T5 provides better efficiency that helps to save costs and remarkable performance. It has no probability of being dimmable and coming in white colour. Commonly T5 is suitable for offices, schools, and other similar environments. For T5 lighting implementation in the case study building, there are three main criteria considered which are design, economic, and visual comfort.

6.1 Design criteria

The design criteria are initially important to be concerned with the overall quantity followed by to integrate with the automatic daylight system since some parts of the corridor and classroom are capable of using a good proportion of natural light to save more energy. The light could be switched on when the light from daylight falls below the desired level due to the weather or during the night. This can be implemented in the future. According to Scorpio et al. (2022), it is important to use daylight as much as possible but when the amount of daylight is not sufficient, the use of electric lighting is the alternative. This means trying to regulate the needs of light intensity based on needs which will help to reduce energy use. Thirdly, it is necessary to comply with the standard code of practice by ensuring safety. Lastly, the lighting installation also ensures that space is provided with appropriate illuminance, which will make it easier for users to feel comfortable and achieve high-quality in their working environment. Based on the Malaysian Standard, the lighting quality according to general office purposes with reading and writing activity is in the range of 300 lux (Mohd Husini et al., 2021). The result is shown in Table 1.

Table 1: Result of Decision Making in Retrofitting for Lighting (Design Criteria)

Main	No	Sub-Criteria	Weightage
Design	1	Lighting quantity	6.342
Design	1	Integration with daylight harvesting	5.693
Design	1	Compliance with standard code of practice	7.199
Design	1	Illuminance	6.591
Total	4		26
	Novice		Best Practice

6.2 Economic criteria

Economics also has been considered especially with the initial cost, energy, and cost-saving. Initial costs are involved in the cost to purchase based on the quantity required and the market price. The energy and cost-saving estimate is usually determined by the input watts and the daily operating hours. This criterion is important since the lighting offers less energy than the non-efficient or traditional incandescent, and it is expected to provide savings to cover the investments made. The energy-efficient purchase is an investment to achieve utility savings. The third criteria are maintenance cost whereby is concerned with minimal replacement expense and less requirement for cleaning or replacing the light. The maintenance will take into account the possibility of lumen degradation, and light burnout which affect the retrofit cost savings (Ikuzwe et al., 2020). The result is shown in Table 2.

Table 2: Result of Decision Making in Retrofitting for Lighting (Economic Criteria)

Main	No	Sub-Criteria	Weightage
Economic	1	Initial cost	11.36
Economic	1	Energy and cost saving analysis	11.75
Economic	1	Maintenance cost	12.86
Total	3		36
	Novice		Moderate Practice

6.3 Visual Comfort Criteria

The light flickering level was one of the objectives for visual comfort, as it is a key factor in achieving comfort for the occupants. Light flickering is important to consider as it contributes to adverse effects such as headaches and migraine which are uncomfortable to the observers (Yoshimoto et al., 2020). The uniformity of lighting is another criteria to consider so that the space occupied for learning, teaching, and research processes is comfortable when dealing with details to ensure eye health. When direct or indirect lighting was uniformly provided, the job stress for occupants will be lower (Vasquez et al., 2022). The result is shown in Table 3.

Table 3: Result of Decision Making in Retrofitting for Lighting (Visual Comfort Criteria)

Main	No	Sub-Criteria	Weightage
Visual	1	Light flickering level	23.873
Visual	1	Uniformity of lighting	17.418
Total	2		41
	Proficient		Moderate Practice

In overall, the results obtained from the decision-making have shown their concern for retrofitting the building by considering several important criteria and sub-criteria. It is found that the main concern is on the lighting quality, initial cost, and the potential of lights flickering level. Each of the main criteria and sub-criteria selected has different Practices and Preferences to achieve where design criteria achieve the lowest concern with basic practice-novice, visual comfort is the second criteria concern by achieving moderate practice-proficient and lastly is economic with moderate practice-novice.

