**Scholars Journal of Engineering and Technology**
Abbreviated Key Title: Sch J Eng Tech
ISSN 2347-9523 (Print) | ISSN 2321-435X (Online)
Journal homepage: https://saspublishers.com

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# Thermal Performance Compliance Analysis of Porta-Cabin Shelters Using EN ISO 13786 and EN ISO 6946

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**DOI:** 10.36347/sjet.2021.v09i10.004 | **Received:** 04.10.2021 | **Accepted:** 10.11.2021 | **Published:** 30.11.2021

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**Abstract** **Original Research Article**

Porta Cabin Shelters are temporary dwellings constructed with Sandwich Panels, and used in operational sites by Oil and Gas Firms in Nigeria and Africa. This study carried out thermal performance analysis of Standard Porta Cabin Shelters used in Nigeria Liquified Natural Gas (NLNG) operational Sites using EN ISO 13786: 2017 and ISO 6946:2017 Calculation Methods and Procedures. The Calculation results were tested against the European Building Regulations Part L for compliance. This study reveals that the Porta Cabin shelters failed the compliance test. Analysis for possible compliance was undertaken and the outcome shows that construction of the roof, ceiling and walls with insulator (Sandwich Panels with Polyurethane Foam (PUF) as core materials thickness within the range of 80mm to 120mm) comply with the provision of European Building Regulations. Further analysis shows that adding about 80mm to 110mm thickness of insulator layer to the floor thermal layers will correct the major non-compliance in the floor construction and enhance thermal comfort of the shelters.

**Keywords:** Porta Cabin Shelters, Polyurethane Foam, Oil and Gas, EN ISO 13786 and ISO 6946 method.



## 1. INTRODUCTION

Porta Cabin shelters are mobile shelters constructed with steel structure as load bearing framework and insulated sandwich panels as walls and partitions. The floors of standard porta Cabin shelters are usually constructed with steel covered with chip board and concrete flooring. Porta Cabins shelters are commonly used as offices, Control rooms and living shelters in oil and gas firm and other firms located in offshore and onshore. Porta cabin shelters are normally fitted with heat regulating devices such as Air conditioners, Water heaters and room heaters depending on the location of use. Porta cabin shelters are dwelling places; just normal buildings, therefore, their compliance with building regulatory codes especially the energy and fuel conservation code is required.

The introduction of Air conditioning systems for internal building temperature regulations comes with the issue of increasing energy consumption in buildings. As the day goes by, more dwellings and public buildings fitted with Air conditioners increases. Two problems are associated with this trend: first, the increasing power consumption and eventual cost implication and secondly, the increasing heat wastage release into the environment causing thermal pollution and disrupting the energy balance of the universe. These problems are some of the issues that propel the European Directive 2002/91/EC to introduce the concept of reducing the building energy demand in 2002. In 1999, the International Organization for standardization (ISO) published the calculation method for dynamic thermal characteristics of building in Code known as ISO 13786:1999 and thermal resistance and thermal transmittance calculation method in ISO 6946:1999. Both were approved by European Committee on Standardization (CEN). Subsequent reviews where carried out on these standards and other versions were published in 2007 known as ISO 13786:2007 and ISO 6946:2007. The 3rd edition which is the latest edition prepared by the ISO Technical Committee ISO/TC163 in collaboration with the CEN Technical Committee CEN/TC89 was published in 2017. It is known as ISO 13786:2017 and ISO 6946:2017.

The European building regulations captured the regulation of thermal performance of building in Part L of the document which covers the energy, power and fuel conservation. The LA1 of the British Building regulations which regulates the conservation of fuel and power in new dwellings was published in 2010 and the amended versions were published in 2013 and 2016 for use in England (NBS, 2016). This document regulates the thermal performance of new dwellings. In 2019, the department of Housing, planning and local Government of Ireland published their building regulations in which part L covers energy and fuel conservation for dwellings in which Thermal performance of dwellings where embedded (Government of Ireland, 2019). The United States of America and the Canadian Building Codes are heavily influenced by conservation of Energy (John, 2017). The ASHRAE Standard 90.1 published in 1975 was one of the earliest Building Energy Standard of the US adopted by many other western countries. In Canada, the National Energy Code for Building (NECB) published in 2011 and the international Energy Conservation Code (IECC) published in 2000 are the current Building Energy regulations in the country (John, 2017). Singapore and Minnesota also have building code on thermal performance of buildings currently in used (Minnesota Energy Code, 1999). While western countries are regulating the thermal performance of dwellings, African countries are yet to adopt these regulations. For instance, the Nigerian National Building Code 2006 has no provision for thermal performance of buildings (National Building Code, 2006).

