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Quantifying Energy Savings using Implementation of Energy Conservation Measures: A Case Study of a Double Storied Residential Building

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Abstract

Energy efficiency and conservation has been gaining much attention in recent years, and is strongly encouraged by the government as well as the energy sector as it is a vital step towards a sustainable global energy ecosystem. However, the identification of the cause of energy wastage and inefficiency in residential buildings is rather challenging. Hence, this paper aims to predict the energy saving through the implementation of Energy Conservation Measures (ECMs) in a double storied residential building. Several studies related to the prediction of energy saving through the implementation of ECMs have been conducted over the years. The majority of these studies are based on commercial and public buildings such as offices, educational institutions and government buildings. The constraint of performing the energy audit for residential buildings can be solved using softwares. In this study, Building Energy Intensity Tool (BEIT) is used to perform the energy simulation on a double storey bungalow to determine the potential energy savings as a result of implementation of ECMs. BEIT is a whole-building energy simulation program that is used to model energy consumption for heating, cooling, lighting and ventilation. The study suggests several improvements that can reduce the overall energy consumption in the building. The data obtained from the simulation before the implementation of ECMs with the actual data from the utility bill are compared for validation by using the Building Energy Intensity (BEI) as the performance index. Another simulations on the building after the implementation of ECMs are done to obtain the energy consumptions, so the energy savings can be calculated. Results show that significant energy savings of 21% can be achieved by installing tinted films for the windows in the building as well as roof insulation. A simple change in the occupants' behaviour such as reducing the lighting and plug load also brings some energy savings. The implementation of ECMs in the residential building is economically viable since the simple payback period of 3.4 years obtained is reasonable. When taking the building lifetime into consideration, the investment cost is a worthwhile to reduce the energy consumption in the building.

1. INTRODUCTION

Nearly one-third of global energy is consumed in commercial, residential and public buildings, where it is utilised for heating, cooling, lighting, ventilation, cooking, refrigeration, as well as operating mechanical and electrical devices [1]. It is expected that the global energy consumption in buildings will grow significantly as towns and cities in developing countries around the world continue to revolutionize and the income levels per capita increase. As a result of the high energy consumption in buildings, there are endless opportunities for energy conservation. Carbon emissions can be reduced by improving energy efficiency at both the generation and consumption stages. Efficient energy consumption can be achieved through the implementation of Energy Conservation Measures (ECMs). ECMs can be implemented through two main steps, namely, by retrofitting outdated inefficient loads and through awareness programs related to efficient energy management. Existing buildings may have inefficient electrical energy usage and poor energy saving due to several factors such as the utilization of inefficient equipment, unanticipated internal power loss and the lack of implementation of energy conservation programs and policies [2]. Consequently, the electricity bill borne is high which will result in high operation cost for the buildings, especially in the case of commercial building.

Approximately 53% of the electricity generated in Malaysia is consumed by buildings [3]. In the last three decades, the carbon dioxide emission in Malaysia escalated significantly from 8.39 to 255.78 million tonnes carbon dioxide [4]. Climate in Malaysia is hot and humid with relatively low wind speeds and variation of indoor air velocity. Initially, in order for residents to endure the hot climate throughout the year, Malaysian traditional houses were constructed using lightweight materials such as thatches bamboo and wood. These houses also had very wide windows for natural air ventilation. However, this type of house is no longer common due to technological advancement these days. The houses and buildings in Malaysian cities and towns are generally made of brick and concrete which trap heat and cause thermal discomfort. Furthermore, modern houses in Malaysia are built as clusters, condominiums or terraced buildings with insufficient ventilation [5]. Hence, these types of buildings make air conditioners almost necessary to endure the hot and humid climate. Due to this reason, people living in these houses resort to air conditioners as the only practical solution to this ventilation problem. Air conditioners are the largest consumers of electricity in residential buildings in Malaysia [6]. This matter raises a major concern in the pursuit of sustainable development through efficient energy consumption and waste reduction.

