International Journal of Technology 14(7) 1487-1495 (2023)
Received July 2023 / Revised September 2023 / Accepted November 2023

International Journal of Technology

http://ijtech.eng.ui.ac.id

Effectiveness Analysis of Insulation and Roof Covering Material in Office Flat Roof

Rossy Armyn Machfudiyanto[1*], Leni Sagita Riantini[1], Titi Sari Nurul Rachmawati[2], Ayomi Dita Rarasati[1], Mochamad Daffa Alfiansyah Rachman[1]

[1]*Department of Civil and Environmental Engineering, Faculty of Engineering, Universitas Indonesia, Kampus UI Depok 16424, Indonesia*
[2]*Department of Architectural Engineering, Kyung Hee University, Yongin-si 17104, Korea*

Abstract. Wasteful consumption of electricity in high-rise building in Indonesia is the primary trigger for the increase in carbon emissions. Predominantly, the excessive use of electrical appliances and air conditioning systems is the principal factor contributing to the use of energy within these structures. To effectively address this issue, the importance lies in adopting suitable building envelope material. Therefore, this study aimed to analyze the effectiveness of different insulation types and roof covering in improving the energy-saving performance of office building. There were six proposed renovation for the flat roof of building, consisting of two approaches, namely (1) the incorporation of insulation and (2) the replacement of roof covering layers. Scenarios A1, A2, and A3 have incorporated 100 mm of polyurethane (PU) foam, polyisocyanurate (PI) foam, and fiberglass batt into the design. Meanwhile, Scenarios B1, B2, and B3 opted for ceramic material, Ethylene Propylene Diene Terpolymer (EPDM) membrane, and grass vegetation as roofing material for the existing roof. The results showed that the addition of insulation to roof through Insight 360 and the replacement of roof covering layers produced an energy reduction of 19.5% to 20.2% and 19.5% and 23.5%, respectively. The implementation of green roof in scenario B3 was selected as the most promising renovation option, achieving a remarkable 23.5% reduction in energy consumption.

Keywords: Covering layers; Energy usage; Flat roof; Insulation layers

1. Introduction

High-rise building in Indonesia is contributing to an increase in carbon gas emissions. The increase in carbon gas emissions is caused by the extensive operations of conventional power plants, required to meet the high electricity demands of building. Among the various types of high-rise building, office is object with the highest energy consumption. In 2020, Energy Use Intensity (EUI) of 213.27 kWh/m2/year was produced (B2TKE-BPPT, 2020). The major factor behind the electricity demand is the excessive use of air conditioning to maintain indoor thermal comfort, regardless of the weather (Hakim *et al.*, 2021). Therefore, providing warm and cool rooms during rainy and dry seasons can reduce excessive reliance on air conditioning and energy use.

*Corresponding author's email: rossyarmyn@eng.ui.ac.id, Tel.: +6281-1253573; Fax.:+6221-7270029
doi: 10.14716/ijtech.v14i7.6665

The presence of a fit building envelope can prevent rapid heat transfer, effectively regulating indoor thermal comfort. Building envelope includes the outermost layer of architectural elements, namely walls, roof, basement, doors, windows, and other external element that withstands the surrounding environment (Bachrun, Ming, and Cinthya, 2019). Roof is one of the most essential envelope components for maintaining the quality of indoor thermal comfort and reducing the energy consumption of building. The study by (Feng *et al.,* 2020) showed that the installation of insulation material on roof reduced energy consumption by up to 78%. Furthermore, (Ibrahim *et al.,* 2018) proved that a roof design with ventilation effectively mitigated overheating. Building designers commonly use various roof insulation material, including polyurethane (PU) foam, polyisocyanurate (PI) foam, and fiberglass batts. Even with the comparable attributes, PU foam is distinguished by its low thermal conductivity and density (Gama, Ferreira, and Timmons, 2018), while PI shows reduced thermal conductivity under low-temperature conditions (Makaveckas, Bliudzius, and Burlingis, 2021). Meanwhile, fiberglass batts are good in insulation performance due to the higher R-value.