There are few researches on the thermal performance of sandwich panels used for buildings. Some are reported here. Hachim and Abed (2017) carried out the thermal analysis of Light weight wall made from Sandwich panels in the aspect of thermal insulation design for sustainable built environment. They undertook a new design and analysis of sandwich panel, incorporating three layers of insulations using COMSOL Metaphysics simulation software. The result of their simulations shows a panel with similar thermal performance as that of brick wall. Alexander *et al.* (2017) carried out a research on simple thermal evaluation of building envelope containing phase change materials using modified admittance method. His proposed admittance method predicted the diurnal energy flux reduction associated with adding microencapsulated phase change materials (PCM) to building walls. However, it failed to predict accurately the transient inner wall heat flux. Li *et al*. (2014) determined the thermal mechanical behaviour of sandwich panels with closed-cell foam core under intensive laser irradiation using thermal-mechanical coupling FE models. The result of this research shows that there exists a critical thermal conductivity at which the temperature changes with conductivity switched trends.

The main objective of this research is to determine the thermal compliance of Porta cabin shelters with the European Building code part L. The calculation method reported in the English version of ISO 13786: 2017 and ISO 6946:2017 were used to determine the values of the thermal parameters of the Porta Cabin shelter. This work also investigates the conditions for compliance where non-compliance is detected. This work will provide scientific data for the firms constructing Porta cabin Shelters and the end users of the shelters.

The ISO 13786: 2017 and 6946:2017 has some terms associated with thermal performance of materials. Some of the terms are explained here.

Thermal Admittance $(Y_{mm})$: Thermal Admittance is the amount of heat released from the surface of material into the room per unit temperature variation when the temperature outside the room is constant (Rossi et al., 2014). It is a measure of heat transfer rate into or from a unit area of a material surface due to a unit change in surrounding temperature when the temperature of the other surface of the material is kept constant (its unit is W/m$^2$K). ISO 13786:2007 defined the concept as the complex amplitude of heat flow rate through the surface in thermal zone 1 of a material separating two thermal zone divided by the complex amplitude of the temperature on that same zone when the temperature of the other thermal zone, (Zone 2) is kept constant. A thermal zone is a space with negligible temperature variations. The lower the thermal admittance value, the better suited the material for building construction. Materials used to separate two thermal zones such as walls and roof of buildings has two admittance values, namely external$(Y_{22})$ and internal admittance $(Y_{11})$ values.

Thermal Time shift:$(\Delta t_y)$ Thermal time shift is the period between the maximum or peak value of thermal transfer and the maximum temperature value resulting from the transfer (Nusrat *et al.,* 2020). For instance, the Admittance time shift is the time delay between the peak thermal transfer between the material and the surrounding air space and the time of the peak temperature of the surrounding. Time shift is measured in hours (h).

Periodic Thermal Transmittance$(Y_{12})$**:** According to ISO 13786:2017, This concept is defined for a material separating two thermal zones (Zone 1 and Zone 2) as the complex amplitude of heat density flow rate through the surface of the material in thermal zone 1 divided by the complex amplitude of the temperature on Zone 2 when the temperature of Zone 1 is kept constant. It is a measure of actual heat energy flowing through a material into an enclosed space (such as inside a building) due to variation of temperature in the outside. It is a measure of the thermal load impact on the building due to external thermal forces such as the sun light irradiation on the external walls.

