VOL. 17, NO. 6, MARCH 2022 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences


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# COMPARATIVE ASSESSMENT OF THE EFFECT OF POLYURETHANE-ALUMINUM ROOFING AND NON-POLYURETHANE ROOFING FOR SUSTAINABLE THERMAL COMFORT

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**ABSTRACT**

Due to the ozone layer depletion, many houses suffer from high thermal solar radiation effects during the dry season in Nigeria's southern and northern parts. This issue makes the use of an insulated roofing system more significant to have a comfortable environment. This research aims to proffer a solution by evaluating the performance of Polyurethane's (P.U.) foam as a thermal insulation material embedded in the aluminum roofing system for adequate human comfort. The thermal analysis was carried out using a data logger to obtain the temperature data with time variation for the two house models' indoor and outdoor environments. The study was carried out for two hours in the morning, afternoon, and evening for both the Polyurethane aluminum roofing and the Non-Polyurethane roofing. The authors employed a contour plot for one-factor analysis to study the time variation effects on the roofing house models. The results show that the P.U. embedded aluminum roofing sheet reduces the temperature by 5% in the morning, 16% in the afternoon, and 10% in the evening compared with the non-Polyurethane roofing sheet. Furthermore, the P.U. foam application on the aluminum roofing shows a uniform heat distribution and provides a sustainable, eco-friendly environment. This study recommends that the manufacturing industry producing roofing sheets should use PU-form as an insulation material for cleaner and eco-friendly thermal comfort.

**Keywords:** polyurethane (PU) foam; thermal insulation materials; data-logger; solar radiation; energy utilization; thermal engineering.

## 1. INTRODUCTION

The utilization of energy in buildings grows with each passing year. It is a variable required to either heating or cooling a building. These buildings can and never would have been suitable for habitation without the menacing presence of energy. There is a constant effort to develop systems for advancement in the already available insulation practices. Thornbush *et al.* [1] research in 2008 revealed that the building industry is gradually heading towards difficult times, coupled with the commitment towards achieving a 2030 carbon-neutral future. Conserving energy in buildings has presented itself as a significant factor in this present time and day. Because increasing energy utilization in various commercial and residential establishments, usually from the installed systems for heating and cooling made available in these houses, provides a more soothing and healthy environment. It was recorded in 2016 that 39.5% of available energy in the world was preferably used for heating and cooling buildings [2]. The total energy used in this particular year amounted to about 16,843 and 15,082 utilized for temperature control in residential buildings and commercial buildings [3]. The European Union (E.U.) has been a significant player in finding long-lasting solutions to climate change effects. Due to their contribution, they submitted to the United Nations in March 2015 their determined contributions for the United Nations Framework Convention on Climate Change (UNFCCC). The proposed goal will be to lower greenhouse gas emissions by 40% by 2030 then the value levels recorded in 1990. This energy's primary use is attributed to heating systems used in buildings and hot water production [4]. A sustainable Engineering building seeks better methods to cut off air pollution and regulate water movement while also seeking to ensure the effective utilization of available materials and resources.

Thermal Insulation materials are used to reduce energy loss in residential and commercial buildings. These insulation techniques can serve all year round by increasing the available heating and cooling systems to full capacity. It also reduces the cost of running electrical water heaters and the air conditioning unit and even the high standing costs of these systems. Electricity consumption can be reduced when there is a significant reduction in $CO_2$, which will afford better living standards and a serene setting for individuals [5-6]. Legal obligations regarding thermal insulation have developed stricter measures to ensure compliance with regular changes to existing regulations. The Kypto protocol and Paris conference seeks to provide measurements in curtailing emissions, stating that appropriate insulation material is a significant thermal resistant object in buildings.

Furthermore, the clean development mechanism (C.D.M.) is a technique that the international community has widely adopted. By reducing the number of carbon emissions being released into the environment, the developing countries do not have. This C.D.M. is designed

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to help developed countries achieve the commitment to meet domestic greenhouse gas reduction [7]. Many insulation materials being made available are produced from polymers, including integrating certain additives to increase their mechanical strength. The different insulation materials are grouped into four major categories: organic or inorganic and composite material or just typical necessary materials. Furthermore, polymers' extensive use in developing insulating materials is in their naturally stable chemical and physical compositions. However, the mechanical constituents can be improved by adding inorganic fillers [8].

The utilization of air conditioners in most regions is a result of the hot-humid climate in these regions. Furthermore, to achieve acceptable thermal comfort, air conditioning must be employed, which would invariably reduce the indoor temperature. There are various means of reducing indoor temperature and air conditioners, including the opening of windows and doors and electric fans. While the former would involve more heat coming into the building or home through the windows and doors, the latter does not consume as much energy as the air conditioners do. However, the air conditioning units will help achieve a certain level of thermal comfort. There are adverse effects associated with a continuous and absolute dependence on this system. It increases the amount of money paid by individuals for their electricity tariffs coupled with increased energy consumed and a resulting emission increase from the power plants during power generation [9]. As a result of the increasing climate change, the environmental temperature is on a steady rise. From literature, it has been observed that particularly in the afternoon, solar radiation causes a heat gain in buildings through the envelope and the windows via heat penetration. Morris *et al.* [10] highlighted the roof as the most affected by solar radiation due to its direct contact with sunlight. Therefore, it is responsible for a more significant part of heat gain in buildings.

Naldzhiev *et al.* [11] highlighted how much building structures constitute the total emissions of $CO_2$ in the U.K. It is about 19% and therefore measures the crucial need for energy efficiency in buildings to reduce a considerable amount of carbon levels. However, careful examination and investigation have revealed that further enhancement in building compartment insulation decreases buildings' heating and cooling requirements by about 20-60%, improving thermal comfort [12]. Various developed mechanisms to improve heating, cooling requirements, and better methods are still being tested and developed. While these techniques seek to manage heating and cooling systems, reducing electricity consumption, there are majorly involved in furthering building insulation. Improving building insulation will reduce energy demands, promoting the cause to a considerable extent and accruing to a short period of return on investment [13]. The importance of making better thermal performance levels through thermal insulation techniques is further stressed through the different comparisons made by energy production and its consumption evaluations. Gino *et al*. [14] stated that by 2035, the energy generation sector would only get 15% of the total energy produced from fossil fuels.

