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Green roof thermal performance of small-scale prototype using IES-VE simulation in tropical climatic condition

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Abstract. This study investigates the thermal performance of green roof systems in a tropical climate, focusing on the small-scale building prototypes. Batu Pahat, Malaysia is experiencing the increasing temperatures due to climate change. Green roofs are considered as a potential solution, but their effectiveness depends on various factors such as building orientation, solar shading, and thermal resistance (R-value). Therefore, modeling and simulation are crucial for understanding green roof thermal behaviour. This study employs the Integrated Environmental Simulation Virtual Environment (IES-VE) software for analysis. Three identical small-scale buildings were constructed, one with *Portulaca Grandiflora* (PGR) plants, another with *Alternanthera Paronychioides* (ATN) plants, and a control roof with no vegetation. The R-values from the on-site green roofs were measured at 0.8899 m^2K/W for PGR and 1.1477 m^2K/W for ATN, while the control roof had an R-value of 0.1 m^2K/W. Green roofs with higher R-values demonstrated a substantial reduction in indoor temperatures, making them a valuable solution for improving thermal comfort in tropical climates. This study underscores the importance of green roofs in mitigating rising temperatures in tropical climates. Simulation using IES-VE approved that green roofs can potentially reduce indoor temperatures, demonstrating their suitability for tropical regions. These findings have significant implications for sustainable building design and urban planning in hot and humid climates.

1. Introduction

Tropical climate is a type of climate that typically characterized by high temperatures and significant humidity levels throughout the year. Malaysia, located near the equator in Southeast Asia, experiences a tropical climate with high humidity and temperatures. The Batu Pahat district in Johor, Malaysia, experiences the country's typical tropical climate where the temperature is usually at the average ranges around maximum of 31°C (87.8°F) and minimum of 23°C (73.4°F) [1]. The prevailing winds in the region are influenced by the monsoons, with the northeast monsoon bringing winds from the South China Sea. These winds support the thermals that contribute to cloud formation and precipitation patterns [2]. Recent studies have highlighted the increasing trend of hot temperatures in Malaysia, which could have significant implications for the environment and human health. The mean daily maximum temperature in Malaysia has been rising because of climate change, and this trend is projected to continue in the coming decades [3]. Another study suggested that urbanization and land use changes contribute to the urban heat island effect, causing urban areas to experience higher temperatures compared to rural areas [4]. Moreover, study in Kluang, Johor, which is near to Batu Pahat, had indicated an extreme temperature trend for the region of the Peninsular Malaysia, where it demonstrated that the majority of the extreme temperature indices for all stations have significantly higher trends [5]. The fluctuated mean temperature with a positive trendline had also demonstrated that the temperature of Batu Pahat is gradually increasing [6].

Green roofs have been proposed as a potential solution to mitigate the impacts of increasing temperatures. Green roofs involve in cultivation of vegetation on building rooftops, which can provide insulation, reduce heat absorption, and improve energy efficiency. However, there are certain challenges associated with the implementation of green roofs. For instance, a study emphasized that the effectiveness of green roofs in temperature regulation depends on factors like plant selection, substrate type, and maintenance practices [7]. Additionally, a study highlighted the needs to consider local climate conditions and building characteristics when designing green roofs to ensure their optimal thermal performance [8]. Green roof is predicted to give benefits in resolving the environmental issues including heat transfers in urban building areas [9][10]. However, designing a green roof system on-site takes a considerable amount of time, and each project needs to be carefully planned out while considering several significant factors. Therefore, modelling and simulation are the most efficient ways to comprehend the thermal condition of the green roof system on any building.

Simulation for buildings is designed to provide predictions for indoor and outdoor environments based on a variety of what-if scenarios [11]. To provide a design baseline, thermal simulation analysis of existing structures is being conducted [12][13]. Most studies have outputs that lead to the development of precise thermal characteristic profiles for buildings, as well as optimization possibilities based on data mining [14]. There are multiple software platforms existence that assist in the development of architectural models and the analysis of building performance [15]. Several software packages are known that can support thermal simulations analysis such as the EnergyPlus, TRNSYS, Ecotect, Green Building Studio (GBS), and others [16]. Another comprehensive toolkit for in-depth and precise whole-building performance simulation which available for thermal study is known as Integrated Environmental Simulation Virtual Environment (IES-VE). This IES-VE is a software that provides users with several modules that are relevant to major aspects of building simulations, such as Heating Ventilation and Air-Condition (HVAC), daylighting, energy, flow dynamics and thermal analysis. Most researchers preferred IES-VE for their energy and thermal simulation programs [17]. Michael [18] in his study had used variety of construction materials for building simulation indicated that the IES-VE has outperformed the GBS software in term of cost and accuracy but somewhat the outputs from the software were similar. Athari [19] also used IES-VE to simulate the energy of green roof on an existing residential building compared to bare roof, shows that IES-VE capable to reduce net radiation through the green roof structure by conduction gain due to the green roof's insulation ability, but IES-VE unable to compute the convection gain and evapotranspiration.

