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Study on Energy Efficiency Using Building Information Modelling (BIM) at Shared Library Pagoh Higher Education Hub

(Kajian Kecekapan Tenaga Menggunakan Pemodelan Maklumat Bangunan (BIM) di Perpustakaan Bersama Hab Pendidikan Tinggi Pagoh)

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ABSTRACT

Structures in Malaysia, particularly commercial buildings, have been exceeding the benchmark of building energy usage over the past few years. By maintaining thermal comfort of building under hot climate in Malaysia, air-conditioning system became a basic demand which incessantly operating to fulfil comfort requirement for the occupants in the library. Regards to this, research on energy efficiency using Building Information Modelling (BIM) software by simulating energy analysis was carried out in order to increase energy efficiency of the library. Mineral wool and Polyurethane Foam (P.U.F.) are the materials which proposed to apply in existing wall of building as the thermal insulation layer to increase thermal resistance when external heat transfer through the walls. The Objective of the study is to determine the existing building energy consumption and compare with energy analysis of mineral wool and polyurethane foam. The findings of the building energy analysis simulated by Green Building Studio (GBS) are then compared to discover the most appropriate walls for reducing the building's energy consumption. P.U.F with its characteristics of high R-value and low U-value, obtain the most effective energy analysis which provide benefits of lowering total annual energy consumption of 294,651 , total annual energy cost of RM 107,645, and energy use intensity (EUI) of 121.7.

Keywords: Energy efficiency; Building Information Modelling (BIM); Mineral wool; Polyurethane Foam (P.U.F.); Green Building Studio (GBS)

ABSTRAK

Struktur di Malaysia, terutamanya bangunan komersial, telah melebihi penanda aras penggunaan tenaga bangunan sejak beberapa tahun kebelakangan ini. Dengan mengekalkan keselesaan haba bangunan di bawah iklim panas di Malaysia, sistem penyaman udara menjadi permintaan asas yang tidak henti-henti beroperasi untuk memenuhi keperluan keselesaan bagi penghuni di perpustakaan. Sehubungan dengan itu, penyelidikan mengenai kecekapan tenaga menggunakan perisian Pemodelan Maklumat Bangunan (BIM) dengan mensimulasikan analisis tenaga telah dijalankan untuk meningkatkan kecekapan tenaga perpustakaan. Bulu mineral dan Buih Poliuretana (P.U.F.) adalah bahan yang dicadangkan untuk digunakan di dinding bangunan sedia ada sebagai lapisan penebat haba untuk meningkatkan rintangan haba apabila pemindahan haba luaran melalui dinding. Objektif kajian ini adalah untuk menentukan penggunaan tenaga bangunan sedia ada dan membandingkan dengan analisis tenaga bulu mineral dan buih poliuretana. Penemuan analisis tenaga bangunan yang disimulasikan oleh Green Building Studio (GBS) kemudiannya dibandingkan dengan menemui dinding yang paling sesuai untuk mengurangkan penggunaan tenaga bangunan. P.U.F dengan ciri-ciri nilai R yang tinggi dan nilai U yang rendah, memperoleh analisis tenaga yang paling berkesan yang memberikan faedah menurunkan jumlah penggunaan tenaga tahunan sebanyak 294,651, jumlah kos tenaga tahunan sebanyak RM 107,645, dan intensiti penggunaan tenaga (EUI) sebanyak 121.7 .7

Kata kunci: Kecekapan tenaga; Pemodelan Maklumat Bangunan (BIM); bulu mineral; Buih Poliuretana (P.U.F.); Green Building Studio (GBS)