Furthermore, the actual result to help combat the heat transfer's adverse effect has on the environment. Various steps, including redirecting appropriate funds into sustainable energy development, energy efficiency level improvement in buildings, will be highly needed. As this part of the building, the sector has not been fully exploited as of 2012 [15]. Incorporating thermal insulation materials in commercial and residential buildings will further improve energy deficit management resulting from energy consumption in building structures. This technique will reduce energy loss, which functions for up to a year, ensuring the proper heating and cooling systems present in the building structure. In addition to these merits, selecting these appropriate materials in developing a building will see a drastic decline in the operational cost of electricity through heating and cooling systems and the cost of insulation of this equipment for heating and cooling [16]. Every society requires energy for its daily running of activities [17]. This energy provides a platform for all life processes while also being traded as a commodity for revenue generation. Energy is used for generating new materials when applied to the system. As much as its importance cannot be overemphasized, the end-users should manage energy appropriately as its supply is not unlimited [18]. Electrical power is considered one flexible form of energy. It can also be easily distributed and highly managed by optimizing its thermal comfort [19], [20], [21].

However, this research aimed at carrying a comparative assessment of P.U. roofing with the non-PU roofing system in the two different house model developed for this study. Also, the time variation effects on the thermal performance were studied using a single factor contour plot from Minitab 18. The study also determines the heat transformation process to know the heat absorption capability of the P.U.Al-foam-roofing compared with the non-P.U.-roofing sheet for sustainable insulation material for roofing application. This study will assist the thermal comfort of all the houses in the Northern and Southern parts of Nigeria since the energy supply is not stable.

## 2. MATERIAL AND METHODS

The study observation was carried out for a 5-day study period. The average temperature values for the indoor environments for the morning, afternoon, and evening for the Polyurethane aluminum roofing system and non-polyurethane roofing system were obtained. Each domain has the same 2-hour variation. The morning environment is between 7:05 am to 9:00 am, the afternoon environment between 1:05 to 3:00 pm, and the evening environment analysis was carried out between 6:05 pm and 8:00 pm.

### 2.1 Insulation Material

The insulation material utilized in this experiment is polyurethane foam. In this study, testing out different insulation materials was not paramount. This experiment examines the thermal effectiveness performance developed by Queensway Aluminium, the polyurethane foam manufacturer for other temperature regions. The side view of the polyurethane foam sample is shown in figure-1(a). The developed data logger presented in Figure-1(b) has two sensors; one was connected to the outdoor environment and the other sensor for the indoor environment. The sensors are placed very close to the roofing made with both materials considered for this study, as shown in Figure-1(c) and 1(d). The data logger employed in this study measures the time (min.) and both environments' temperature. Figure-1(c) was built with non-PU roofing. The second house model, Figure-1(d), was created with a P.U. aluminum roofing sheet of 21mm thick polyurethane foam. This research compared both house models' thermal performances to effectively study the P.U. foam's effect as a sustainable insulation material for residential buildings. The study was carried out at Covenant University, Ota Ogun State, Nigeria. The experimental result is analyzed using excel software and Minitab 18.

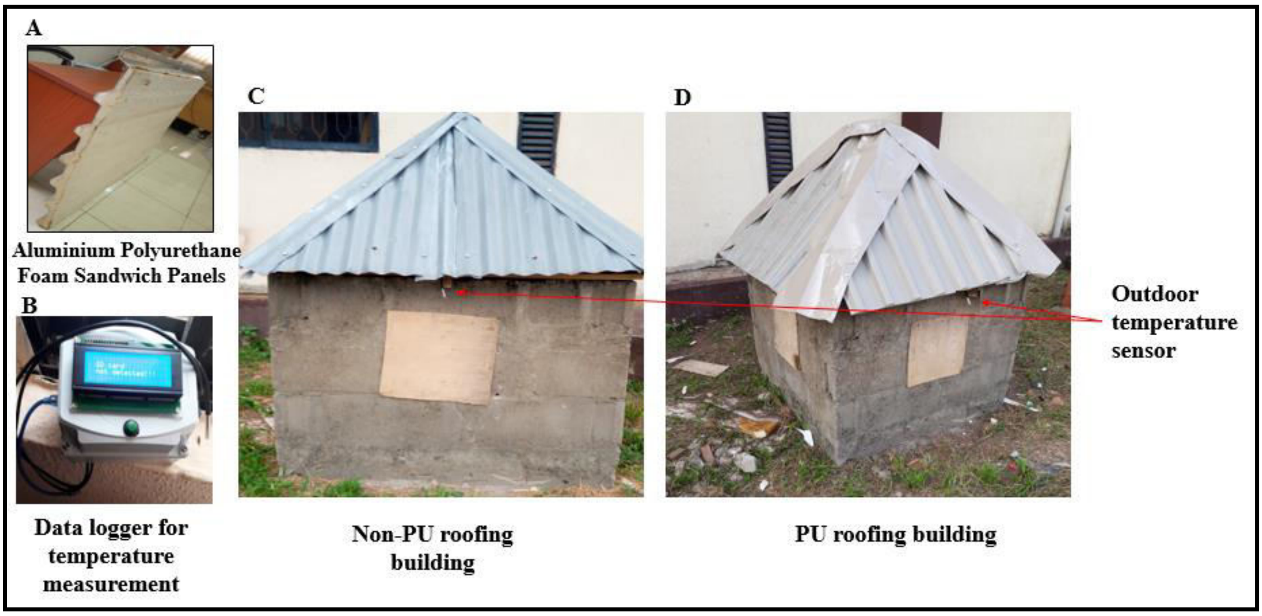


**Figure-1.** The experimental setup for the thermal analyses (a) Aluminium Polyurethane Foam Sandwich Panels, (b) data logger, (c) non-PU roofing house model, and (d) PU-roofing house model.

**2.2 Heat Transfer Analysis**

The house model's materials' dimension and thermal conductivity on this experiment are presented in Table-1.