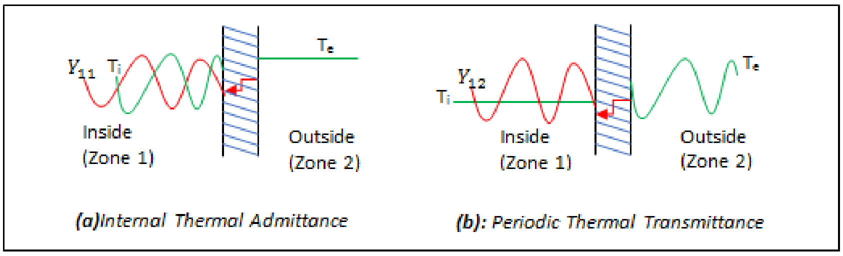


**Fig-1: Illustration of Thermal Admittance and Periodic thermal Transmittance**

Areal Heat Capacity($\kappa$): This is the heat capacity of the components or materials separating two thermal zones divided by the area of the materials (Stazi *et al*., 2018). It is the amount of heat stored in the material per unit area per unit temperature over the first half heat flow variations; the same is released in the second half of the variations. Areal heat capacity of materials determines how much heat the material will absorbed from the in-coming heat energy from the external surrounding actually passing through to the other side of the material. This can thus be described as the thermal storage capacity or thermal mass of the material. Materials used in separating thermal zones such as walls, roofs and floors have both internal($\kappa_1$) and external ($\kappa_2$) areal heat capacities. The areal heat capacity is a measure of how much heat is conducted into or from an enclosed space (Inside a building) through the materials (Wall, Roof and Floors) that enclose the space so as to cause change in temperature of the space. It is measured in KJ/m$^2$K. $\kappa_1$Determines the capacity of the building to accumulate heat in the inside and hence can be described as a measure of thermal comfort of the inside of a building (Rossi *et al*., 2014).

Thermal Resistance($R$): Thermal resistance is the property of materials or structure to resist heat flow through it. The total thermal resistance also known as R-Value of a structure is the sum of all the thermal resistances of the components layers of the structure. Its unit is m$^2$K/W.

Thermal Transmittance($U$): Thermal Transmittance is also known as the Steady State Thermal Transmittance, Overall Heat Transfer Coefficient or just U – value. This is the overall rate at which heat is transmitted through a unit area of a structure (Single Material or Composite) when there is a unit temperature difference. In calculating U-value, heat transfer due to conduction, convection and radiation are taken into account. The lower the U-value, the lower the heat loss and the better suited the material for building construction. Its unit is W/m$^2$K.

Decrement Factor($f$): This is the modulus of the ratio of periodic thermal Transmittance to the overall heat transfer coefficient.

Heat Transfer Matrix($Z$): The heat transfer matrix is a matrix relating the complex values of heat transfer rate and temperature on one thermal zone to the complex values heat transfer rate and temperature on the other thermal zone; the two thermal zones being separated by components (Building materials).

## 2. En iso 13786 and en iso 6946 specifications and the building regulations part l

EN ISO 13786:2017 is the English Version (European Standard) of the International Organization for Standardization which specifies thermal performance of building components – Dynamic thermal characteristics and Calculation Methods, while EN ISO 6946:2017 specifies Building Components and Building Elements – Thermal Resistance and Thermal Transmittance.

EN ISO 13786: 2017 specifies as follows: That the calculation procedures for assessing the thermal compliance of building should proceed as follows:

a. Identification of materials. This includes getting the thermal conductivity, specific heat capacity, density and thickness of the material layer in the structure.
b. Thermal Variations Period – The period of thermal variations shall be (i) one hour (3600 s) if temperature control system shall be installed in the building, (ii) one day (86400 s) if there is no temperature control system and daily meteorological variation is observed, (iii) one week (604800 s) for long term averaging and (iv) one year (31536000 s) for heat transfer through the ground.
c. Calculation of Penetration depth of heat wave in the building materials
d. Evaluation of the element of the heat transfer matrix
e. Determination of the thermal properties and reporting

### 2.1 Computation report shall contain

The area of the element, a list layers with layer 1 as the innermost layer for building envelope components, the value of surface resistances, the elements of heat transfer matrix, and the thermal admittances, the decrement factor, the periodic thermal transmittance, the thermal transmittance and areal heat capacity.