INTRODUCTION

Over the past few years, construction and building industry started to concern and adopt with energy efficiency green building strategies with respect to its design and characteristic. (Lu, Wu, Chang, & Li 2017) mentioned that many construction developers focus on building sustainability to reduce energy consumption and energy dependency on electricity and fossil fuels. Basri, Zakaria, & Kamarudina, (2021) have reviewed a lowered energy consumption building able to achieve energy efficiency which also contribute to reduce the environmental pollution. Buildings account for approximately 40% of total energy consumption and 36% of carbon dioxide emissions worldwide. Wang & Zhao, (2018) explained that among all buildings such as residential buildings, educational buildings, industrial buildings, infrastructure buildings, and business buildings, the commercial buildings have been categorized as one of the most rapidly expanding segments of the construction industry, particularly in big cities. Commercial buildings with full sets of air-conditioning systems and other equipment utilize approximately 50–100 kWh/m2 of energy, which about 10 times higher than the number of residential buildings in Malaysia. The Heating, Ventilation, Air-Conditioning system contributes the highest consumption percentage of energy in the office buildings.

Building components such as windows, doors, walls and skylights can gain or lose heat from external distraction such as the sun. Hence, difference type of components material has different energy which required for maintaining cooling or heating in the buildings. Related to this, Kang, Ahn, Park, & Schuetze (2015) explained that Overall Thermal Transfer Value (OTTV) need to be considered into building envelope when design an energy efficiency building with respect to MS 1525:2007 Clause 5.2. The average heat input into a building through the building envelope is measured by OTTV. The goal of OTTV is to create a building design that can limit heat gain through the building wall while also lowering the cooling demand on the air conditioning system. Besides, energy efficiency of the buildings can be manipulated by considering the heat loss through a material in building. Pásztory (2021) highlighted that the thermal transmittance (U-value), which manipulates the building material's thermal insulation, plays a significant role in preventing heat loss during the heating period and reducing heat gain during the cooling period. Thermal transmittance, defined as U-value also known as the ability of a structural element to transport heat under steady-state circumstances. A low U-value of material which indicates high thermal insulation that able to reduce the external heat to transfer into the buildings and reduce internal cooling air loss through building envelope. Buzatu, Stan-Ivan, Mircea, & Manescu (2017) mentioned that applying the thermal insulation layer will decrease the energy consumption and provide good energy efficiency of building.

To overcome this situation, the application of Building Information Modelling (BIM) software takes place which contributes to analyze and simulation building energy performance. By referring Milyutina (2018), BIM is a set of software tools that allows to model not only the construction components themselves, but also their properties as they relate to the construction process. BIM processes for facilitating the usage and creating of the digital rendering of the functional characteristics of a building and its physical characteristics as well (Ang et al. 2020). In this study, BIM software is used to prepare a 3D model and simulate the building energy analysis as the objective of the study to achieve energy efficiency. Both Autodesk Revit and Green Building Studio as the BIM software play an important role in simulation building energy performance in which providing 3D model and generate data for analyzing total consumption in the aspect of energy and cost.

MATERIAL AND METHODS

MATERIALS

The chosen materials which apply in the existing building of Share library Pagoh Higher Education Hub to simulation are mineral wool and polyurethane Foam (P.U.F.). Both materials have similar characteristics of R-value and U-value which suitable to apply as an insulation layer on wall to increase the thermal resistance. Mineral wool can be applied as thermal insulation for building walls. It has several types of insulation which include glass wool and rock wool (Wang et al. 2018). Rock wool is a furnace product made from molten rock called 'basalt' generated at a temperature of roughly 1600 °C, through which a stream of air or steam is pushed, whereas glass wool is made from molten recycled glass with 20 to 30 percent recycled industrial waste and post-consumer content (Balazs 2020). Generally, mineral wool has a moderate price and environmentally friendly as shown below in Fig.1a. Its thermal resistance, R-value is 3.1), while thermal transmittance, U-value is 0.32) (Shine, 2021). Besides, that mineral wool is non-flammable and does not melt or support combustion when fire breakdown on building.