The type of covering material used for roof affects its ability to absorb or reflect heat. The study by (Algarni, Almutairi, and Alqahtani, 2022) showed that green roof with shallow-rooted grass lowered energy usage by 3.6% in six months (Shaharuddin, Khalil, and Saleh, 2019). Apart from the use of green roof, ceramic tiles and Ethylene Propylene Diene Terpolymer (EPDM) membranes can also serve as roofing material. (Sedaghat *et al.,* 2023) showed that these tiles were capable of reflecting solar radiation by up to 50%, resulting in energy savings for building. EPDM membranes also show commendable reflective qualities, particularly when white in color. Therefore, the incorporation of suitable insulation material and roof covering can help anticipate an increase in electricity consumption due to rapid heat transfer.

Insulating and using covering material must be adapted to the geometric shape of an office building. In this context, flat roof represents the most prevalent geometric configuration found in office building, satisfying the functional requirements of HVAC system components. Prior study substantiated the effectiveness of using insulation and covering material on flat roof. The comparison between roof insulation usage and the addition of covering layers has not been addressed. Therefore, this study aims to analyze the effectiveness of different insulation types and roof covering in improving the energy-saving performance of office building. Building designers should be assisted in selecting the most effective flat roof renovation options to minimize energy usage.

2. Methods

In this section, a description of the study process is provided and the flow of each stage is shown in Figure 1. This study used a design model in which the dimensions and location of the selected design were determined based on the latest government data on building energy consumption (B2TKE-BPPT, 2020). From this data, the subject was configured with dimensions of 30 meters and 31.5 meters in length and width, under the office typology observed in government data. Furthermore, the model was assumed to be situated in Jakarta, which was a metropolitan city with numerous office building. This allowed the results to better represent office building in Indonesia. To define building components, information was obtained by referring to (Fitriani *et al.,* 2022) and (Berawi *et al.,* 2022) for material selection. Meanwhile, the material thickness was adjusted based on the availability in Jakarta building supply stores, as shown in Table 1.