Assumptions

a) Heat transfer through the wall is one-dimensional and occurs in a direction normal to the surface (x-direction)
b) Heat transfer is steady, with the temperature remaining constant
c) The thermal conductivity values are assumed constant
d) For the PU insulated aluminum, it is assumed the different layers have perfect thermal contact

**Table-1.** Dimension and thermal conductivity of materials employed in this study.

| Materials for the house model | Dimensions |
|---|---|
| Roof Thickness (PU-roof) aluminium | 0.4mm = $4\ X\ 10^{-4}m$ |
| Roof thickness (non-PU sheet) | $0.15mm = 1.5\ X\ 10^{-4}m$ |
| Roof dimension (aluminum) | $126cm\ X\ 151cm$ $= 1.26m\ X\ 1.51m$ |
| Roof dimension (non-PU roofing) | $125cm\ X\ 151cm$ $= 1.25m\ X\ 1.51m$ |
| **Materials** | **Thermal Conductivity** |
| Aluminum sheet | $237w/m^oC$ |
| non-PU sheet | $43w/m^oC$ |
| Polyurethane foam | $0.02w/m^oC$ |
| Cement block | $1.37w/m^oC$ |
| The thickness of PU foam insulation | $21mm = 0.021m$ |
| The thickness of the wall of the model of the house | $15cm = 0.15m$ |

Using the thermal resistance concept for (PU insulated aluminum), equations (1)-(6) are employed.

$$Q_t = \frac{T_1 - T_3}{R_1 - R_2} \quad (1)$$

Where

$$Q_t = Q_1 + Q_2 \quad (2)$$

$$Q_1 = \frac{K_1 A(T_1 - T_2)}{L_1}, Q_2 = \frac{K_2 A(T_2 - T_3)}{L_2} \quad (3)$$

$$\text{Where; } \left[R_1 = \frac{L_1}{K_1 A}\right], \left[R_2 = \frac{L_2}{K_2 A}\right] \text{PU} \quad (4)$$

$$Q_t = Q_1 + Q_2 = \frac{T_1 - T_2 + T_2 - T_3}{R_{1+} R_2} = \frac{T_1 - T_3}{R_1 + R_2} \quad (5)$$

Equation (6) shows the rate of heat transfer analysis

$$Q_t = \frac{T_1 - T_3}{R_1 + R_2} \quad (6)$$

**For the morning period between 7:00 - 9:00 am**

$T_1 = 26^O C, \quad T_2 = 23.5^O C$

**Heat transfer through PU-aluminum**

The analysis of the heat penetrating through the PU foam roofing sheet in the morning is shown in equation (7).

$$Q_t = \frac{T_1 - T_3}{R_1 + R_2} ; R_1 = \frac{L_1}{K_1 A} \quad (7)$$

$$\frac{4 X 10^{-4}}{237 X (1.26 X 1.51)} = 8.87 X 10^{-7} C/w$$

$$R_2 = \frac{L_2}{K_2 A} = \frac{0.021}{0.02 X (1.26 X 1.51)} = 0.552 C/w$$

$$Q_t = \frac{26 - 23.5}{(8.87 X 10^{-7} + 0.552)} = 4.5W$$

Therefore, Heat Flow through polyurethane aluminum is 4.5W

**Heat transfer through the non-PU sheet**

Equation (8) shows the heat penetrating through the non-PU roofing sheet in the morning section

$$Q = \frac{KA(T_1 - T_2)}{L} \quad (8)$$

$$\text{where; } k = 43 \frac{W}{m^o C}, L = 1.5 X 10^{-4} m, T_1 = 26^o C, T_2 = 25.5^o C$$

$$Q = \frac{43 X (1.25 X 1.51)(26 - 25.5)}{1.5 X 10^{-4}} = 270541.7W$$

Therefore, Heat Flow through a non-PU roofing sheet is 270.5KWr the Afternoon Period between 1:00 – 3:00 pm

The heat transfers through both the insulation material and the traditional roof sheet are very high because the solar radiation at this time is at its peak. The heat transfer becomes 15.5 W for the PU Aluminum roofing sheet. The pattern used for the morning section was also employed in the other too medium or sections.

**Heat Transfer across PU-aluminum roofing in the afternoon**

$$Q_t = \frac{T_1 - T_3}{R_1 + R_2}, R_1 = \frac{L_1}{K_1 A} = 8.87 X 10^{-7} \text{C/w}$$

$$R_2 = \frac{L_2}{K_2 A} = 0.552 C/w$$

$$Q_t = \frac{34 - 25.5}{(8.87 X 10^{-7}) + (0.552)} = 15.4W$$

Therefore, Heat Transfer across PU-aluminum in the afternoon was 15.4W

**Heat transfer through the** non-PU **roofing sheet**

Equation (9) was used to determine the heat transfer through the non-PU roofing sheet.

$$Q = \frac{KA(T_1 - T_2)}{L} \quad (9)$$

$T_1 = 34^o C \;\; T_2 = 33^o C$

$$Q = \frac{43 X (1.25 X 1.51)(34 - 33)}{1.5 X 10^{-4}} = 541083$$

Therefore, Heat Flow through the non-PU sheet is 541KW

**For the Evening period between (6:00 – 8:00 pm)**

Heat transfer through PU-aluminum In the evening analysis of the thermal resistance or temperature calculation, the same method employed using equation (7) is expressed as follows:

$$Q_t = \frac{T_1 - T_3}{R_1 + R_2}, R_1 = 8.87 X 10^{-7} c/W, R_2 = 0.552\, c/W$$

$$Q_t = \frac{27.5 - 24}{((8.87 X 10^{-7}) + 0.552)}$$

Therefore, Heat Flow through the PU-Aluminum roofing system in the evening period was 6.3W

**Heat Transfer through the non-PU Roofing Sheet**

$$Q = \frac{KA(T_1 - T_2)}{L} ; T_1 = 27.5^o C \quad T_2 = 26^o C$$

$$Q = \frac{43 \text{ X } (1.25 \text{ X } 1.51)(27.5 - 26)}{1.5 \text{ X } 10^{-4}} = 811625$$

Therefore, Heat Flow through non-PU roofing sheet = 811KW

**Table-2.** Summary of the heat transfer flow rate of the PU-aluminum and non-PU roofing sheet.

| Roofing Sheets | Heat transfer flow rate |
|---|---|
| **Morning** | |
| PU-aluminum roofing sheet | 4.5W |
| non-PU roofing sheet | 270.5KW |
| **Afternoon** | |
| PU-aluminum roofing sheet | 15.4W |
| non-PU roofing sheet is | 541KW |
| **Evening** | |
| PU-Aluminum roofing sheet | 6.3W |
| non-PU roofing sheet | 811KW |

## 3. RESULTS AND DISCUSSIONS

This section contains the results for both performance analyses for the thermal study carried out for Non-PU-Roofing and the PU-AL- Roofing System. The experimental results between the outdoor temperature for the non-PU- roofing house with the P.U. roofing house differ from the indoor temperature. The morning's outdoor temperature was between 24.5 to 25 $^{o}$C, for the afternoon 28 to 33 $^{o}$C and evening 26 to 27 $^{o}$C. Therefore, this research also carried out the time effect variation with the solar radiation for the indoor of both environments.