Polyurethane foam is also a famous thermal insulator for building walls nowadays. It is a spray insulation with polyurethane which considered as a modern technology of buildings insulation. Kurańska, Pinto, Salach, Barreiro, & Prociak (2020) explained that spray polyurethane foam (SPF) insulation has grown in popularity and recognition as a high-performance alternative for building thermal insulation in recent years as shown below in Fig.1b. Nowadays, polyurethane foams contain material of non-chlorofluorocarbon (CFC) gas for use as a blowing agent which helps to reduce damage to the ozone layer. Polyurethane is a polymer made up of organic units linked together by carbamate/urethane linkages. By altering the isocyanate, polyol, or additives, polyurethane may be manufactured in a range of densities and hardness. The polyurethane foam provides high efficiency in thermal insulation, the price on market also higher compared to mineral wool. Its thermal resistance, R-value is 6.3) while thermal transmittance, U-value is 0.16). Besides, that polyurethane foam is flammable but indirectly provide great sound insulator for building walls (Kurańska et al. 2020)

(a)

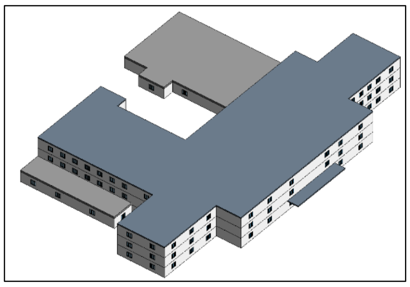
(b)

FIGURE 1. (a) Mineral Wool, (b) Polyurethane Foam

Method

This case study is categorized as comparative study where it's a non-experimental but apply technological software study which impact evaluation design by involving the analysis and synthesis of similarities, differences, and patterns across two or more examples with a shared focus or aim in a way that yields knowledge that is simpler to generalize about the study's major title. Most of the theoretical content in this study is done by research from secondary sources such as articles, journals, magazines, books, previous research studies, \ etc. Quantitative method has been utilized in study where the result of study is being analyze and supported by numerical data which simulated from software. From the fundamentals of being representative to those utilized in statistical sampling to illustrate a study's specific analysis, this technique is supported. The process has undergone certain process such as evaluating, analyzing, comparing, data collection and recording.

The first objective of this study is to simulate the existing building of energy consumption at Shared Library Pagoh Higher Education Hub with total building gross area of 15446.84 m2. To achieve the first objective, the target selection building model for simulation is Shared Library Pagoh Higher Education Hub as the first step. Next, continue with obtain the building data information of selected building from related authority. The 3D drawing prepared from Autodesk Revit is then import into Green Building Studio (GBS) after complete with managing building settings such as location, weather and energy. After completing building analytical model for existing building, the research is done to identify the various type of thermal insulator which suitable to apply in commercial building to reduce energy consumption. The 3D simulation model and 3D energy model are shown in Fig. 2.



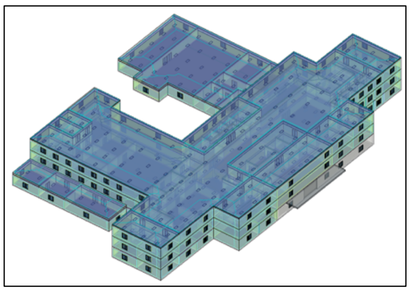


FIGURE 2. 3D Simulation Model and 3D Energy Model

In this study, the chosen thermal insulation wall is polyurethane foam and mineral wool. Then, the other two sets of building energy data performance are ready to simulate GBS. The final product of simulation with GBS will comes with three versions of data which are existing wall of building, polyurethan foam insulation thermal wall and mineral wool insulation wall. Last part of methodology is to analyze and compare the data performance among the three sets and choose the best effective thermal insulation wall which minimize the largest energy consumption and best use for energy efficiency

AUTODESK REVIT

The obtained building drawing and information of Shared Library Pagoh Higher Education Hub from Sime Darby Property is then inserted into Autodesk Revit to produce a complete 3D model. Autodesk Revit is good to processed automatically to detect energy and power analysis using existing building of Shared Library Pagoh Higher Education Hub. The process in Autodesk Revit as below:

1. First, preparing 3D model for simulation is location settings. By using Internet Mapping Service in Autodesk Revit, the location of selected building can be allocated accurately as the project address.
2. In weather settings make sure HVAC design data from weather station (1449134_2006). In weather settings, cooling design temperatures consist of dry bulb, wet bulb and mean daily range temperature for whole year. The heating design temperature is 22o C and clearness number is 1.0.
3. Then, select options in advanced energy setting of building in Autodesk Revit. Select the building as commercial office and default central HVAC system. Outdoor air information also can be edit from advanced energy settings.
4. The 3D analytical model from Autodesk Revit is now ready to simulate in Green Building Studio (GBS). The GBS is a type of cloud-base service which a product from Autodesk to simulate the building data performance in energy consumption. There steps to simulate with Green Building Studio as below:
5. First, create new projects in GBS and enter the Project Name.
6. Then, select a Building Type from the list of approximately 30 typologies and a unique building schedule, which is optional.
7. Set the location of the project. Check the checkbox below the map, and click the Next button. Make sure the project address is located nearby the selected project location. Time zone must be selected same to the Malaysia or Singapore zone that suitable to project time.
8. Send the energy model by exporting gbXML file into GBS analysis cloud service.
9. By running GBS analysis early and frequently during design according to size file, the model will give better outcomes.

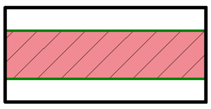
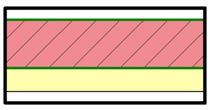
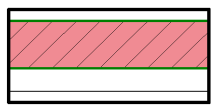
RESULTS AND DISCUSSIONS

CHARACTERISTICS OF DIFFERENT WALLS

Table 1 shows the different types of wall model which use in simulate various types of energy analysis. There are three types of walls to perform simulation which are existing wall, mineral wool insulation wall, and polyurethane foam insulation wall. All the walls are same in terms of thickness which are 203.2 mm and the insulation are standard in 50 mm (E. Khalid 2019). The difference between these walls is in aspects of its thermal resistance and thermal conductivity. Building thermal comfort and energy savings are intimately connected to the thermal properties of exterior wall structures. When add another layer of insulation to a wall, the total thermal resistance of the wall will improve. It depends on the thermal characteristic of the added insulation layer. Polyurethane foam which has lowest thermal conductivity of 0.0285 W/mK W/mK provides highest thermal resistance of 1.947 m^2K/W m$^2K/W$ for the wall. While mineral wool contains 0.035 W/mK W/mK thermal conductivity and strengthen the thermal resistance of wall to become 1.621 m^2K/W m$^2K/W$ (Wang, et al. 2018). It proved that the lower thermal conductivity material of insulation will yield a stronger thermal resistance characteristic to the external wall.

Based on Table 2, the existing wall of Shared Library Pagoh Higher Education Hub is 380,875 kWh kWh. When applying thermal insulation material of mineral wool to existing wall, the electric consumption is reduced to 354,104 kWh kWh where the consumption of electric shows significantly reduced of energy consume by the building. The P.U.F. is a strong thermal resistance material where it able to resist the heat enter to the internal building. With its strong thermal characteristic, P.U.F. insulation wall only consumed 294,651 kWh kWh which the lowest total energy used by the building for a year among three types

TABLE 1. Type of simulation wall model

Type of walls	Model	Insulation Layer (mm)	Resistance ($m^2K/Wm^2K/W$)	Thermal Conductivity ($W/mKW/mK$)
Existing wall		0	0.193	-
Mineral wool		50.000	0.193	0.035
Polyurethan Foam (P.U.F.)		50.000	1.947	0.029

of walls. For most commercial building such as library in Malaysia, the usage of electricity is typically high where most of the demand of electricity used on lighting, HVAC system, and miscellaneous appliances. Nevertheless, the commercial buildings are usually designed on the belief of that occupants in the building will use it as designed. Occupants in library such as students, lecturer and staffs are considered the main concern of comfort environment other than energy conservation. Hence, this resulted the library to demand higher electricity to fulfil occupants comfort requirements (Sarah 2019).