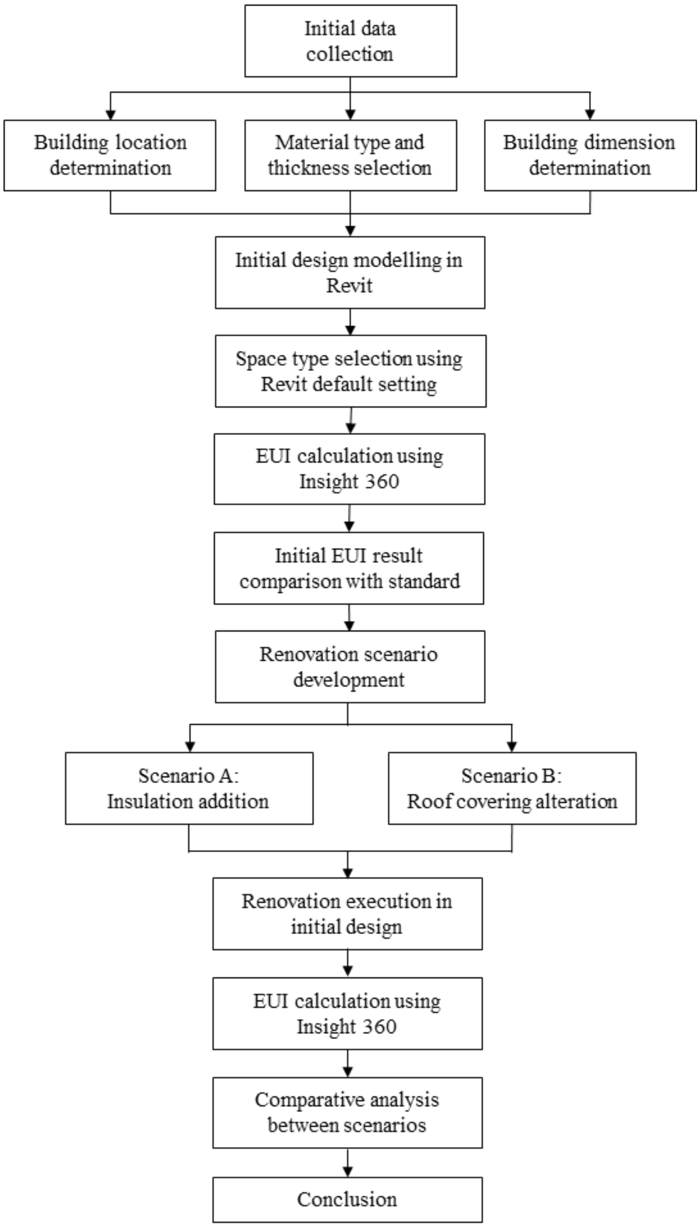

Figure 1 Study methods workflow

Table 1 Summary of material types and thickness for initial design

Envelope Component	Material selection	Thickness
Basement Exterior Wall	Concrete, Cast-in-place	150 mm
	Sand/cement screed	20 mm
	Exterior Insulation	100 mm
	Plaster	12.5 mm
Façade Wall	Concrete, Precast	100 mm
	Sand/cement screed	20 mm
	Rigid insulation	50 mm
	Gypsum wallboard	12 mm
	Plaster	12.5 mm
Curtain Wall	Aluminium frame	50 mm
	Triple glazing Low-e glass	30 mm

Table 1 Summary of material and thickness for initial design [Cont.]

Envelope Component	Material selection	Thickness
Floors	Concrete, Cast-in-place	100 mm
	Sand/cement screed	20 mm
	Plaster	12 mm
	Carpet tile	10 mm
Ceiling	Metal stud layer	45 mm
	Rigid insulation	50 mm
	Gypsum wallboard	12 mm
Roof	Concrete, Cast-in-place	150 mm
	Sand/cement screed	50 mm
	Vapor retarder	membrane
	Roofing felt	4 mm

The initial building design was created using Autodesk Revit and default settings. The default settings are inherently consistent with ASHRAE standards, obviating the necessity for system adjustments, as explained in Table 2. Following the completion of the initial building design, the initial EUI analysis was conducted using Insight 360. The energy analysis used an equation created based on the DOE 2.2 engine program, where the initial EUI calculations were compared to the six renovation scenarios.

Table 2 Summary of space type distribution for each room

Room name	Space type	Criteria
Lobby	Lobby - Office	6 Am to 11 PM operating schedule Heating set point: 21.11^{o}C Cooling set point: 23.89^{o}C Lighting load: 13.99 W/m^{2} Power load: 5.81 W/m^{2}
Canteen; Meeting room	Office Enclosed; Dining Area	6 Am to 11 PM operating schedule Heating set point: 21.11^{o}C Cooling set point: 23.89^{o}C Lighting load: 10 W/m^{2} Power load: 5.81 W/m^{2}
Praying room	Religious Building	Retail lighting operating schedule Heating set point: 21.11^{o}C Cooling set point: 23.89^{o}C Lighting load: 13.99 W/m^{2} Power load: 5.81 W/m^{2}
Working area	Office - Open plan	6 Am to 11 PM operating schedule Heating set point: 21.11^{o}C Cooling set point: 23.89^{o}C Lighting load: 11.84 W/m^{2} Power load: 16.15 W/m^{2}
Toilet	Dressing/Locker/Fitting room	6 Am to 11 PM operating schedule Heating set point: 21.11^{o}C Cooling set point: 23.89^{o}C Lighting load: 6.03 W/m^{2} Power load: 5.81 W/m^{2}

The two categories of renovation implemented in this study are 1) the incorporation of 100 mm-thick roof insulation and 2) the adoption of novel roofing material. The first type of renovation introduced PU foam, PI foam, and fiberglass batt materials onto roof, denoted as Scenarios A1, A2, and A3, respectively. The selection of these three materials was informed by the existence of prior studies discussing the characteristics, as shown in the Introduction section. Furthermore, the second renovation category comprised the use of glossy ceramic, EPDM membrane, and vegetation layers, identified as Scenarios B1, B2, and B3. The vegetation layer included a waterproof to prevent seepage into the concrete, soil serving as a growth medium, and a layer of grass and rocks as the topmost cover. These three roofing materials were selected for the capacity to create a cool roof environment by reflecting or absorbing sunlight, which cools the space beneath. Finally, the most preferable renovation scenario for diminishing EUI value is shown in the conclusion.