1.1. Small-Scale Green Roof Prototype

Small-scale building experiments are frequently used to investigate the thermal effects of green roof systems on buildings and structures because this method allows for the control and adjustment of building, green roof systems, and indoor conditions [20][21][22][23]. A small-scale model building with green roof system at ratio of 1:20 to a typical low-rise residential building was constructed in a hot and arid climate [20]. The results showed that the green roof reduced the building's heat transfer coefficient, resulting in lower cooling loads and energy savings [20]. Another green roof prototype with ratio of 1:20 scale with its building in Mediterranean climate had indicated that the extensive green roof system could reduce indoor air temperature up to 3.3 °C [22]. Studies conducted in cold and humid climatic conditions also show similar results on thermal performance of green roof buildings where the indoor air temperature were reduced [21][23], cooling load decreased more than 22.4% [23] and improve the building's energy performance.

To investigate the effects of green roof systems in urban areas it is recommended to use test box samples with tall buildings. Plywood is a common material used by researchers to make the test models for their experiments [24][25][26]. One of the experiments by [27] used plywood models measuring of 60 cm (L) × 60 cm (W) × 140 cm (H). Due to its accessibility, affordability, and light weight, it is a good choice for small-scale approaches. It is also easy to build different shapes with plywood in short time. An insulation layer of drywall or polystyrene inside the test box samples controls inside condition against outside climatic changes [24][25][26].

1.2. Passive Design of Building Prototype

Passive design is about taking advantage of natural energy flows to maintain thermal comfort [28]; which using the right building orientation, building materials, and landscape are important. The fabric of the building envelope should be specified, and the buildings should be orientated properly to prevent or minimise heat gain. Shading also should be provided to reduce solar radiation [29]. For improving health and well-being in the built environment, these tactics and strategies may also be facilitated by a variety of factors, such as the use of technology (passive and/or active) and customizable controls [28].

Effective thermal insulation is crucial in tropical buildings to reduce heat transfer through the building envelope and maintain comfortable indoor temperatures. Recent studies have focused on innovative insulation materials, such as phase change materials (PCMs) and aerogels, which offer enhanced thermal performance and energy efficiency in tropical climates [30]. Hence, the integration of greenery in tropical buildings can provide numerous benefits, including shade, evaporative cooling, air purification, and aesthetic enhancement. To improve thermal comfort and lower energy use, studies have explored the use of vertical green walls, green roofs, and indoor courtyard, where it assessed the impact of different plant species and configurations on building performance [31].

Hence, this study is carried out by using the prototype buildings to collect information data for green roof thermal analysis based on tropical climate and to provide input simulation data for building simulations. The thermal simulation and analysis of the prototype building are conducted using the IES-VE software. This paper provides information related to the workflow of analysis of thermal simulation on a building prototype model using the software with additional of a green roof as an insulator.

2. Materials and Methods

2.1 Initial Experimental Setup

In this study, three identical small-scale green roof buildings were constructed, one covered with potted green plants (Figure 1) that generates the highest carbon uptake which is *Alternanthera Paronychioides* (ATN), another roof was covered with the second-highest carbon uptake, the *Portulaca Grandiflora* (PGR), and the third was the control roof with no plants (conventional roof).

(a) (b)

Figure 1. (a) *Portulaca Grandiflora* (PGR), and (b) *Alternanthera Paronychioides* (ATN)

Figure 2 shows the design of test boxes/buildings based on passive design concept. Plywood was used as the material for these test boxes/building. The dimension of each box was 60 cm (L) × 60 cm (W) × 140 cm (H), using plywood walls thickness of 1.5 cm for the whole test boxes. The roof was extended until 10 cm along the margins to provide shade and passive design. To ensure proper air circulation and prevent the influence of trapped hot air on the results, each test box had two openings on the east side. One opening was located near the top of the wall, while the other was situated above the bottom finishing edge. To facilitate irrigation, the small-scale roofs were set at a slight 5° slant. The structure and configuration of the roofs remained unchanged throughout the monitoring period, allowing for the collection of results related to thermal conductivity requirements. All these prototype buildings were located at the open space at the Research Centre for Soft Soil (RECESS), UTHM.