### 2.2 Related EN ISO 13786:2017 equations

ISO 13786: 2017 exert methods and calculation sequences are recorded in equations (11)-(26), Periodic penetration depth of heat wave in the building materials ($\delta$) is defined by equation (11) of ISO 13786:2017 as;

$$\delta = \sqrt{\frac{\lambda T}{\pi \rho c}} \quad (1)$$

$where \delta = periodic\ penetration\ depth,\ \lambda = Thermal\ Conductivity\ (W/mK), T = Period\ of\ variation\ (s)$, $\rho = density\ (Kg/m^3), c = specific\ heat\ capacity\ (KJ/KgK)$

The Ratio of the layer thickness to the penetration depth ($\xi$) is defined by equation (13) of ISO 13786:2017.

$$\xi = \frac{d}{\delta} \quad (2)$$

$$where d = thickness\ of\ layer\ (m)$$

The Heat transfer Matrix ($Z$) and its elements is defined mathematically by equation (14) of ISO 13786:2017.

$$Z = \begin{pmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{pmatrix} \quad (4)$$

$where$ ;

$$Z_{11} = Z_{22} = \cosh(\xi)\cos(\xi) + j sinh(\xi)\sin(\xi) \quad (5)$$

$$Z_{12} = \frac{\delta}{2\lambda}\{\sinh(\xi)\cos(\xi) + cosh(\xi)\sin(\xi) + j[\cosh(\xi)\sin(\xi) - \sinh(\xi)\cos(\xi)\} \quad (6)$$

$$Z_{21} = \frac{\lambda}{\delta}\{\sinh(\xi)\cos(\xi) - cosh(\xi)\sin(\xi) + j[\sinh(\xi)\cosh(\xi) + \cosh(\xi)\sin(\xi)\} \quad (7)$$

The Thermal Resistance Matrix of air ($Z_a$) and surfaces, ($Z_{s1}, Z_{s2}$) are defined by equations (15) and (18) of ISO 13786:2017.

$$Z_a = \begin{pmatrix} 1 & -R_a \\ 0 & 1 \end{pmatrix} \quad (8)$$

$$Z_{s1} = \begin{pmatrix} 1 & -R_{si} \\ 0 & 1 \end{pmatrix} \quad (9)$$

$$Z_{s2} = \begin{pmatrix} 1 & -R_{se} \\ 0 & 1 \end{pmatrix} \quad (10)$$

$$where R_a = Thermal\ Resistance\ of\ Air\ Space\ (m^2K/W),$$
$$R_{si} = Thermal\ Resistance\ of\ Internal\ Surface\ (m^2K/W),$$
$$R_{si} = Thermal\ Resistance\ of\ External\ Surface\ (m^2K/W)$$

The Heat transfer Matrix updated with Resistance ($Z_{ee}$) is defined by equations (16) and (17) of ISO 13786:2017.

$$Z_{ee} = \begin{pmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{pmatrix} = Z_{s2}Z_nZ_{n-1} \ldots Z_2Z_1Z_{s1} \quad (11)$$

The Thermal Admittance ($Y_{11}$) and ($Y_{22}$) are defined by equation (19) of ISO 13786:2007.

$$Y_{11} = \frac{Z_{11}}{Z_{12}} \quad (12)$$

$$Y_{22} = \frac{Z_{22}}{Z_{12}} \quad (13)$$

Time shift of Thermal Admittance ($\Delta t_Y$) is defined by equation (20) of ISO 13786:2007.

$$\Delta t_Y = \frac{T}{2\pi}\arg(Y_{mn});\ \text{m = 1, n = 1, 2.} \quad (14)$$

arg( 2020) is given in table C.1 of ISO 13786: 2007

$$T = Period\ of\ thermal\ variations$$

Internal and External Areal Heat Capacity ($K_1, K_2$) are defined by equations (22) and (23) of ISO 13786:2017.

$$K_1 = \frac{T}{2\pi}\left|\frac{Z_{11}-1}{Z_{12}}\right| \quad (15)$$

$$K_2 = \frac{T}{2\pi}\left|\frac{Z_{22}-1}{Z_{12}}\right| \quad (16)$$

The Periodic Thermal Transmittance ($Y_{12}$) is defined by equation (24) of ISO 13786:2017.