3. Results and Discussion

This section shows the outcomes derived from the calculations conducted through Insight 360. Subsequently, a comprehensive discussion will be provided, delving into the comparative analysis among the various scenarios. Building design model is shown in Figure 2, where the colors do not influence the energy analysis results. In Figure 2, the basement and roof floors are black and gray, respectively.

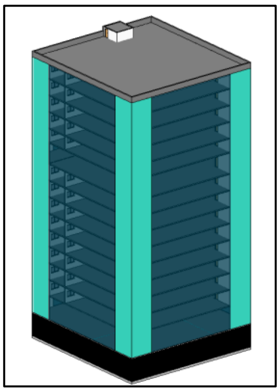

Figure 2 Building design model using Autodesk Revit: basement (black) and roof (gray)

Energy analysis conducted using Insight 360 showed that the initial EUI value for the designed building was 272 kWh/m^2/year. According to the government data (B2TKE-BPPT, 2020), the value was settled in the third quartile range from 161.75 kWh/m^2/year to 297.13 kWh/m^2/year. Therefore, the proposed design was appropriate, allowing the continuation of the renovation scenario. Based on the calculations conducted using Insight 360, EUI for each renovation scenario is listed in Table 3. The percentage reductions were obtained by calculating the difference between EUI values obtained from the renovation scenario and the initial. The installation of insulation in Scenarios A and B resulted in an average percentage reduction of 19.98% and 20.96%. Therefore, the approach adopted in Scenario B, which included the installation of roof covering, showed a more significant impact on reducing EUI value of building.

Table 3 EUI calculation results for each renovation scenario

Scenario id	Criteria	Initial EUI value (kWh/m^2/year)	Final EUI value (kWh/m^2/year)	% Reduction
A1	Insulating PU foam	272	219	19.49
A2	Insulating PI foam	272	217	20.22
A3	Insulating fiberglass batt	272	217	20.22
B1	Using glossy ceramic	272	219	19.49
B2	Using EPDM membrane	272	218	19.85
B3	Implementing green roof	272	208	23.53

Previous studies showed that EUI calculation was influenced by the heat transfer capability of building envelope material. The capability can be measured using thermal coefficient commonly referred to as U-value (W/m^2. K). Based on the basic formula, U-value is affected by thermal conductivity (λ) and material thickness. Table 4 presents λ values of each material used in Scenarios A and B, with the corresponding U-value and roof thicknesses after the renovation. Roof thickness in Scenario A remains consistent using the same insulation thickness, specifically 100 mm. Meanwhile, Scenario B shows variations in roof thickness due to adjustments made to accommodate the dimensions of each type of roof covering.

Table 4 Summary of U-value for each material used

Material type	λ (W/m.K)	Thickness (mm)	U-value (W/m^2.K)
PU foam	0.032	204	0.2955
PI foam	0.02	204	0.1902
Fiberglass	0.019	204	0.1811
Glossy ceramic	0.84	238	3.748
EPDM membrane	0.138	278	1.6202
Green roof	-	251	0.4694

As presented in Table 4, Scenario A reported lower U-value compared to Scenario B. U-value increases with higher λ, even though Scenario A had the same roof thickness. The results were consistent with the theory that an increase in U-value was directly proportional to λ but inversely related to material thickness. Despite a lower λ value and thicker layer compared to green roof, the calculation showed that green roof U-value was lower than EPDM membrane. This contradicts existing theories, suggesting the presence of other factors influencing U-value of material.

The drainage and substrate layers act as heat absorbers while simultaneously providing a cooling effect on roof area of building. This phenomenon occurs because the substrate and drainage layers consist of organic material with high emissivity values, facilitating an extremely efficient heat transfer circulation. According to (Yildirim, Ozburak, and Ozden, 2023) and (Wang, Huang, and Li, 2021), green roof possesses the capability to provide a cooling effect on building roof through effective heat transfer circulation. A reduction in U-value becomes possible through this mechanism and green roof was intentionally designed with densely packed grass vegetation. This was conducted to ensure that incoming heat could be effectively absorbed by the high grass density, reducing heat convection into building. The observation is consistent with (Arabi, 2018), where the thermal performance of tropical plants depends on factors such as canopy density and coverage area percentage. Therefore, U-value can also be influenced by the effectiveness of heat transfer circulation depending on the type of roof covering used.