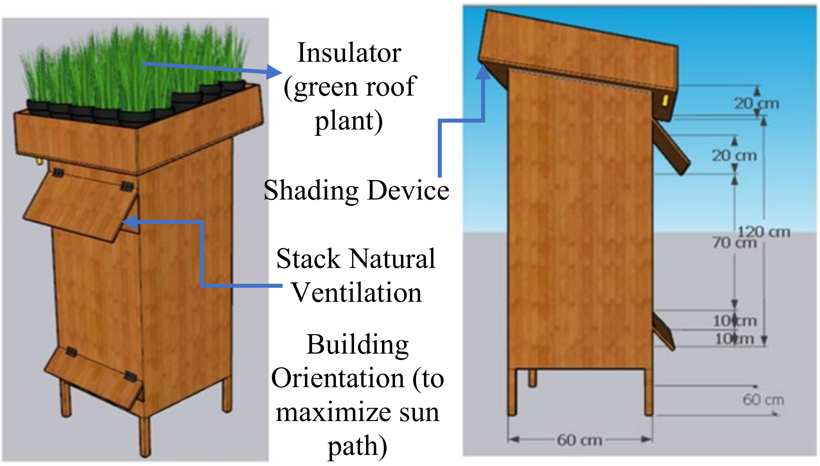


Figure 2. The dimension of the small-scale green roof building

2.2 Thermal Analysis Simulation

This study consists of two stages that are separated into pre-simulation and post-simulation phases. To develop the thermal profile of the studied building, the details of the building data and parameter are used to have significant impact on the simulation in the software.

To run thermal analysis simulations, information such as building layout, details on surface volume and openings such as natural ventilation and window opening are required. As the main factor affecting roof thermal performance, thermal resistance greatly impacts green roof. In this study, two types of plants were used as the roof insulators use to generate their current thermal resistance. Furthermore, when internal load sources like daylighting, occupants, and environmental factors are considered, the accuracy of the analysis will increase [35]. To develop the building profile, initial information was gathered as shown in Table 1.

Table 1. Building descriptions: small-scale green roof prototype.

Properties	Description
Roof area	3600 cm^2
Soil thickness	150 mm
Green roof Thermal Resistance, R_{PG}-value (*Portulaca Grandiflora*)	0.8899 m^2K/W
Green roof Thermal Resistance, R_{ATN}-value (*Alternanthera Paronychioides*)	1.1477 m^2K/W
Green roof Thermal Resistance, R_P-value (Plywood)	0.1 m^2K/W
Thickness wall/roof (plywood)	15 mm

The sketch of building sub-model is created by IES-VE using ModelBuilder (Figure 3). Building sub-models in Figure 3 are developed based on Figure 2, without assigning any details of furniture, occupants, and building services such as lighting systems and HVAC systems. Afterward, ApacheSim was used to perform a preliminary thermal analysis. The analysis will provide information about indoor thermal comfort conditions by verifying the contributed heat load [15]. It is being complimented by using another IES module namely the Suncast module. The solar analysis is then conducted based on the design weather data for Batu Pahat climates throughout the year period (as listed in the ASHRAE database) (Figure 4(a)). This system is used to determine the sun paths and it helps to determine on how much solar radiation will be available to enter into the building, in which this situation will ultimately affects the total amount of heat that is generated from the sun. Moreover, the change in radiation will be dynamically depending on the object's surface characteristics and temperature throughout the movement of sun for a year [36]. The orientation of the building is depending on the location of the on-site building with respect to its exact latitude and longitude (Figure 4(b)). For proper selection of weather date for simulation, the historical temperature data between 2007 to 2017 from the Batu Pahat meteorological station was analysed. The analysis shows that the recorded monthly average of max temperatures for the 10 years period has the highest temperature at 32.66°C in month of May. Therefore, May is selected for validation of the simulation software and was also the month of the previous on-site experiment.