The residential sector is responsible for a large part of the total electricity demand and consumption in Malaysia [7]. The majority of consumers are unaware about the possibility of saving energy through the implementation of ECMs in their homes. Besides, there is difficulty in assessing the energy savings achieved through the implementation of these measures as it is a somewhat complex subject since buildings and energy types differ from one another. One way of overcoming this problem is by utilising building energy performance simulation software and tools, which can calculate the energy and thermal load used based on the building architecture and HVAC systems used. These tools can be used to predict the energy saving in buildings through the implementation of ECMs such as window treatment for sun shading and feasible renewable energy systems. Energy simulation programs offer simplified and efficient prototypes for potential forecast on energy consumption in buildings. Most literature sources reveal that the major energy consumption measured by simulation programs is based on heating or cooling load [8], [9].

One of the building simulation programs used by designers and researches is EnergyPlus, a complete building recreation program designed by the Department of Energy. This software is capable of producing accurate results and calculations for system controls, air flow as well as cooling and heating in the building [9], [10]. The assessment of solar penetration, shading, glazing, thermal insulation type and placement, air-tightness, climate response, air ventilation, and HVAC systems is also possible using EnergyPlus [11]. However, this software has a rather complex interface which renders it less user-friendly. Another prominent energy simulation program is Integrated Environmental Solutions Virtual Environment (IESVE) [8], [12]. IESVE is the leader in the industry for energy analysis and sustainability modelling applications. It is a comprehensive software that can accurately carry out energy analysis to address a variety of building performance workflows as it allows the analysis of heating and cooling loads, daylighting, carbon emissions, thermal performance, as well as overall physical form in buildings. However, this tool is rather costly and is generally used by designers and experts in the industry. Building Energy Intensity Tool (BEIT) is a software developed by the Association of Consulting Engineers Malaysia (ACEM) in 2010 for assessing energy usage in residential and commercial buildings. The software has an Excel format and contains built in input parameters. This means that the user can simply select the input value based on the description provided by the software. Due to this reason, BEIT is used in this study to determine the potential energy savings as a result of implementation of ECMs.

2. METHOD AND SYSTEM

In order to address energy consumption in a building, a baseline must first be established. In this study, the baseline is formed based on energy consumption data obtained from the monthly utility bill of the residential building over a reporting period of one year (August 2018 to July 2019). This baseline will serve as a reference tool in order to compare the energy performance and savings before and after the implementation of Energy Conservation Methods (ECMs) in the building. In this study, Building Energy Intensity (BEI) is used as the performance index and can be calculated by using (1):

$$\text{BEI} = \frac{(\text{Total Energy Consumption a year})(kWh/year)}{(\text{Total Occupied or Net Floor Area})(NFA)m^2} \tag{1}$$

Once the data has been collected, the study proceeds with the building simulation using BEIT. Many of the input parameters in BEIT are based on MS1525:2014 which is the Malaysian Standards and code of practice for energy efficiency in buildings [13]. This software works by comparing the baseline building and the proposed building. The baseline building is essentially the existing building and the proposed building refers to the same building with improvements through the implementation of ECMs. In order to keep the simulation simple, the shape of the building is always assumed to be a shoe-box model. This is advantageous since defining the building is significantly simplified without compromising the accuracy of the energy simulation results. BEIT takes into account several parameters when analysing the energy intensity in buildings, namely the Overall Thermal Transfer Value (OTTV), Roof Thermal Transfer Value (RTTV), lighting load, plug load and the air-conditioning and mechanical ventilation (ACMV System).