The examination of the relationship between U-value and EUI shows interesting trends. Scenario A, comprising A1, A2, and A3, shows that smaller U-value corresponds to lower EUI value, particularly evident with fiberglass batts. However, Scenarios B1 and B2 reports EUI value that can match or be lower than A1, despite having U-value five times higher. This contradicts the results of (Carvalho *et al.*, 2021), where smaller U-value leads to lower EUI value. This phenomenon is attributed to the low emissivity values of glossy ceramic and EPDM membranes in B1 and B2, which effectively block excessive solar heat radiation, showing a reflective effect. This study also explores the influence of thermal conductivity and thickness on EUI, as presented in Figure 3. A linear relationship was observed between higher thermal conductivity and larger EUI value, as well as a negative correlation with thickness. However, the very low R^2 value is due to the lack of data samples, resulting in a non-normal distribution. The need for additional data samples becomes apparent to ensure and strengthen the statistical validity of the results. However, the trendline shows a relationship consistent with the results in this study.

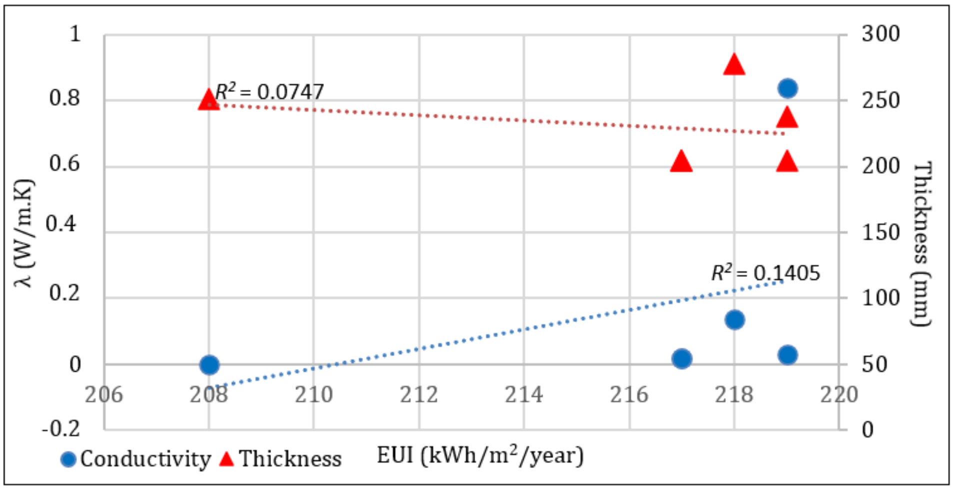

Figure 3 The trendline of thermal conductivity and thickness with EUI value

The results complement previous studies on energy assessment in building roof renovation, as shown in Table 5 with five previous examples. The study by (Borras *et al.*, 2022) reported the installation of three types of building roof renovation including 2 green roofs in 6 different climate zones in Spain. Therefore, a more comprehensive change in building envelope led to a higher reduction in EUI. According to (He *et al.*, 2020), cool roof was more effective in reducing a building's EUI due to the excellent reflectivity compared to green roof. However, (Jovanovic, Zivkovic, and Stevanovic, 2018) stated the advantages of green roof in improving indoor and outdoor building quality by generating additional oxygen and absorbing air pollutants. (Cai *et al.*, 2019) also provided evidence that green roof was effective in reducing EUI and room temperature.