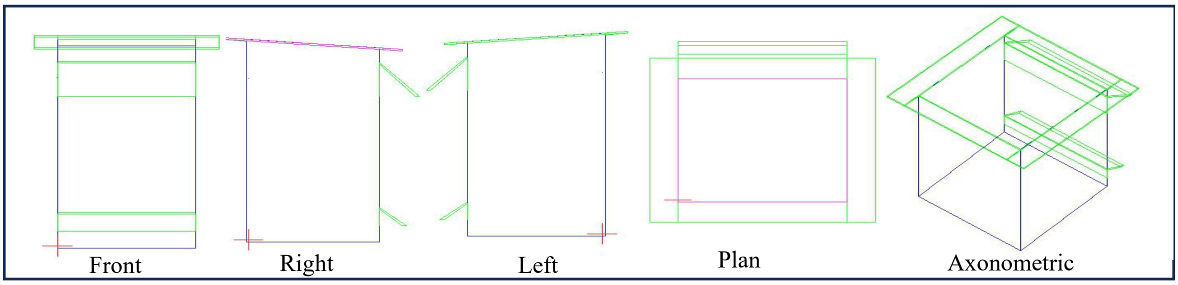


Figure 3. Sketch view from sub model ModelIT and Component

(a) (b)

Figure 4. (a) The ASHRAE database for Batu Pahat weather data, and (b) latitude and longitude setup for site location

Once the model design is completed using ModelBuilder, each building component material must be assigned based on its thermal properties, especially the R-value. There are four main components used for the simulation, which are external wall, external window, floor cavity, and roof (Figure 5).

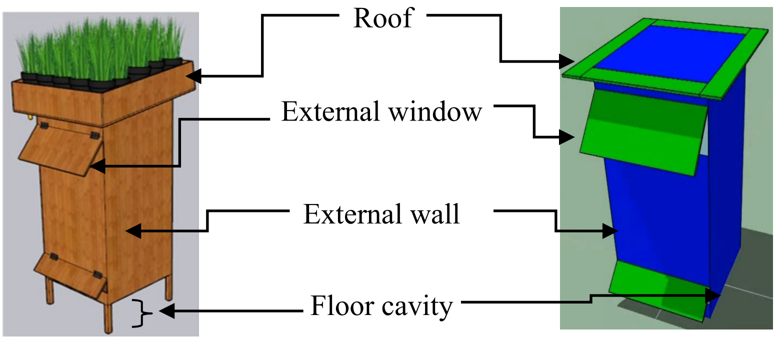


Figure 5. Sketch view of the component areas involved in IES-VE

All four components for the three prototype buildings have the same R-value using the plywood material. While the other two building's roofs have additional insulation layers that simulate the additional of green roof layer based on two plant types with two different R-values (Table 1); the *Alternanthera Paronychioides* (ATN), and the *Portulaca Grandiflora* (PGR) plant. The third roof has the original layer of plywood roof that used as a control. Since the floor for the prototype building has height space (between ground and the bottom floor), the floor cavity component also has a cavity insulation layer of 1.3175 m^2K/W, to represent on this space (Figure 5).

3. Result and Discussion

After assigning all the components, next to do is simulation of building orientation. The IES-VE SunCast sub-model is used for solar shading analysis simulation and is related to the actual situation of the building's orientation (Figure 6). Building orientation is a critical factor in thermal analysis because the passive design concept and amount of solar radiation received by a simulated building is dependent on its direction; to accurately simulate the building's thermal behaviour. This feature allows the accurate simulation of local weather conditions in Batu Pahat, which are critical in determining the building's thermal behaviour.

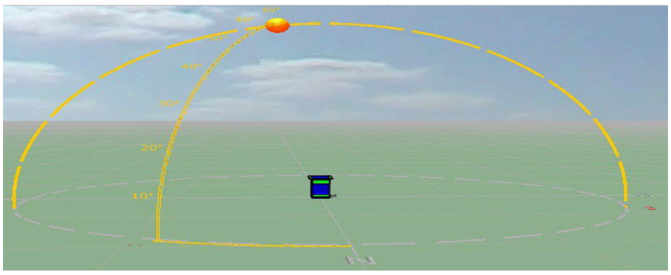


Figure 6. Simulation of building orientation

Additionally, this activity is intended to check whether the prototype building's position has any shadows. In this study it is obviously demonstrated that the solar shading simulation for the roof had no shadows between the hours of 8 a.m. and 5 p.m (Figure 7). The simulation was generated for May data, the same month as the previous field measurements. Hence, roof is the location where sun radiation is the most intense structure on this building where the green roof is recommended to be installed (Figure 8).