OTTV measures the heat gain through the walls, shading and glazing of the building. However, OTTV does not include the heat gain from the roof of the building [14]. According to MS 1525:2014 Clause 5.2, the OTTV should not exceed 50 W/m^2. The overall OTTV value of the building is given by (2).

$$\mathrm{OTTV} = \frac{A_{o1} \times \mathrm{OTTV}_1 + A_{o2} \times \mathrm{OTTV}_2 \ldots + A_{0n} \times \mathrm{OTTV}_n}{A_{o1} + A_{o2} \ldots + A_{\mathrm{on}}} \tag{2}$$

where, A_{oi} = gross area of the exterior wall for orientation $i(m^2)$; and OTTV$_i$ = OTTV for orientation $i(W/m^2)$.

A vital parameter in the calculation of the OTTV is the U-value of walls and glazing, which measures the heat transfer rate per square metre of a material [15]. Since the intention of this study is to minimise the heat gain into the building, a lower U-value is more desirable. The U-value calculation is given by (3).

$$U = \frac{1}{R} \tag{3}$$

where, R = thermal resistance of the material (m^2K/W).

The RTTV is a measure of the heat gain into the building envelope through the roof. The RTTV value can be obtained using (4)

$$\mathrm{RTTV} = \frac{\left(A_r \times U_r \times \mathrm{TD_{eq}}\right) + (A_s \times U_s \times \Delta T) + (A_s + SC + SF)}{(A_r + A_s)} \tag{4}$$

where,A_r = opaque roof area (m^2);

U_r = thermal transmittance of the roof area (W/m^{2}K);

TD_{eq} = equivalent temperature difference (K);

A_s = the skylight area (m^2);

U_s = thermal transmittance of the skylight area (W/m^{2}K);

Δ_T = temperature difference between the exterior and interior design condition (5 K);

SC = shading coefficient of the skylight;

SF = solar factor (W/m^2); and

A_o = total roof area (m^2) where $A_o = A_r + A_s$.

Lighting power refers to the kWh of lighting per square metre of the building floor area. Plug loads are loads that are other than ventilation, heating, cooling or lighting. Some examples of plug loads are computers, kitchen appliances and personal amenities.

Once all input parameters have been defined, the simulation of the energy consumption in the building can be carried out. For calibration, the results for the energy consumption of the baseline building are compared with the actual data obtained from the utility bill. The error between both sets of data should not exceed 10% to obtain an accurate results. Once the data is calibrated, ECMs are selected and implemented in the proposed building. Five different simulations were carried out using different ECMs. The ECMs applied are installation of tinted film for windows and 50 mm rockwool roof insulation, installation of tinted film for windows and 50 mm glasswool roof insulation, installation of tinted film for windows, installation of 50 mm rockwool roof insulation and finally installation of 50 mm glasswool roof insulation.

The final step is to predict the energy savings in the building as a result of ECMs implementation. The results obtained from the simulation of the modelling process will determine the potential of energy savings in the building. This is carried out by comparing the energy consumption of the baseline building and the proposed building in the simulations. The most suitable ECMs to be implemented in a residential building will then be identified. The simple payback period, which is the time taken for the total initial investment to be recovered by the total accumulated annual savings [16], is then calculated to determine the duration for the owner of the building to obtain the benefit of energy savings from the implementation of ECMs. The flowchart of the method can be found in Figure 1.