TABLE 2. Total Annual Energy Consumption for Different Walls

Type of Wall	Electric Consumption (*kW hKW h*)	Fuel Consumption (*thmthm*)
Existing Wall	380,875	286
Mineral Wool	354,104	262
P.U.F.	294,651	125

Total Annual Energy Cost

Table 3 presents the total annual energy cost for different type of walls. The existing building with regular wall generated RM139,019 electricity cost while mineral wool insulation wall and P.U.F. insulation wall generated RM129,248 and RM107,548 respectively. When applying thermal insulation material of mineral wool to existing wall, the electric cost is reduced about RM9771 while application of P.U.F. reduce electric cost of RM31471. It shows that applying thermal insulation layer to existing wall able to reduce electricity cost where it saves the cost of using HVAC system. The simulation in building energy cost of Shared Library Pagoh Higher Education Hub is following the commercial tariffs and pricing of Malaysia Tenaga Nasional standards. The tariff category of library is Tariff C1- medium voltage general commercial tariff. The rate of the tariff is 36.5 for all kilo watt hours. The demand charge is the portion of the bill that covers the maximum amount of power that may be required at any point during a year, ensuring that the building has access to all of the energy it requires at all times. The greatest energy use throughout the billing period is used to calculate the building demand fee. Operating many HVAC units at maximum capacity during the hottest part of the day consumes a significant amount of energy, resulting in an unintentionally higher demand charge in library. Hence, (Sarah, 2019) explained that applying thermal insulation wall can reduce the usage of HVAC to prolong cooling space and resulted lower electricity cost of building.

TABLE 3. Total Annual Energy Cost for Different Walls

Type of wall	Electric Cost (RM)	Fuel Cost (RM)	Total Energy Cost (RM)
Existing Wall	139,019	223	139,242
Mineral Wool	129,248	204	129,452
P.U.F.	107,548	98	107,645

Energy Use Intensity

Table 4 demonstrates the total energy use intensity for different walls. The existing building recorded the yearly energy use intensity of 147.5. While mineral wool insulation wall and P.U.F. insulation wall recorded 144.4 and 121.7 respectively. The energy usage intensity (EUI) of a building's design and/or activities is a measure of its energy efficiency. The EUI is expressed as energy per square foot per year. It's computed by multiplying the total energy spent by the entire gross floor area of the building over a year. Besides, (Berhane, 2018) stated that EUI is a per-area statistic that may be used to compare energy consumption when the building model under consideration employs diverse energy sources

TABLE 4. Total Energy Use Intensity for Different Walls

Type of Wall	Energy Use Intensity ($kBtu/ft^2/yr$ $kBtu/ft^2/yr$)
Existing Wall	147.5
Mineral Wool Insulation Wall	144.4
P.U.F.	121.7

CONCLUSION

The energy efficiency using building information modelling (BIM) at Shared Library Pagoh Higher Education Hub is successful as the objectives of the study is achieved. The application of thermal insulation wall is a good way to increase energy efficiency of buildings especially commercial building as library. Thermal insulation wall with contains high amount of thermal resistance, R-value and low value of thermal transmittance, U-value play an important role in manipulate the energy consumption of buildings in terms of decrease usage of electricity by HVAC system. Among the three types of walls, which are existing building wall, mineral wool insulation wall, P.U.F. insulation wall, the P.U.F. insulation wall which has highest thermal resistance yields the best result in conserving energy efficiency of building. The layer of P.U.F. protects the internal cooling air by hardening the process of heat transfer from sun through the external wall into the building. Not only that, it also slowdown the process of cool air escape to outside. Its thermal characteristic helps to reduce the energy consumption where it reduces total annual energy consumption, total annual energy cost, and energy use intensity. BIM tools have given an integrated method for testing a building throughout the design phase and softly exporting the model from one tool to another inside the same software in BIM platform with full version of interoperability. The model may be automatically analyzed, allowing for a quick examination of different options to be discussed in this BIM collaborative environment. The use of BIM to investigate this small test cell has a number of drawbacks, including the inability to examine passive behavior on the test cell and the decision to employ an HVAC system to calculate the heating and cooling load.