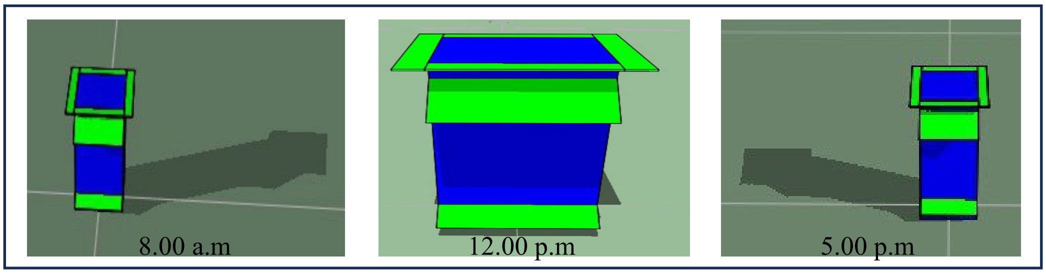


Figure 7. Shadow area for the study's building (on real onsite)

Building simulations were also done to demonstrate the need to limit direct radiation to building's roofs hence may reduce urban heat island. Figure 8 shows the simulation also highlighted that roof region is the most exposed area and has the longest exposure time in 24 hours shown with the red contour with 4320 hours per year. The north, south, east and west are the orientation facing view of each building wall. Hence, treating roof with layer of insulation is one of the good options, and in this study, green roof was used. This simulation is part of the sub-modelling of IES-VE using Model Viewer.

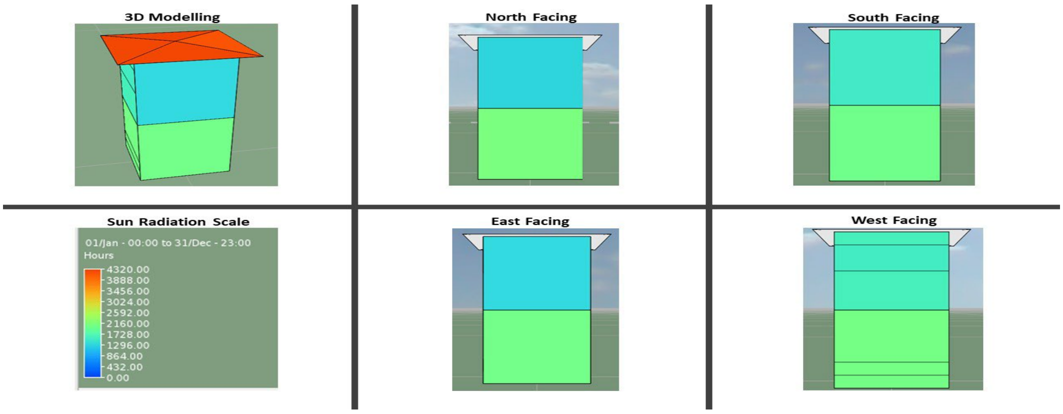


Figure 8. Longest hours exposure for roof area

The small-scale building treatments with additional of green roof as insulation layers has the potential to reduce solar radiation as reported by the previous study. This study reported that the material with higher thermal resistance, R-value, will radiates less heat into indoor buildings [38]. Figure 9 depicts the R-values, with the red contour indicating area with the highest R-value, and dark blue contour with the lowest. The differences between the R-value of control roof and the roofs with additional green roof layers of PGR and ATN showed different contours at approximately 89% and 86%, respectively.

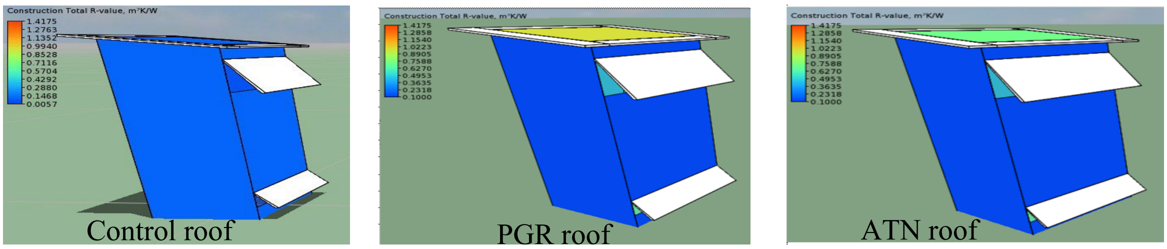
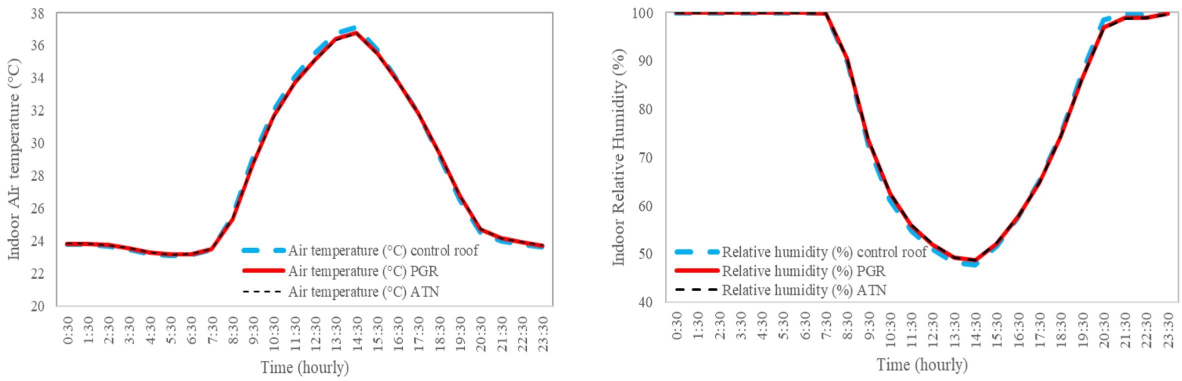