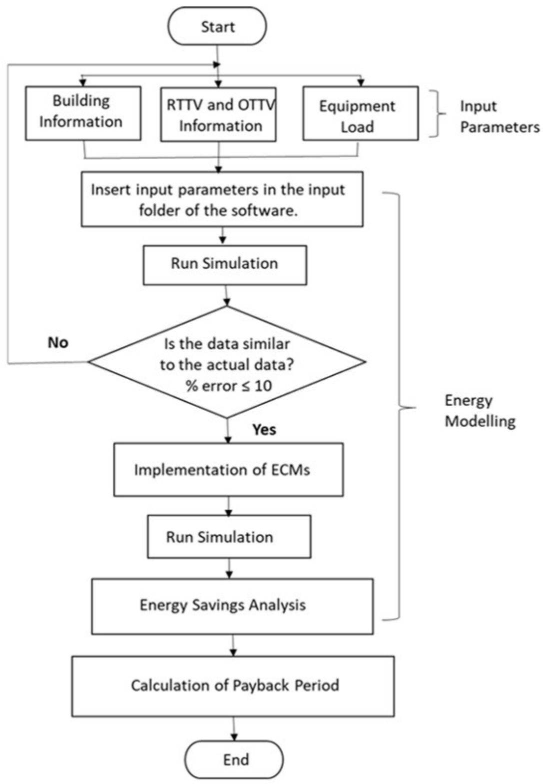

Figure 1. Flowchart of the Method

3. RESULTS AND DISCUSSION

The baseline will serve as the basis for setting the ECMs in the building and analysing the overall performance of the building in terms of energy efficiency and conservation. It is formed based on energy consumption data obtained from the monthly utility bill of the residential building over a reporting period of one year (August 2018 to July 2019) as shown in Figure 2. From the data, the total energy consumptions of the building is 7695 kWh/year. The total Net Floor Area (NFA) is 160 m^2, which then gives the BEI as 48.1 kWh/m^2/year.

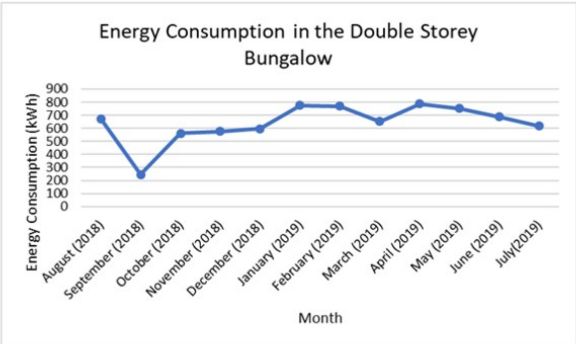

Figure 2. Baseline of energy consumption in the building

The building information such as the floor area, building length and width, building orientation and number of floors was obtained from the architect's plans. The windows-to-wall ratio, width and height of fenestrations and windows were measured manually. Table 1 shows the building information.

Table 1. Building Information

Parameter	Input
Total Net Floor Area (m^2)	160
No of Floors (including Ground)	2
Floor to Floor Height (m)	2.6
Building Orientation (Local North facing where?)	North
Building Length (m)	6.3
Building Width (m)	12.6
Average Electricity Cost (RM)	0.39
Occupancy (m^2/person)	40
Total No of People in the Building	4
AC Operating Hours (hours/day)	4
Working Days (days/year)	365
Hours of Operation (hours/year)	1460

Using the data collected, the simulation was carried out using BEIT. To validate the simulation, the BEI for the baseline building is compared with the BEI calculated using the actual energy consumptions. The BEI of the baseline building from the simulation is 52.5 kWh/m^2/year, giving a difference of about 9% from the calculated BEI, which is reasonable. The software automatically generates the energy intensity for the baseline and proposed building in the form of tables and charts. It can be seen from Figure 3 that the heat gain through the facades and roof of the proposed building is significantly lower than that of the baseline building. The lighting energy, plug load energy and cooling energy also experienced a reduction after ECMs were implemented in the building.

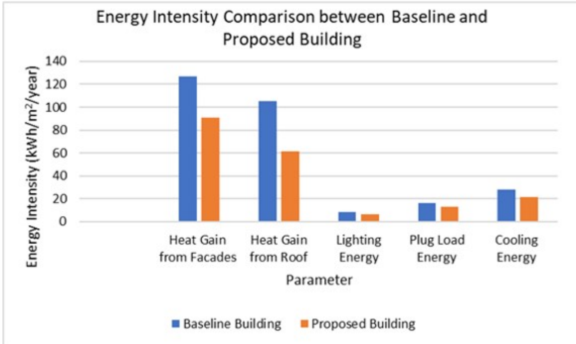

Figure 3. Energy Intensity Comparison between the Baseline and Proposed Building

Table 2 summarises the energy intensity breakdown in the baseline building and proposed building as well as the reduction achieved through the implementation of the ECMs.