Table 5 Five examples of previous study outcomes

No	Previous study title	Study outcomes
1	Contribution of green roof to energy savings in building renovation (Borras *et al.*, 2022)	Among the three types of roof renovation, showed a decrease in energy consumption by 9% to 13%
2	Thermal and energy performance of green roof and cool roof: A comparison study in Shanghai area (He *et al.*, 2020)	Cool roof was superior in reducing room temperature, resulted in more significant electricity savings compared to green roof
3	Inverted roof insulation kits and their durability (Francke and Gerylo, 2018)	The decrease in the quality of insulation material was caused by freeze-thaw cycles.
4	The impact of building envelope with the green living system on the built environment (Jovanovic , Zivkovic, and Stevanovic, 2018)	The utilization of green roof and vertical gardens on facades reduced air pollutant levels by up to 11 g/m²/year, eliminated air bacteria, and contributed to building energy savings.
5	Reduction in Carbon Dioxide Emission and Energy Savings Obtained by Using Green Roof (Cai *et al.*, 2019)	The use of green roof reduced energy consumption by up to 11.53 kWh/m²/year while effectively preserving heat.

From Table 5, this study complements information regarding building energy analysis concerning the addition of insulation and replacement of covering layers in building roof renovation in a single discourse. This study also developed six different scenarios including three types of insulation material and covering layers. The energy calculation results showed that the use of green roof in Scenario B3 obtained the highest percentage reduction in EUI. Meanwhile, the addition of insulation in Scenarios A1-A3 did not have a significant impact on reducing EUI despite the better heat transfer capability. Furthermore, the study conducted by (Francke and Gerylo, 2018) reported the limitations of insulation material quality in response to environmental temperature changes. Based on EUI calculation, the use of green roof is selected as the best solution for application in office building roof in Jakarta.

4. Conclusions

In conclusion, the optimization of flat roof was reported to prevent excessive building energy consumption. The implementation of several envelope renovation showed that the addition of insulation or alterations to roof covering effectively reduced EUI value. The additional insulation layer restricted the solar heat radiation rate due to extremely low conductivity, acting as a heat-absorbing material. Covering material had a cooling effect on roof area. Through Insight 360 analysis, six scenarios were investigated, resulting in energy consumption reductions ranging from 19.49% to 20.22% for scenarios A1–A3. Similarly, Scenarios B1, B2, and B3 reduced energy consumption by approximately 19.49%, 19.5%, and 23.53%, respectively. The final energy analysis and previous results showed that green roof system in Scenario B3 yielded the most significant energy savings. However, this study necessitated the incorporation of additional data regarding insulation thickness and the varieties of covering material. This inclusion aimed to enhance the data distribution efficacy, obtaining more accurate results.

Acknowledgments

This study was funded by the Directorate of Research and Development, Universitas Indonesia, under Hibah PUTI Q2 (Grant No. NKB-821/UN2.RST/HKP.05.00/2023).

References

Algarni, S., Almutairi, K., Alqahtani, T., 2022. Investigating the Performance of Energy Management in Office Buildings by Using a Suitable Green Roof Design to Reduce the Building's Energy Consumption. *Sustainable Energy Technologies and Assessments*, Volume 54(102825), pp. 1–8

Arabi, R., 2018. Assessment of Vegetation Cooling Effect Through the Application of Green Roofs in Tropical Campus Environment. *Environmental Science*. Available online at: http://psasir.upm.edu.my/id/eprint/76306, Accessed on September 19, 2023

B2TKE-BPPT, 2020. Benchmarking Specific Energy Consumption in Commercial Building, Serpong: Indonesian Government. Available online at: https://simebtke.esdm.go.id/sinergi/assets/content/20210527150029_Laporan_Akhir_SEC-130120.pdf, Accessed on July 2, 2023

Bachrun, A.S., Ming, T.Z., Cinthya, A., 2019. Building Envelope Component to Control Thermal Indoor Environment in Sustainable Building: A Review. *Sinergi*, Volume 23(2), pp. 79–98

Berawi, M.A., Sari, M., Salsabila, A.A., Susantono, B., Woodhead, R., 2022. Utilizing Building Information Modelling in the Tax Assessment Process of Apartments Buildings. *International Journal of Technology*, Volume 13(7), pp. 1515–1526

Borras, J.G., Lerma, C., Mas, A., Vercher, J., Gil, E., 2022. Contribution of Green Roofs to Energy Savings in Building Renovations. *Energy for Sustainable Development*, Volume 71, pp. 212–221