Figure 9. Contour Thermal Resistance (R-Value) of ATN, PGR and control roof

The Apache simulation is also utilized to see on how the green roof effects on the inside of the building. The Apache Sim (dynamic simulation) sub model in IES-VE is employed. Room categories that represent indoor with two selected factors such as relative humidity (RH) and air temperature (T) are used as the selection categories. Figure 10 shows the blue dotted line represents for the control roof while red and black dotted lines describe the PGR and ATN, respectively. These two variable factors were the output chosen that reflects the parameters measured on-site on the month of May.

Based on Figure 10, both T and RH shows similar trends, where all roofs had no major movement during nighttime which T values maintain around 24°C with RH at 99%. During daytime, starting from 07:30, both parameters start showing the increasing of T and decreasing of RH, until it reaches maximum T ranges between 36.8°C and 37.1°C; with minimum RH ranges between 47.7% and 48.6% at the peak hour of 14:30 for all roofs. After reaching peaks at 14:30, T started to decrease with increasing RH and both parameters were then back to the initial condition for nighttime at 20:30. However, there is no significant difference between the roof with green roof insulation and the control roof. This may be due to the small-scale roof building. Still, at the peak hour of 14:30, for T values, both green roof insulations show slightly reduction of 0.9% and 1% compared to the control roof, with 0.1% reduction of ATN roof temperature compared to the PGR roof. Similar trend with the opposite performance was observed for RH, where both green roof insulations present slightly higher RH than the control roof at 1.8% and 2% for PGR and ATN, respectively; with 0.2% higher RH of ATN roof compared to the PGR roof.



(a) (b)

Figure 10. The simulation outputs for indoor (a) air temperature (T) and (b) relative humidity (RH)

These observations indicated that both types of green roofs could potentially contribute on thermal comfort by mitigating indoor temperature fluctuations. Moreover, the ATN green roof consistently outperformed the PGR green roof, maintaining slightly lower indoor temperatures throughout the day. These findings highlight the potential of green roofs, especially ATN green roofs, in improving indoor thermal conditions and reducing the energy needed for cooling in small-scale buildings.

4. Conclusion

From this simple building simulation, conventional roof is always shown the highest temperature values. The simulation had demonstrated that green roof as one of alternative insulator could always provide as great impact on the temperature reduction in the simplest passive design concept especially in related to increase indoor thermal comfort for tropical climates.

It can be concluded that by adapting green roof especially ATN as a green roof plant that has potentially provides more benefits in temperature and higher carbon uptakes are the great choice for a future development of green roof technology. This study of thermal simulation is the constructive instrument that can demonstrate the well-being of building services by identification while ensuring the indoor environment thermal comfort is achieved.

5. References

[1] Climate Data. (n.d.). *Batu Pahat Climate*. Retrieved from https://www.climate-data.org/. Retrieved on January 1, 2023.

[2] Ahmad, N M, & Kavikumar, J 2015 Spatial and temporal characteristics of the atmospheric boundary layer height over Peninsular Malaysia. *J of Env. Sc. and Eng.*, **4**(5), 55-63.

[3] Yusof, N A M, & Johari, A M 2020 Trend analysis of the daily maximum temperature in Peninsular Malaysia. *Int. J. of Eng. and Adv. Tech.*, **9**(3), 4822-4828.