Based on the simulation results, the greatest heat gain for both the baseline building as well as the proposed building is through to the building facades (walls and windows) and the roof. Nevertheless, these features also hold the greatest potential for reducing the energy consumption in the building. If all the proposed ECMs were to be implemented in the residential building, the overall building energy consumption can be reduced by 21%. However, it is important to determine the viability of the implementation of these ECMs in the building. This can be done by calculating the annual cost savings and the simple payback period obtained from the implementation of each energy conservation measure as shown in Table 3.

From Table 3, it can be seen that the installation of both tinted film for the windows and 50 mm rockwool roof insulation in the residential building bring about an overall energy consumption reduction of 22% These ECMs result in the greatest reduction in the overall building energy intensity. However, the payback period of 4.4 years, is the longest when compared to the other ECMs implemented. This is due to the high improvement cost. Although the cost of improvement is high, RM 731 per year is saved which is the greatest when compared to the implementation of the other ECMs.

If the ECMs applied to the building are the installation of tinted film for the windows and 50 mm glasswool roof insulation, the overall BEI is reduced by 21% and a total of RM 707 per year can be saved. The calculated payback period is 3.4 years is reasonable and attractive considering the significant reduction in the energy consumption in the residential building.

On the other hand, if only tinted film for the window is implemented while keeping all other parameters constant, the overall BEI is reduced by 19% which is still rather significant. The cost savings obtained as a result of the implementation of this energy conservation measure is RM

Table 2. Energy Intensity Breakdown and Reduction

Energy Intensity Breakdown (kWh/m^2/year)	Baseline Building	Proposed Building	Reduction	% Reduction
Heat Gain from Facades	126.8	90.9	35.9	28
Heat Gain from Roof	105.1	61.3	43.8	42
Lighting Energy	8.3	6.8	1.5	18
Plug Load Energy	16.1	13.1	3	18
Cooling Energy	28.2	21.5	6.7	24
Overall Building Energy Intensity (BEI)	**52.5**	**41.5**	**11**	**21**

Table 3. Type of ECMs Applied and Payback Period

Type of ECMs Applied	% Reduction in Overall BEI	Estimated Cost Savings (RM/year)	Estimated Installation Cost (RM)	Simple Payback Period (years)
Installation of tinted film for windows & 50 mm rockwool roof insulation	22	731	3,200	4.4
Installation of tinted film for windows & 50 mm glasswool roof insulation	21	707	2,433	3.4
Installation of tinted film for windows	19	614	1,200	2.0
Installation of 50 mm rockwool roof insulation	18	575	2,000	3.5
Installation of 50 mm glasswool roof insulation	17	550	1,233	2.2

614 per year and the cost of investment can be recovered within 2 years. The payback period is the shortest compared to the payback period obtained from the implementation of the other ECMs.

The results of the energy simulation for the installation of 50 mm rockwool roof insulation while keeping all other parameters constant resulted in a BEI reduction of 18% and a cost savings of RM 575 per year. The investment cost can be recovered within 3.5 years. This is due to the high cost of improvement. The payback period for the implementation of this ECM is slightly longer than that obtained from the installation of tinted film for the windows and 50 mm glasswool roof insulation which is only 3.4 years. The latter also resulted in a greater overall BEI reduction. This is because the cost savings obtained from the installation of 50 mm of rockwool roof insulation alone are lower compared to the savings obtained when the roof insulation and tinted film for windows are both implemented. This indicates that the installation of only 50 mm of rockwool roof insulation is not an economically advantageous ECM for the building.

The installation of 50 mm glasswool roof insulation with all other parameters kept constant brings about a BEI reduction of 17%, which is the lowest compared to the BEI reduction when other ECMs are implemented in the building. The cost savings of RM 550 per year is also the lowest although the cost of improvement of RM 1,233 is the third-highest among all the ECMs implemented. Thus, this suggests that the installation of 50 mm of glasswool roof insulation is not a worthwhile ECM for the residential building.