7. Conclusion

Energy usage in campus buildings has been an important topic to discuss due to the increase in interest in building sustainability. Campus universities could represent specific groups of the diverse available buildings in terms of the current building energy used. The BEI helps provide insight into the building's condition and whether it is efficiently utilised. The results from the case study have shown that the building utilised following the recommended Standard. This indicated that the implementation of EE equipment successfully helped to achieve EE. This paper also proposes decision-making for energy-efficient equipment implemented in the case study building. In decision making, it is found that design, economic and visual comfort have shown the most significant criteria taken into account. The contribution of this study is the decision-making approach assists in providing an optimal strategy for EE implementation and could assist decision-makers when investing in energy-efficient equipment.

References

Ahmad A.S., Hassan M.Y., Abdullah H., Rahman H.A., Majid M.S., Bandi M., 2012, Energy efficiency measurements in a Malaysian public university, Proceedings of the IEEE international conference on power and energy (PECon).

Diakaki C., Grigoroudis E., Kolokotsa D., 2008, Towards a multi-objective optimisation approach for improving energy efficiency in buildings, Energy and Buildings, 40(9), 1747–1754.

Duc Pham A.D., Ngo N.T., Ha Truong T.T., Huynh N.T., Truong N.S., 2020, Predicting energy-consumption in multiple buildings using machine learning for improving energy efficiency and sustainability, Journal of Cleaner Production, 260, 121082

Guan J., Nord N., Chen S., 2016, Energy planning of university campus building complex: Energy usage and coincidental analysis of individual buildings with a case study, Energy and Buildings, 124, 99–111.

He Y., Liao N., Bi J., Guo L., 2019, Investment decision-making optimisation of energy efficiency retrofit measures in multiple buildings under financing budgetary restraint, Journal of Cleaner Production, 215, 1078–1094.

Ikuzwe A., Xia X., Ye X., 2020, Maintenance optimization incorporating lumen degradation failure for energy efficient lighting retrofit projects, Applied Energy, 267, 115003.

Idiana, 2014, Handover of Final UTM Building under RMK-9 Project. <http://new-academia.com/utm-news-events/2014/08/page/5/> accessed 23.05.2023.

Kolokotsa D., Gobakis K., Papantoniou S., Georgatou C., Kampelis N., Kalaitzakis K., Santamouris M., 2016, Development of a web-based energy management system for University Campuses: The CAMP-IT platform, Energy and Buildings, 123, 119–135.

Kumar A., Sah, B., Singh A. R., Deng Y., He X., Kumar P., Bansal R. C., 2017, A review of multi criteria decision making (MCDM) towards sustainable renewable energy development, Renewable and Sustainable Energy Reviews, 69, 596–609.

Maletta H., Aires B., 2007, Weighting, Spsstools, 1–19.

Mohd Husini E., Raja Md Yazit R.N.S., Arabi F., Wan Ismail W.N., Jaafar N.H., 2021, Light, daylighting and fluctuation of illuminance level in office buildings, IOP Conference Series: Materials Science and Engineering, 401, 012021, 2nd International Conference on Architecture and Civil Engineering 2018, Penang, Malaysia.

Ruparathna R., Hewage K., Sadiq R., 2016, Improving the energy efficiency of the existing building stock: A critical review of commercial and institutional buildings, Renewable and Sustainable Energy Reviews, 53, 1032–1045.

Scorpio M., Ciampi G., Gentile N., Siblio S., 2022, Effectiveness of low-cost non-invasive solutions for daylight and electric lighting integration to improve energy efficiency in historical buildings, Energy and Buildings, 270, 112281.

Tian C., Li C., Zhang G., Lv Y., 2019, Data driven parallel prediction of building energy consumption using generative adversarial nets, Energy Buildings, 186, 230-243.

Vasque N.G., Rupp R.F., Andersen R.K., Toftum J., 2022, Occupant's responses to window views, daylighting and lighting in buildings: A critical review, Building and Environment, 219, 109172.

Yoshimoto S., Jiang F., Takeuchi T., Wiliins A.J., Webster M.A., 2020, Visual discomfort from flicker: Effects of mean light level and contrast, Vision Research, 173, 50-60.

Yu Y., Cheng J., You S., Ye T., Zhang H., Fan M., Liu S., 2019, Effect of implementing building energy efficiency labelling in China: A case study in Shanghai, Energy Policy, 133, 1–12.