[4] Kho, M L, & Lee, S H.2019 Urban heat island assessment for sustainable urban development in Kuala Lumpur, Malaysia. *IOP Conf. Ser.: Earth Environ. Sc.* **263**(1), 012028.

[5] Rosli, M A M, & Ash'Aari, Z H 2023 Analysis of trends in extreme temperature indices over selected areas in Peninsular Malaysia from 1991-2020. *IOP Conf. Ser.: Earth Environ. Sc.* **1167**(1). https://doi.org/10.1088/1755-1315/1167/1/012008

[6] Kasmin H, Abd Razak K A, Buzaimi A S, Mohd Azman H N, Muhammad Suhaimi A F, Wan Mohamed W A, Rahmat S N and Ahmad N A 2021 Potential alternative evapotranspiration estimation methods for Batu Pahat climatic condition: A quantitative comparison *IOP Conf. Ser.: Earth Environ. Sc.* **1022** 012078

[7] Seyedmahmoudian, M, Oo, M T, & Horan, B 2019 A review on the factors affecting the energy performance of green roofs. *Renewable and Sust. Energy Rev.*, **102**, 93-101.
[8] Li, D, Chen, Y, & Xu, L 2021 The thermal performance of green roofs and their effects on the urban environment. *Building and Enviro.* **194**, 107674.
[9] Jutta S, Sofia L and Joel L 2021 The thermal performance of a green roof on a highly insulated building in a sub-arctic climate. *Energy and Building*.
[10] Mihalakakou, G, Souliotis, M, Papadaki, M, Menounou, P, Dimopoulos, P, Kolokotsa, D, Paravantis, J A, Tsangrassoulis, A, Panaras, G, Giannakopoulos, E, & Papaefthimiou, S 2023 Green roofs as a nature-based solution for improving urban sustainability: Progress and perspectives. *Renewable and Sust. Energy Rev.* **180** (November 2022), 113306. https://doi.org/10.1016/j.rser.2023.113306
[11] Hemsath, T L 2013 Conceptual energy modeling for architecture planning and design: impact of using building performance simulation in early design stages. *Proceedings of BS2013: 13th Conf. of Int. Building Perf. Simulation Assoc.* 376-384.
[12] Yang, Y, Tai, H, Liu, L, Yu, B, & Song, W 2023 A simulation approach of indoor temperature in existing buildings driven by short-term field measured data. *J of Asian Arch. and Building Eng.*, **22**(3), 1343–1360. https://doi.org/10.1080/13467581.2022.2085714
[13] Calixto-Aguirre, I, Huelsz, G, Barrios, G, & Cruz-Salas, M V 2021 Validation of thermal simulations of a non-air-conditioned office building in different seasonal, occupancy and ventilation conditions. *J of Building Eng.* **44** (February), 102922. https://doi.org/10.1016/j.jobe.2021.102922
[14] Bahar, Y N, Pere, C, Landrieu, J, & Nicolle, C 2013 A thermal simulation tool for building and its interoperability through the building information modeling (BIM) platform. *Buildings*, **3**(2), 380-398.
[15] Zhu, D., Hong, T, Yan, D, & Wang, C 2013 A detailed loads comparison of three building energy modeling programs: EnergyPlus, DeST and DOE-2.1 E. *Building Simulation,* **6**(3), 323-335.
[16] Cho, Y K, Alaskar, S, & Bode, T A 2010 BIM-integrated sustainable material and renewable energy simulation. In *Construction Research Congress 2010: Innovation for Reshaping Construction Practice,* 288-297.
[17] Attia S 2009 *Architect friendly: a comparison of ten different building performance simulation tools* (in: Eleventh International IBPSA conference) [Online] Available from: http//www.googlescholar.com. (Glasgow: Scotland)
[18] Michael S 2008 *BIM + Sustainability: Case Study on IES VE Building Performance Simulation* (Hawai: University of Hawai'i@Manoa, School of Arch., PhD Thesis)
[19] Athari K A 2013 *Investigating energy savings due to implementing green roof on existing residential buildings in UAE* (Dubai: The British University)
[20] Ávila-Hernández, A, Simá, E, Xamán, J, Hernández-Pérez, I, Téllez-Velázquez, E, & Chagolla-Aranda, M A 2020 Test box experiment and simulations of a green roof: Thermal and energy performance of a residential building standard for Mexico. *Energy and Buildings*, **209**. https://doi.org/10.1016/j.enbuild.2019.109709
[21] Zhang, K, Garg, A, Mei, G, Jiang, M, Wang, H, Huang, S, & Gan, L 2022 Thermal performance and energy consumption analysis of eight types of extensive green roofs in subtropical monsoon climate. *Building and Environ.* **216**(March), 108982. https://doi.org/10.1016/j.buildenv.2022.108982
[22] Chagolla-Aranda, M A, Simá, E, Xamán, J, Álvarez, G, Hernández-Pérez, I, & Téllez-Velázquez, E 2017 Effect of irrigation on the experimental thermal performance of a green roof in a semi-warm climate in Mexico. *Energy and Buildings*, **154**, 232–243. https://doi.org/10.1016/j.enbuild.2017.08.082
[23] Huang, Y Y, Chen, C T, & Liu, W T 2018 Thermal performance of extensive green roofs in a subtropical metropolitan area. *Energy and Buildings*, **159**, 39–53.