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REFERENCES

Ang, P. S. E., Pung, Y. L., Tsai, K. L., Zulkaply, M. N., Tey, J. S., Kasim, N. B., ... & Rahman, M. A. 2020. BIM: The setback OR solution to project cost issues in Malaysia construction industry?. *In IOP Conference Series: Earth and Environmental Science* 476(1) 012011. IOP Publishing.

Balazs, N. 2020. Effect of built-in mineral wool insulations durability on its thermal and mechanical performance. Journal of Thermal Analysis and Calorimetry 139:169–181, DOI: 10.1007/s10973-019-08384-5

Basri, S., Zakaria, S. U., & Kamarudina, S. K. 2021. Review on alternative energy education in Malaysia. *J. Kejuruteraan* 33: 461-472.

Berhane, G. 2018. Design, modelling and simulation of a green building energy efficient system. [Online]. Available: https://vuir.vu.edu.au/37849/1/GEBRESLASSIE%2C%20Berhane%20-%20Final%20Thesis_ nosignature.pdf

Buzatu, G. C., Stan-Ivan, F. E., Mircea, P. M., & Manescu, L. G. 2017. Thermal transmittance determination for different components of buildings. In 2017 International Conference on Optimization of Electrical and Electronic Equipment (OPTIM) & 2017 Intl Aegean Conference on Electrical Machines and Power Electronics (ACEMP). 227-232. IEEE.

Eltahir, K. M., Ali, M. H., Obai, Y., & Ahmed, K. 2019. Optimum Thermal Insulation Thickness for Building Under Different Climate Regions - A Review. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 59 (2): 2289-7879.

Kang, J. E., Ahn, K. U., Park, C. S., & Schuetze, T. 2015. Assessment of passive vs. active strategies for a school building design. *Sustainability* 7(11): 15136-15151.

Kurańska, M., Pinto, J. A., Salach, K., Barreiro, M. F., & Prociak, A. 2020. Synthesis of thermal insulating polyurethane foams from lignin and rapeseed-based polyols: A comparative study. *Industrial Crops and Products* 143: 111882.

Lu, Y., Wu, Z., Chang, R., & Li, Y.2017. Building Information Modeling (BIM) for green buildings: A critical review and future directions. *Automation in Construction* 83: 134-148.

Milyutina, M. A. 2018. Introduction of Building Information Modeling (BIM) Technologies in construction. *Journal of Physics: Conference Series* 1015(4): 042038).

Pásztory, Z. 2021. An overview of factors influencing thermal conductivity of building insulation materials. *Journal of Building Engineering* 44: 102604.

Sarah, L. 2019. Conference Paper Autodesk Green Building Studio an Energy Simulation Analysis in the Design Process. Equity, Equality, And Justice In Urban Housing Development At: Bali, DOI: 10.18502/kss.v3i21.5007

Wang, H., Chiang, P. C., Cai, Y., Li, C., Wang, X., Chen, T. L., & Huang, Q. 2018. Application of wall and insulation materials on green building: a review. *Sustainability* 10(9): 3331.

Wang, Z., & Zhao, J. 2018. Optimization of passive envelop energy efficient measures for office buildings in different climate regions of China based on modified sensitivity analysis. *Sustainability* 10(4): 907.