### 3.1 Comparative Analysis of the Results between the Non-PU-Roofing and the PU-AL- Roofing System

A comparative analysis is further carried out in Figure 2, which shows the polyurethane roofing system's thermal performance and the non-polyurethane roofing system in the six environments. Figure-2 shows the Non-PU roofing system's thermal performance and the PU-AL roofing system in the three domains (morning, afternoon, and evening). Both roofing building materials begin with the same heat resistance level. The non-PU roofing system is slightly higher in the morning environment. However, the afternoon environment witnesses a complete spike in the thermal performance level of the Non-PU roofing system as it reaches its limit of heat resistance. On the other hand, the PU-AL roofing system increases the afternoon environment with optimum thermal comfort temperature.

The evening environment experiences another slight increase in roofing systems' thermal resistance with a PU-AL roofing system, with a better thermal performance. Figure 2 shows the morning results from the time variation from 7.05 am to 9.00 am, the afternoon from 1.05 pm to 3.00 pm. Also, the evening time variations start from 6.00 pm to 8.00 pm.

Figures 3 to 5 show the Non-PU roofing system's average indoor temperature and PU-AL roofing system for the morning, afternoon, and evening environments, for the period of the experiment, respectively. The chart shows a better performance of the PU-AL roofing system over the Non-PU roofing system. The PU-AL roofing sheet reduces the indoor temperature by 5% in the morning, 16% in the afternoon, and 10% in the evening compared with the Non-PU roofing system. This difference is that the P.U. foam could resist the solar radiation from rising the Sun in the morning. In the afternoon, the radiation effect is very high. The PU foam embedded in the aluminum roofing house model was able to absorb the heat flow. Nazir et al. [22] reviewed different materials employed forenergy storage. The study also supported developing insulation materials for building a roofing system to reduce the occupant's heat effects and reduce energy consumption in the buildings. In a recent survey, air-conditioning in the buildings consumed more energy, leading to ozone layer depletion in Nigeria [23], [24]. The primary energy source is the combustion of fuel. Equation (10) shows the P.U. foam's chemical structure embedded in the aluminum roofing sheet, indicating that the PU-aluminum roof is eco-friendly to the environment and the end-users.