Therefore, it is evident that the most sustainable and attractive measure for energy conservation in the residential building is to install both tinted film for the windows and 50 mm glasswool roof insulation. It may be argued that rockwool insulation results in a greater BEI reduction. However, taking a closer look at the results of the simulation, it is found that the difference in BEI reduction when using rockwool instead of glasswool is a mere 1%. However, the payback period is a year longer than that obtained when glasswool is used to insulate the roof of the building. The difference in cost savings is also rather insignificant with only RM 24 saved per year, as compared to the difference in the cost of improvement which is RM 767.

For this reason, the most applicable and economically attractive ECMs is the installation of tinted film for the windows and 50 mm glasswool roof insulation. When the lifetime of the building is taken into account, the cost of improvement is definitely a sustainable solution. Moreover, these improvements do not require significant lifestyle changes. When these improvements to the building are coupled with no-cost energy conservation measures such as reducing the plug load, lighting load and ACMV load, the energy consumption in the residential building can be reduced by 21% which is very significant.

4. CONCLUSION

All in all, the implementation of various ECMs in the proposed building result in a BEI of about 41 kWh/m^2/year. The predicted energy savings of 21%, represents a total savings of 2 MWh/year. Through the implementation of ECMs that reduce the lighting load, plug load and cooling load, the energy consumption in the residential building can be reduced significantly. However, when these ECMs are implemented together with high cost ECMs such as the installation of tinted film for the windows and roof insulation, the energy savings achieved is much greater. The total investment cost of the building to achieve the predicted energy savings of 21% is RM 2,433 which provides a simple payback period of 3.4 years. This investment is economically feasible and attractive. When taking the building lifetime into consideration, the investment cost is a worthwhile to reduce the energy consumption in the building.

Despite the advantages of ECMs, the implementation is still somewhat uncommon in most residential buildings in Malaysia. This is most likely due to the lack of awareness among the general public. It is essential for the government and other regulatory bodies to provide encouragement and support for developers and homeowners in order to cultivate an understanding and awareness on the importance of energy conservation and the usage of green technologies in buildings. A developing country like Malaysia can greatly benefit from the implementation of ECMs in all types of buildings. The global energy scene is at an important and interesting juncture in the energy efficiency evolution. The energy industry is constantly growing and energy efficiency and conservation is a vital step towards a sustainable global energy ecosystem and future.

As a recommendation, the research must be continued in order to study the heat gain trend for different types of residential buildings. The building in this particular study is a double storey bungalow and the majority of the heat gain in the building was through the roof and facades. The heat gain for an apartment, for instance would not be through the roof and could possibly be due to other parameters. Since the majority of the heat gain in the studied residential building is through the roof, the feasibility of installing a solar panel on the roof could be explored.

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REFERENCES

[1] I. E. Agency. (2019). “Buildings-a source of enormous untapped efficiency potential,” [Online]. Available: https://www.iea.org/topics/buildings (visited on 01/24/2020).

[2] S. M. Aris, N. Y. Dahlan, M. N. M. Nawi, T. A. Nizam, and M. Z. Tahir, “Quantifying energy savings for retrofit centralized hvac systems at selangor state secretary complex,” *Jurnal Teknologi*, vol. 77, no. 5, Nov. 2015. DOI: 10.11113/jt.v77.6125.

[3] J. S. Hassan, R. M. Zin, M. Z. A. Majid, S. Balubaid, and M. R. Hainin, “Building energy consumption in malaysia: An overview,” *Jurnal Teknologi*, vol. 70, no. 7, Oct. 2014. DOI: 10.11113/jt.v70.3574.

[4] (Jun. 14, 2019). “Carbon dioxide emissions, million tonnes carbon dioxide,” Knoema Corporation, [Online]. Available: https://knoema.com/BPWES2017/bp-statistical-review-of-world-energy-main-indicators (visited on 06/25/2019).