$$Y_{12} = \frac{1}{Z_{12}} \quad (17)$$

The Decrement Factor ($f$) is defined by equation (25) of ISO 13786:2017.

$$f = \frac{|Y_{12}|}{U_o} \quad (17)$$

$$U_o = steady\ state\ thermal\ transmittance\ without\ thermal\ bridges$$

Time shift of Periodic Thermal Transmittance ($\Delta t_f$) is defined by equation (26) of ISO 13786:2017.

$$\Delta t_Y = \frac{T}{2\pi} \arg(Z_{12}) \qquad (18)$$

$\arg(2020\ )$ is given in table C.1 of ISO 13786: 2017 for range of $-2\pi$to 0

**2.3 Related ISO 6946 equations**

The following equations were specified by ISO 6946: 2017 for calculation of thermal performance of building components.

Thermal Transmittance ($U$) is defined by equation (1) of ISO 6946:2017.

$$U = \frac{1}{R_{tot}} \qquad (19)$$

Total Thermal Resistance ($R_{tot}$) is defined by equation (4) of ISO 6946:2017.

$$R_{tot} = R_{si} + R_1 + R_2 + \ldots + R_n + R_{se} \qquad (20)$$

$where R_1, R_2 \ldots\ , R_n = design\ thermal\ resistance\ of\ each\ layer\ (m^2K/W)$

Thermal Resistance of any Layer ($R$) is defined by equation (3) of ISO 6946:2017.

$$R = \frac{d}{\lambda} \qquad (21)$$

Thermal Resistance of Roof Air Gap ($R_a$) is defined by equation (D.1 – D.4) of ISO 6946:2017.

$$R_a = \frac{1}{h_a + h_r} \qquad (22)$$

$$h_a = h_{a:90} + (h_{a:90} - h_{a:0})(\frac{\alpha - 90}{90}) \qquad (23)$$

Where; $h_{a:90} = 0.73 \times (\Delta T)^{\frac{1}{3}}$ and $h_{a:0} = 1.14 \times (\Delta T)^{\frac{1}{3}}$

$$\Delta T = T_e - T_i (24)$$

$$h_r = \varepsilon h_{ro} \qquad (25)$$

$$\in = \left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1\right)^{-1} \qquad (26)$$

Where; $\varepsilon_1 = \varepsilon_2 = 0.9$

$$h_{ro} = 4\sigma T_e{}^3\ ;\ \sigma = 5.67 \times 10^{-8} \qquad (27)$$

$where h_a = conduction/convection\ coefficient\ (W/m^2K)$

$h_r = Radiative\ Coefficient\ (W/m^2K), T_e\ = External\ Surface\ Temperature$ (°C)
$T_i\ =\ Internal\ Surface\ Temperature$ (°C), $\in = Intersurface\ emittance$ ,
$\varepsilon_1 = \varepsilon_2 =\ hemispherical\ hemissivity\ of\ the\ surfaces\ bounding\ the\ airspace$
$h_{ro} = Radiative\ Coefficient\ of\ Black - body\ surface$ ,
$\sigma = Stefan - Boltzmann\ constant\ (W/m^2K^4)$ , $\alpha = Roof\ inclination\ angle$ (°)

Thermal Resistance of External and Internal Surfaces ($R_{se}, R_{si}$) are defined by equations

(C.1 – C.6) of ISO 6946:2017.

External Surface **(**$R_{se}$**)**

$$R_{se} = \frac{1}{h_{ce} + h_r} \qquad (28)$$

$$h_{ce} = 4 + 4v \qquad (29)$$

Where; $v = velocity\ of\ air\ in\ the\ surrounding$ (m/s)

**Internal Surface ($R_{si}$)**

$$R_{si} = \frac{1}{h_{ci} + h_r} \qquad (30)$$

Where; $h_{ci} =\ 0.7$
$where h_{ce} = External\ Surface\ Convective\ Coefficient\ (W/m^2K)$,
$h_r = Radiative\ Coefficient\ (W/m^2K)$,
$h_{ci}\ = Internal\ Surface\ Convective\ Coefficient\ (W/m^2K)$

 