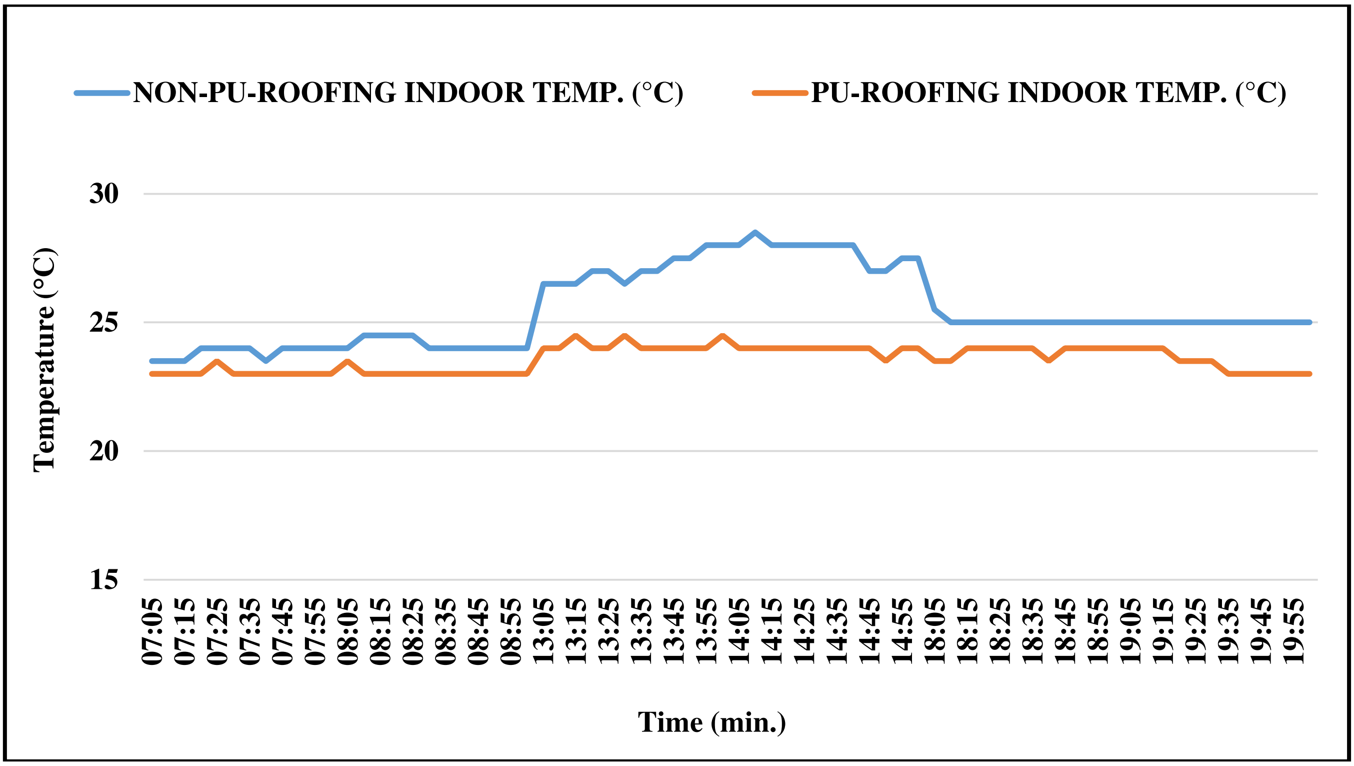


**Figure-2.** Comparative analysis of non-PU and PU aluminum roofing sheet for the three environments.

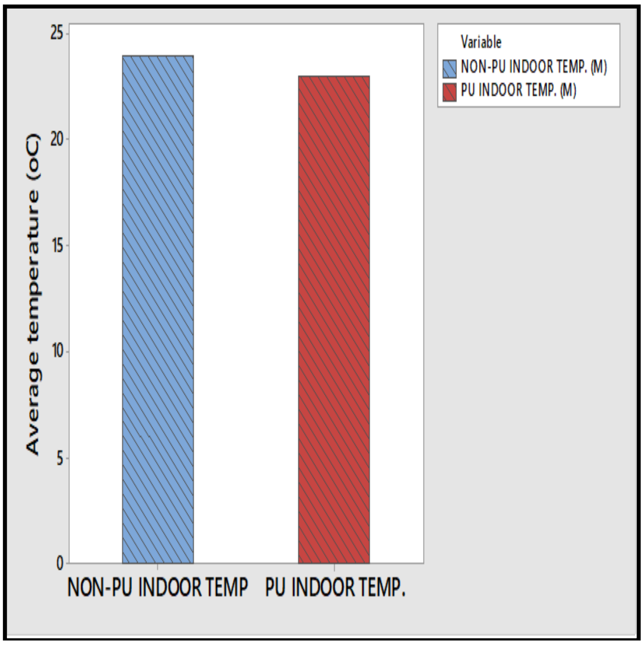


**Figure-3.** Comparative Average temperature for non-PU indoor and PU indoor morning house model.

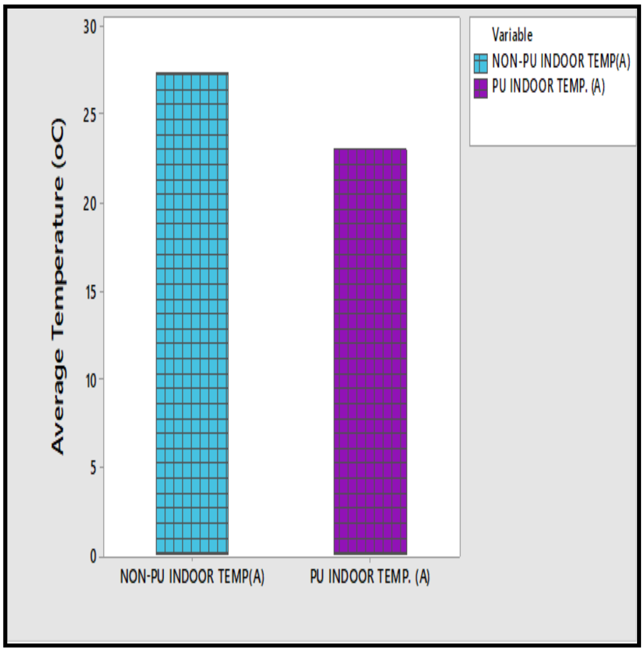


**Figure-4.** Comparative Average temperature for non-PU indoor and PU indoor afternoon house model.

VOL. 17, NO. 6, MARCH 2022 ISSN 1819-6608
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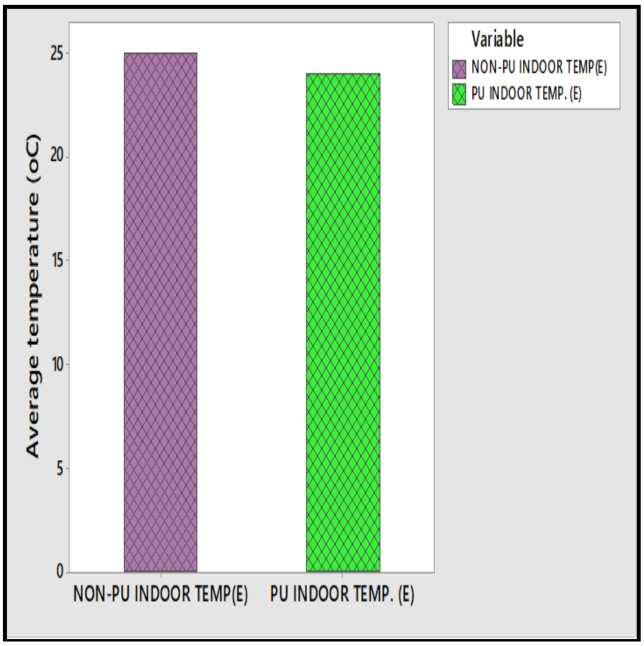


**Figure-5.** Comparative Average temperature for non-PU indoor and PU indoor for evening house model.

### 3.2 Effects of Time Variation on the Thermal Performance of the Non-PU and PU Roofing House Models

Figure-6 (a-b) presents the contour plot showing the morning environment's thermal analysis carried out Non-PU roofing system and the PU-AL roofing system for indoor temperature. Figure-6(a) shows that have time increases, the temperature in the non-PU roofing system increase steadily. The region with the light green offers the minimum temperature achieved in the morning with 23.5 $^{o}$C from 7.05 am to 7.20 am. After some time, the weather was stable from 7. 40 am to 8. 40 am, having between 23.75 $^{o}$C to 24 $^{o}$C. As the Sun's solar radiation increases, the temperature progressively increases from 24 oC to 25 $^{o}$C, as shown in the high concentration region in Figure-6(a) between 8.40 am above. Figure-6(b) shows the time effects variation with fit temperature for the P.U. roofing house model for morning analyses. The result shows that in the morning, the P.U. roofing was able to withstand the heat and reduce the indoor environment's thermal effect, which leads to good thermal comfort for the residential occupants. Figure-6(a) as the time increases from 7.05 am to 9. 00 am, the P.U. roofing house model maintained a constant temperature of about 23 $^{o}$C. The change that occurs due to the interaction effects of the Fit temperature and time shows that assuredly there was solar radiation on the top surface of the P.U. roofing building. Due to the insulation material, the thermal effects were not as significant as the non-PU roofing system (Figure-1c). Equation (10) Polyurethane foam mixture containing the urethane family –N.H.-(C=0)-0- Link unit of molecules.