[5] N. A. Malek, M. H. Khairuddin, and M. F. Rosli, “Thermal comfort investigation on a naturally ventilated two- storey residential house in malaysia,” *IOP Conference Series: Materials Science and Engineering*, vol. 88, p. 012 014, Sep. 2015. DOI: 10.1088/1757-899x/88/1/012014.

[6] N. A. Hisham, S. A. Zaki, A. Hagishima, and N. M. Yusoff, “Load and household profiles analysis for air-conditioning and total electricity in malaysia,” *KnE Social Sciences*, Aug. 2019. DOI: 10.18502/kss.v3i21.5010.

[7] K. A. Rahman, A. M. Leman, M. F. Mubin, M. Z. M. Yusof, A. Hariri, and M. N. M. Salleh, “Energy consumption analysis based on energy efficiency approach: A case of suburban area,” *MATEC Web of Conferences*, vol. 87, A. Hasan, A. Khan, M. A. Mannan, C. Hipolito, N. M. Sutan, A.-K. H. Othman, M. Kabit, and N. A. Wahab, Eds., p. 02 003, Dec. 2016. DOI: 10.1051/matecconf/20178702003.

[8] N. Hussin, F. Baharum, A. A. Razak, and M. S. Suhaimi, “Preliminary study on energy consumption at uitmcpp library using ies simulation,” *International Journal of Engineering & Technology*, vol. 7, no. 4.38, p. 1387, 2018.

[9] J. Litardo, R. Hidalgo-Leon, J. Macias, K. Delgado, and G. Soriano, “Estimating energy consumption and conservation measures for ESPOL campus main building model using EnergyPlus,” in *2019 IEEE 39th Central America and Panama Convention (CONCAPAN XXXIX)*, IEEE, Nov. 2019. DOI: 10.1109/concapanxxxix47272.2019.8976931.

[10] L. D. Ratnasari, S. S. S. T. M. T., and E. S. S. T. M. T., “Evaluation of energy consumption with energy-plus simulation in office existing buildings,” in *INTERNATIONAL CONFERENCE ON SCIENCE AND APPLIED SCIENCE (ICSAS2020)*, AIP Publishing, 2020. DOI: 10.1063/5.0031273.

[11] M. F. Hossain, “Advanced building design,” in *Sustainable Design and Build*, Elsevier, 2019, pp. 137–230. DOI: 10.1016/b978-0-12-816722-9.00004-5.

[12] IES. (2019). “IES virtual environment (IESVE),” [Online]. Available: https://www.iesve.com/software (visited on 11/16/2019).

[13] Z. Zuhari and L. Sheau-Ting, “Indoor thermal comfort in university classroom: A case of universiti teknologi malaysia,” *International Journal of Real Estate Studies*, vol. 13, no. 2, 2019.

[14] J. L. M. Felix, S. A. Dominguez, L. R. Rodriguez, J. M. S. Lissen, J. S. Ramos, and F. J. S. de la Flor, “ME3a: Software tool for the identification of energy saving measures in existing buildings: Automated identification of saving measures for buildings using measured energy consumptions,” in *2016 IEEE 16th*

International Conference on Environment and Electrical Engineering (EEEIC), IEEE, Jun. 2016. DOI: 10.1109/eeeic.2016.7555821.

[15] B. P. Numbi, S. J. Malinga, R. F. Chidzonga, and T. C. Mulangu, "Energy cost saving potential in educational buildings-case study of MUT campus," in *2017 International Conference on the Industrial and Commercial Use of Energy (ICUE)*, IEEE, Aug. 2017. DOI: 10.23919/icue.2017.8068004.

[16] M. Teni, K. Čulo, and H. Krstić, "Renovation of public buildings towards nZEB: A case study of a nursing home," *Buildings*, vol. 9, no. 7, p. 153, Jun. 2019. DOI: 10.3390/buildings9070153.