### 2.4 Building Regulations Part L

**a.** Part L (Conservation of Fuel and Energy – Dwellings) and the European Union (Energy Performance of Buildings (No.2)) Regulations 2019 – Technical Guidance Document, Par 1.3.2.2, Table 1 and Diagram 1 specifies the maximum thermal transmittance of building elements as follows (Government of Ireland, 2019):

1. The thermal transmittance of building roof should not exceed $0.16\,W/m^2K$ for Pitched roof and $0.2\,W/m^2K$ for Flat roof
2. The thermal transmittance of building walls should not exceed $0.18\,W/m^2K$
3. The thermal transmittance of building ground floors and other exposed floors should not exceed $0.18\,W/m^2K$
4. The thermal transmittance of building doors and windows should not exceed $1.4\,W/m^2K$

**b.** Approved Document L1A of the English Building Regulations 2013 for new dwelling, section 2.35 specifies the maximum thermal transmittance of building elements as follows (NBS, 2016):

1. The thermal transmittance of building roof should not exceed $0.20\,W/m^2K.$
2. The thermal transmittance of building walls should not exceed $0.30\,W/m^2K$
3. The thermal transmittance of building ground floors and other exposed floors should not exceed $0.25\,W/m^2K$
4. The thermal transmittance of building doors and windows should not exceed $2.0\,W/m^2K$

## 3. Thermal performance of porta cabin shelter

Standard porta cabin shelters used in oil and gas industries in Nigeria are constructed with 50 mm thick Sandwich panels walls and roofs with core materials being either Mineral wool, Polyurethane foam (PUF), Polyisocyanurate (PIR), Expanded Polystyrene (EPS) or other high-density fire-retardant insulator panel meeting material type Class B s1 d0, Class B s2 d0 and Class B s3 d0. The thermal conductivity of these materials ranges from 0.02-0.04 W/m-K.

**Fig-3: Picture of Porta Cabin Shelters Made for NLNG, Bonny**

### 3.1Calculation Procedure

The calculation procedure is based on EN ISO 13786:2017. All calculations were done in MATLAB calculation workspace with the help of Scripts written based on ISO 13786: 2017 equations (11) – (26) and ISO 6946: 2017, Equation (1) – (4), and tested using ANNEX D (D1 and D2 Examples) of ISO 13786: 2017.

### 3.2 Input Data

Data used in this study was extracted from a typical construction details of Porta Cabin Guard Shelters used in Nigeria Liquefied Natural Gas (NLNG), Bonny. The construction details and energy flow are illustrated in the sketch in Figure 3. The temperature inside ($T_i$) the shelter is set at $20^0$C because Air Conditioners are used to regulate the internal temperature to achieve the set value. The average yearly environmental Temperature ($T_e$) in Port Harcourt is $26.4^0$C (Climate-Data.org, 2020).