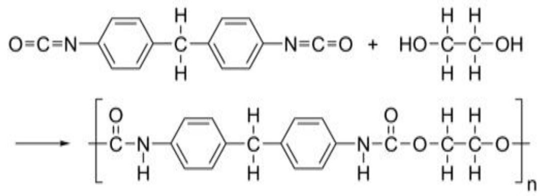

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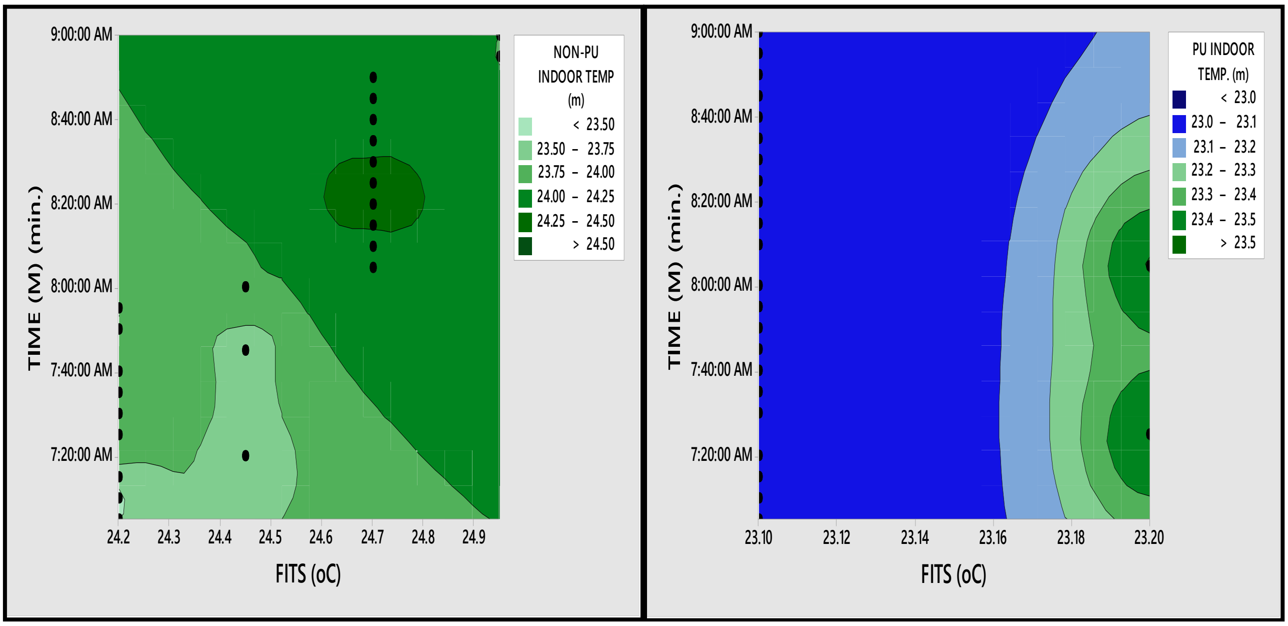
Figure-7(a-b) gives a typical representation of our residential building's thermal radiation effects in the afternoon. The results show that as time increases in the noontime, buildings without insulation materials suffer high thermal radiation effects, which is highly detrimental to the occupant's health. From Figure-7(a), the non-PU roofing house model has a minimum temperature of 26.8 $^{o}$C (blue color) with a maximum temperature of about 28 $^{o}$C (green color) in the legend of the contour plot. The non-insulated house model shows no uniform heat distribution; that is, the solar radiation from the Sun acts directly on the environment.

Figure-7(b) indicates that the P.U. insulation roofing house model has a uniform distribution of heat. Also, it has a minimum temperature of 23.5 $^{o}$C (blue) and a maximum of 24 $^{o}$C (light-green), as shown in the legend of the contour plot for the P.U. roofing system in Figure-7(b). These findings prove that P.U. roofing is eco-friendly to the environment and has provided a good and comfortable environment for the community end users. This result is supported by the recommendation made by [23]. Figure-8(a-b) illustrates the time variation effects, concerning indoor temperature, on thermal resistance for non-PU and PU-AL roofing systems. The house model with non-PU roofing sheets shows the same indoor temperature. Results reveal that this non-Pu roofing system has no effect on the thermal resistance and records the same temperature as the solar radiation temperature falling on it. This result implies that there is no decrease in heat coming into the house.

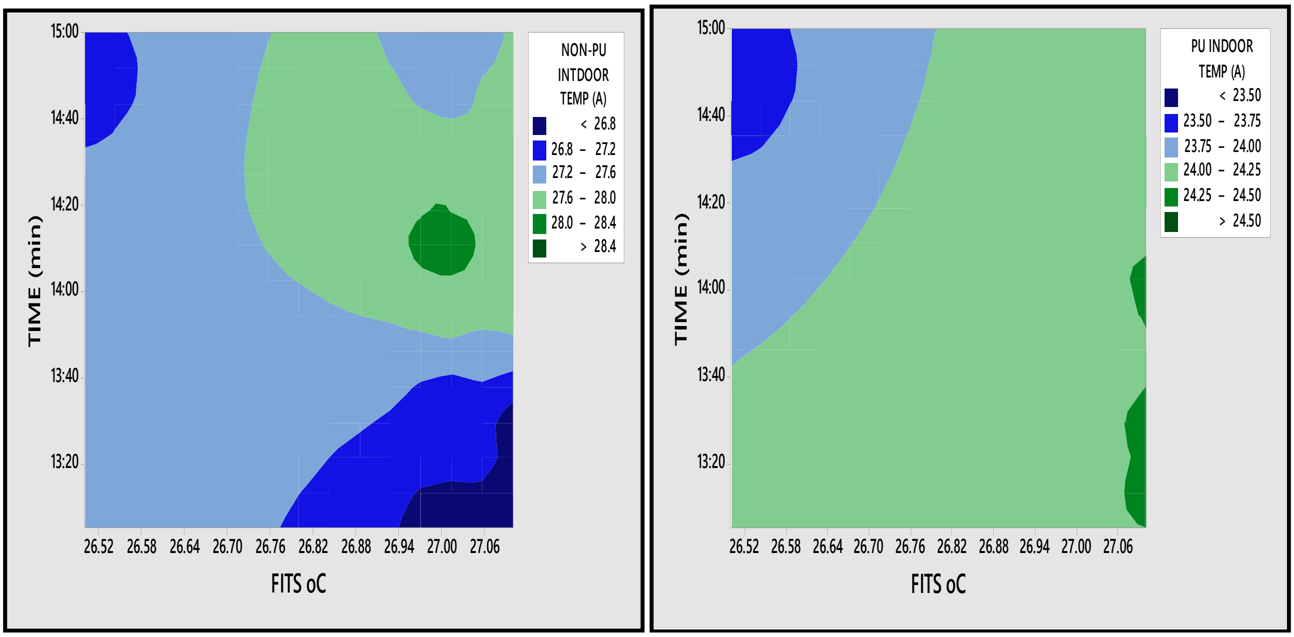
Figure 8(b) illustrates an even temperature distribution due to P.U.'s addition to the roofing system. Results show that adding a PU-AL roofing system resists heat comfortably for a long time giving maximum thermal comfort for the time duration. This analysis proves the relevance of adopting -hermal insulation materials such as P.U. in designing roofing systems. The temperature for the evening analyses for the P.U. roofing house model was between 23. 5 $^{o}$C to 24.5 $^{o}$C and for non-insulation roofing system having between 25 $^{o}$C to 25.5 $^{o}$C. Morsy *et al.* [24] and Beemkumar *et al.* [25] studies thermal performance analyses on the roofing system and recommended a sustainable insulation material for the smart roofing system should be developed and implemented. Thereby creating an environment that is comfortable for human heathy. This research has studied it, and the results have shown that insulation materials are reliable and sustainable for thermal comfort. The vital part of this research is that when the manufacturers use the PU-foam on their roofing system, it will save costs and give excellent sustainability [26-28]. The presence of carbon, nitrogen, oxygen, and hydrogen in the P.U. foam has proven that the P.U.

roofing is eco-friendly for human comfort. It will boost the application of P.U. roofing in the construction industry.