Cai, L., Feng, X-P., Yu, J-Y., Xiang, Q-C., Chen, R., 2019. Reduction in Carbon Dioxide Emission and Energy Savings Obtained by Using Green Roof. Aerosol and Air Quality Research, Volume 19, pp. 2432–2445

Carvalho, J.P., Almeida, M., Braganca, L., Mateus, R., 2021. BIM-based Energy Analysis and Sustainability Assessment-Application to Portuguese Buildings. *Buildings*, Volume 11(246), pp. 1–25

Feng, H., Liyanage, D.R., Karunathilake, H., Sadiq, R., Hewage, K., 2020. BIM-based life Cycle Environmental Performance Assessment of Single-Family Houses: Renovation and Reconstruction Strategies for Aging Building Stock in British Columbia*. Journal of Cleaner Production,* Volume 250(119543), pp. 1–17

Fitriani, H., Rifki, M., Foralisa, M., Muhtarom, A., 2022. Investigation of Energy Saving Using Building Information Modeling for Building Energy Performance In Office Building. *Civil Engineering and Architecture*, Volume 10(4), pp. 1280–1292

Francke, B., Gerylo, R., 2018. Inverted Roof Insulation Kits And Their Durability. Warsaw, MATEC Web of Conference. Available online at: https://doi.org/10.1051/matecconf/201816308005, Accessed on September 6, 2023

Gama, N.V., Ferreira, A., Timmons, A.B., 2018. Polyurethane Foams: Past, Present, and Future. *Materials,* Volume 11(10), pp. 1–35

Hakim, F.N., Muhamadinah, Y., Atthaillah, ., Mangkuto, R.A., Sudarsono, A.S., 2021. Building Envelope Design Optimization of a Hypothetical Classroom Considering Energy Consumption, Daylighting, and Thermal Comfort: Case Study In Lhokseumawe, Indonesia. *International Journal of Technology*, Volume 12(6), pp. 1217–1227

He, Y., Yu, H., Ozaki , A., Dong, N., 2020. Thermal and Energy Performance of Green Roof and Cool Roof: A Comparison Study in Shanghai Area. *Journal of Cleaner Production*, Volume 267(122205), pp. 1–15

Ibrahim, S.H., Roslan, Q., Affandi, R., Razali, A.W., Samat, Y.S., Nawi, M.N.M., 2018. Study on the Optimum Roof Type with 30° Roof Angle to Enhance Natural Ventilation and Air Circulation of a Passive Design. *International Journal of Technology*, Volume 9(8), pp. 1692–1701

Jovanovic , D., Zivkovic, P., Stevanovic, Z., 2018. The Impact of the Building Envelope with the Green Living System on the Built Environment. *Thermal Science*, Volume 22, pp. 1033–1045

Makaveckas, T., Bliudzius, R., Burlingis, A., 2021. Determination of the Impact of Environmental Temperature on the Thermal Conductivity of Polyisocyanurate (PIR) Foam Products. *Journal of Building Engineering*, Volume 41(102447), pp. 1–14

Sedaghat, A., Salem, H., Hussam, W.K., Mahdizadeh, A., Al-Khiami, M.I., Malayer, M.A., Soleimani, S.M., Sabati, M., Narayanan, R., Rasul, M., Khan, M.M.K., 2023. Exploring Energy-Efficient Building Solution in Hot Regions: A Study on Bio-Phase Change Material and Cool Roof Coatings. *Journal of Building Engineering*, Volume 76(107258), pp. 1–22

Shaharuddin, S., Khalil, N., Saleh, A. A., 2019. Review of Significant Maintenance Criteria for Tropical Green Roofs in Malaysia. *International Journal of Technology*, Volume 10(1), pp. 69–80

Wang , L., Huang, M., Li, D., 2021. Strong Influence of Covective Heat Transfer Efficiency on the Cooling Benefits of Green Roof Irrigation. *Environmental Research Letters*, Volume 16(084062), pp. 1–13

Yildirim, S., Ozburak, C., Ozden, O., 2023. Green Roofs, Vegetation Types, Impact on the Thermal Effectiveness: An Experimental Study in Cyprus. Sustainability, Volume 15(2807), pp. 1–19