https://doi.org/10.1016/j.enbuild.2017.10.039
[24] Binabid, J 2010. *Vertical Garden: The study of vertical gardens and their benefits for low-rise buildings in moderate and hot climates*. M.B.S. University of Southern California.
[25] Figueroa, M 2008 *Green roof performance in Los Angeles, California*. M.B.S. University of Southern California.
[26] Schumann, L 2007 *Ecologically inspired design of green roof retrofit*. M.S. University of Maryland, College Park.
[27] Safikhani, T, Abdullah, A M, Ossen, D R, & Baharvand, M 2014 Thermal impacts of vertical greenery systems. *Environ. and Climate Techno.* **14**(1), 5–11. https://doi.org/10.1515/rtuect-2014-0007
[28] Taleb, H. M. 2014 Using passive cooling strategies to improve thermal performance and reduce energy consumption of residential buildings in U.A.E. buildings. *Frontiers of Architectural Research*, **3**(2), 154–165. https://doi.org/10.1016/j.foar.2014.01.002
[29] Agboola, O P 2011 Importance of Climate to Architectural Designs in Nigeria. *Journal of Environmental Issues and Agriculture in Developing Countries*, **3**(1), 15–28. http://www.doaj.org/doaj?func=openurl&issn=21412731&date=2011&volume=3&issue=1&spage=15&genre=article
[30] Rashid, F L, Al-Obaidi, M. A, Dulaimi, A, Mahmood, D M N, & Sopian, K 2023 A Review of Recent Improvements, Developments, and Effects of Using Phase-Change Materials in Buildings to Store Thermal Energy. *Designs*, **7**(4). https://doi.org/10.3390/designs7040090
[31] Hosseinzadeh, A, Bottacin-Busolin, A, & Keshmiri, A 2022 A Parametric Study on the Effects of Green Roofs, Green Walls and Trees on Air Quality, Temperature and Velocity. *Buildings*, **12**(12), 1–19. https://doi.org/10.3390/buildings12122159
[32] Yacob, M N M, Kasmin, H, & Hashim, M I H 2021 Estimating Carbon Sequestration of Green Roof Plants in Tropical Climate. *Int. J of Integrated Eng.* **13**(3), 200–206. https://doi.org/10.30880/ijie.2021.13.03.024
[33] Irfandi, Munir, A, Muslimsyah, & Huda, K 2021 The Effect of Plants on Extensive Green Roofs in Urban Heat Island Mitigation Efforts in Humid Tropical Cities. *IOP Conf. Ser.: Earth Environ. Sc.* **881**(1), 0–8. https://doi.org/10.1088/1755-1315/881/1/012043
[34] Puay Yok, T S A 2008 *A Selection of Plants for Green Roofs in Singapore (2nd ed.)*. National Parks Board, 2008.
[35] Clarke, J A, and Hensen, J L M 2015 Clarke, J.A., & Hensen, J L M 2015 Integrated building performance simulation: Progress, prospects and requirements. *Building and Env.* **91**, 294-306.
[36] Patra, P K, and Tripathi, D P 2014 Monitoring the room and controlling its temperature and light industry from a remote location over a network. *Int. J of Adv. Computing Technique and Applications*, **2**(2), 96-101.
[37] Nalamwar, M R, Parbat, D K, & Singh, D P 2016 Optimum Building Orientation Study For Central India By Simulation. *Int. J on Theoretical and Applied Research in Mech. Eng. (IJTARME)*, **5**(3), 25–27.
[38] Abdulsada, G K, & Salih, T W M 2022 The impact of efficient insulation on thermal performance of building elements in hot arid region. *Renewable Energy and Env. Sustainability*, **7**, 2. https://doi.org/10.1051/rees/2021050.

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