(a) (b)

**Figure-6.** Time Variation vs. Fits temperature indoor on Thermal Resistance for the morning (a) Non-PU- Roofing (b) PU- Roofing.




(a) (b)

**Figure-7.** Time Variation vs. Fits Indoor temperature on Thermal Resistance for Afternoon (a) Non-PU- Roofing (b) PU- Roofing

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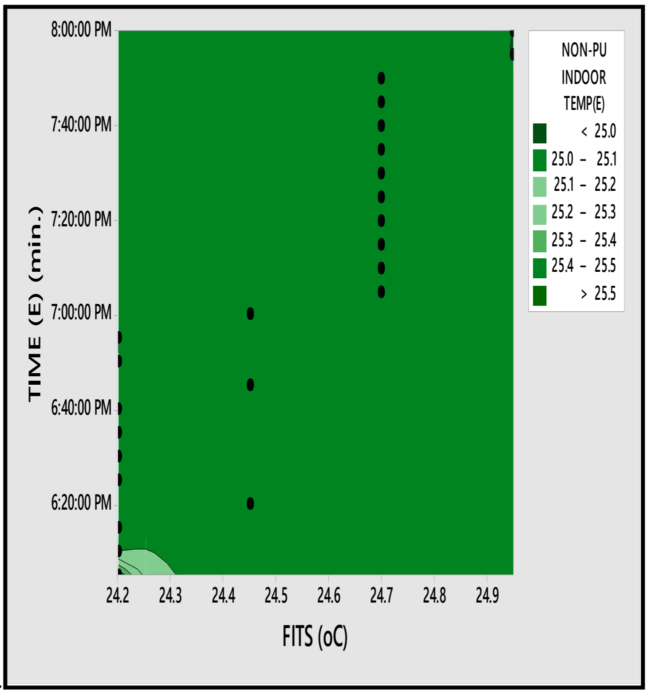
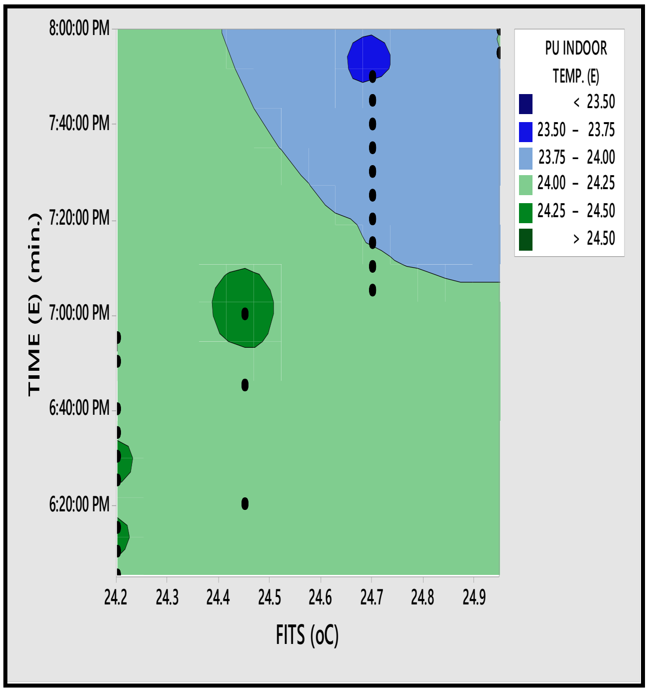



(a)




(b)

**Figure-8.** Time Variation vs. Fits temperature indoor on Thermal Resistance for an evening of the (a) Non-PU roofing and (b) PU-AL-Roofing.

## 4. CONCLUSIONS

The comparative analyses between an insulated roofing house model and a non-insulated house model have been carried out in this research. The study employed polyurethane foam of 21 mm thickness as the roofing system's insulation material to study its performance on thermal resistance for residential thermal comfort. This research, as the following conclusion:

a) The PU-aluminium roofing sheet absorbs and crates the heat uniformly across the eco-friendly environment for offices and residential buildings for human comfort. The heat analysis from the two house models shows that the P.U. aluminum roofing has a heat penetration of 15.4W. The non-PU roofing system has 541W in the Afternoon period.
b) The PU-aluminium roofing sheet reduces the environment's temperature by 5% in the morning, 16% in the afternoon, and 10% in the evening compared with the non-PU aluminum roofing sheet.
c) The contour plot study showed that the P.U. roofing system reduced and maintained 23 $^{o}$C for a long time. It also shows that time variation affects the thermal performance of the roofing system. An increase in the time (minutes.) variation increases the temperature for all the environment. The difference between temperature reductions is due to the urethane family present in the P.U., which helps absorb the heat compared with the non-PU roofing house model.

Therefore, since the PU roofing house model has proven to create an eco-friendly environment, further work can improve the system by varying the thickness and studying the elemental composition for a smart roofing system.

## ACKNOWLEDGMENT

The authors wish to acknowledge the Covenant University Management for paying for the publication fees.

## REFERENCES

[1] Thornbush M., Golubchikov O. and Bouzarovski S. 2013. Sustainable cities targeted by combined mitigation-adaptation efforts for future-proofing. Sustainable Cities and Society, 9, pp. 1-9. http://dx.doi.org/10.1016/j.scs.2013.01.003

[2] Palz W. and Steemers T.C. eds. 2016. Solar Houses in Europe: How They Have Worked. Elsevier.

[3] IEA C.E.M. 2017. Global ev outlook 2017. Tech. Rep.

[4] Al-Karaghouli A. and Kazmerski L.L. 2013. Energy consumption and water production cost of conventional and renewable-energy-powered desalination processes. Renewable and Sustainable Energy Reviews, 24, pp. 343-356 https://doi.org/10.1016/j.rser.2012.12.064.

[5] Habibollahzade A., Houshfar E., Ashjaee M., Behzadi A., Gholamian E. and Mehdizadeh H. 2018. Enhanced

power generation through integrated renewable energy plants: Solar chimney and waste-to-energy. Energy Conversion and Management, 166, pp. 48-63 https://doi.org/10.1016/j.enconman.2018.04.010.

[6] Yüksek I. and Karadayi T.T., 2017. Energy-efficient building design in the context of building life cycle. Energy Efficient Buildings, pp.93-123.

[7] JEMLI R. and Chtourou N., Renewable Energy sources are on track for climate change mitigation: Classification of their carbon intensity by neural approach.

[8] Liu Q., Zhang Y. and Xu H. 2008. Properties of vulcanized rubber nanocomposites filled with nanokaolin and precipitated silica. Applied Clay Science, 42(1-2): 232-237 https://doi.org/10.1016/j.clay.2007.12.005.

[9] Popp J., Lakner Z., Harangi-Rakos M. and Fari M. 2014. The effect of bioenergy expansion: Food, energy, and environment. Renewable and Sustainable Energy Reviews, 32, pp. 559-578 https://doi.org/10.1016/j.rser.2014.01.056

[10] Morris F., Ahmed A.Z. and Zakaria N.Z. 2011, June. Thermal performance of naturally ventilated test building with pitch and ceiling insulation. In 2011 3rd International Symposium & Exhibition in Sustainable Energy & Environment (ISESEE) (pp. 221-226). IEEE.

[11] Naldzhiev D., Mumovic D. and Strlic M., 2020. Polyurethane insulation and household products–A systematic review of their impact on indoor environmental quality. Building and Environment, 169, p.106559. https://doi.org/10.1016/j.buildenv.2019.106559

[12] Jannat N., Hussien A., Abdullah B. and Cotgrave A. 2020. A comparative simulation study of the thermal performances of the building envelope wall materials in the tropics. Sustainability, 12(12): 4892. https://doi.org/10.3390/su12124892.

[13] Moshiri S., Lechtenböhmer S., Atabi F., Knoop K., Massarrat M., Panjehshahi M.H., Prantner M., Seifried D. and Supersberger N. 2015. Sustainable energy strategy for Iran.

[14] Barbosa S. and Ip K. 2014. Perspectives of double skin façades for naturally ventilated buildings: A review. Renewable and Sustainable Energy Reviews, 40, pp. 1019-1029. https://doi.org/10.1016/j.rser.2014.07.192

[15] Asdrubali F., D'Alessandro F. and Schiavoni S., 2015. A review of unconventional sustainable building insulation materials. Sustainable Materials and Technologies, 4, pp.1-17. https://doi.org/10.1016/j.susmat.2015.05.002.

[16] Abu-Jdayil B., Mourad A.H., Hittini W., Hassan M. and Hameedi S. 2019. Traditional, state-of-the-art and renewable thermal building insulation materials: An overview. Construction and Building Materials, 214, pp. 709-735. https://doi.org/10.1016/j.conbuildmat.2019.04.102

[17] Kayri M. 2016. Predictive abilities of bayesian regularization and Levenberg–Marquardt algorithms in artificial neural networks: a comparative empirical study on social data. Mathematical and Computational Applications, 21(2): 20. https://doi.org/10.3390/mca21020020

[18] Oyedepo S.O., Babalola P.O., Nwanya S., Kilanko O.O., Leramo R.O., Aworinde A.K., Adekeye T., Oyebanji J.A., Abidakun O.A. and Agberegha O.L., 2018. Towards a sustainable electricity supply in nigeria: the role of decentralized renewable energy system. European Journal of Sustainable Development Research, 2(4). https://doi.org/10.20897/ejosdr/3908

[19] Saracoglu B.O., Ohunakin O.S., Adelekan D.S., Gill J., Atiba O.E., Okokpujie I.P. and Atayero A.A. 2018. A framework for selecting the location of very large photovoltaic solar power plants on a global/supergrid. Energy Reports, 4, pp.586-602. https://doi.org/10.1016/j.egyr.2018.09.002.

[20] Okokpujie I.P., Okonkwo U.C., Bolu C.A., Ohunakin, O.S., Agboola M.G. and Atayero A.A. 2020. Implementation of multi-criteria decision method for selection of suitable material for development of horizontal wind turbine blade for sustainable energy generation. Heliyon, 6(1): e03142. https://doi.org/10.1016/j.heliyon.2019.e03142.

[21] Ohunakin O.S. and Saracoglu B.O. 2018. A comparative study of selected multi-criteria decision-making methodologies for location selection of very large concentrated solar power plants in Nigeria. African journal of science, technology,

innovation and development, 10(5): 551-567.https://doi.org/10.1080/20421338.2018.1495305

[22] Beemkumar N., Yuvarajan D., Arulprakasajothi M., Ganesan S., Elangovan K. and Senthilkumar G. 2020. Experimental investigation and numerical modeling of room temperature control in buildings by the implementation of phase change material in the roof. Journal of Solar Energy Engineering, 142(1). https://doi.org/10.1115/1.4044564.

[23] Morsy M., Fahmy M., Elshakour H.A. and Belal A.M. 2018. Effect of thermal insulation on building thermal comfort and energy consumption in Egypt. Journal of Advanced Research in Applied Mechanics. 43(1): 8-19.

[24] Van Lith A.P., Entrop A.G. and Halman J.I.M. 2018. Assessment of the thermal performance of holistic flat roof systems of industrial buildings. Journal of Construction Engineering, 1(1): 1-17. https://doi.org/10.31462/jcemi.2018.01001017

[25] Nazir H., Batool M., Osorio F.J.B., Isaza-Ruiz M., Xu X., Vignarooban K., Phelan P. and Kannan A.M. 2019. Recent developments in phase change materials for energy storage applications: a review. International Journal of Heat and Mass Transfer, 129, pp. 491-523. https://doi.org/10.1016/j.ijheatmasstransfer.2018.09.126

[26] Okokpujie I.P., Fayomi O.S.I. and Leramo R.O. 2018, September. The role of research in economic development. In IOP Conference Series: Materials Science and Engineering (413(1): 012060). IOP Publishing. https://doi.org/10.1088/1757-899X/413/1/012060.

[27] Fayomi O.S.I., Okokpujie I.P. and Udo M. 2018, September. The role of research in attaining sustainable development goals. In IOP Conference Series: Materials Science and Engineering (413(1): 012002). IOP Publishing. https://doi.org/10.1088/1757-899X/413/1/012002.

[28] Stirna U., Beverte I., Yakushin V. and Cabulis U. 2011. Mechanical properties of rigid polyurethane foams at room and cryogenic temperatures. Journal of cellular plastics, 47(4): 337-355. https://doi.org/10.1177/0021955X11398381.