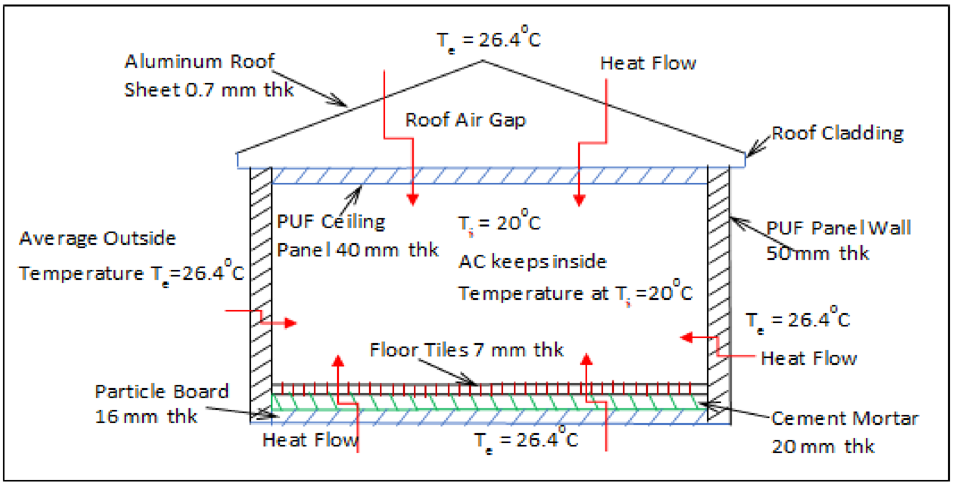


**Fig-3: A sketch showing the construction details and heat flow**

### 3.3. Input Data Used for Calculation of External Wall Heat Transmission Coefficient

The Porta Cabin walls considered in this study were constructed with Polyurethane Foam (PUF) Sandwich Panels. The panel has PUF as the middle layer of thickness 49.2 mm and the outer layers made of 0.4 mm panted RAL 9002 Galvanized Steel Sheet. Thus, we have three layers of heat transfer, layer 1 – Painted RAL 9002, Layer 2 – PUF, and Layer 3 – Painted RAL 9002.

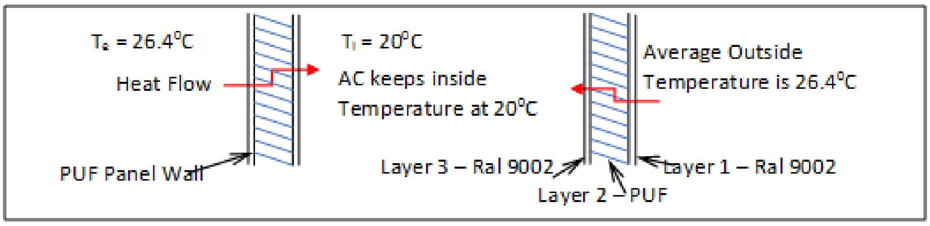


**Fig-4: A sketch showing the wall thermal layers**

**Table-1: External Wall Thermal Layers and data**

| | | | | |
|---|---|---|---|---|
| **EXTERNAL WALL** | | | | |
| **INNER LAYER (LAYER 1) – PAINTED RAL 9002 GALVANIZED STEEL SHEETS** | | | | |
| S/N | **Thermal Property** | **Value** | **Unit** | **Source** |
| 1 | Thermal Conductivity ($\lambda$) | 45 | W/mK | Izopanel (2020) |
| 2 | Specific Heat Capacity ($c$) | 480 | J/KgK | Izopanel (2020) |
| 3 | Density ($\rho$) | 7850 | $Kg/m^3$ | Izopanel (2020) |
| 4 | Thickness ($d$) | 0.4 | mm | Izopanel (2020) |
| MIDDLE LAYER (LAYER 2) – POLYURETHANE FOAM (PUF) | | | | |
| 1 | Thermal Conductivity ($\lambda$) | 0.022 | W/mK | Izopanel (2020) |
| 2 | Specific Heat Capacity ($c$) | 1000 | J/KgK | Izopanel (2020) |
| 3 | Density ($\rho$) | 40 | $Kg/m^3$ | Izopanel (2020) |
| 4 | Thickness ($d$) | 49.2 | mm | Izopanel (2020) |
| INNER LAYER (LAYER 3) – PAINTED RAL 9002 GALVANIZED STEEL SHEETS | | | | |
| 1 | Thermal Conductivity ($\lambda$) | 45 | W/mK | Izopanel (2020) |
| 2 | Specific Heat Capacity ($c$) | 480 | J/KgK | Izopanel (2020) |
| 3 | Density ($\rho$) | 7850 | $Kg/m^3$ | Izopanel (2020) |
| 4 | Thickness ($d$) | 0.4 | mm | Izopanel (2020) |

Penetration Period (T) = 1 Hour (Due to the presence of Air Conditioning System)

### 3.4Input Data Used for Calculation of Roof Heat Transmission Coefficient

The Porta Cabin roof used in this study was constructed with Aluminum roofing sheet, 0.7 mm thick, then hanging ceiling panels of thickness 40 mm made of PUF core, covered on both sides with 0.4 mm thick RAL 9002. Cladding was provided around the roof. Therefore, the construction of the roof has 5 thermal transfer layers namely; Layer 1 – RAL 9002, Layer 2 – PUF, Layer 3 - RAL 9002, Layer 4 – Air Gap between Ceiling and Roof, and Layer 5 – Aluminum roof sheet.

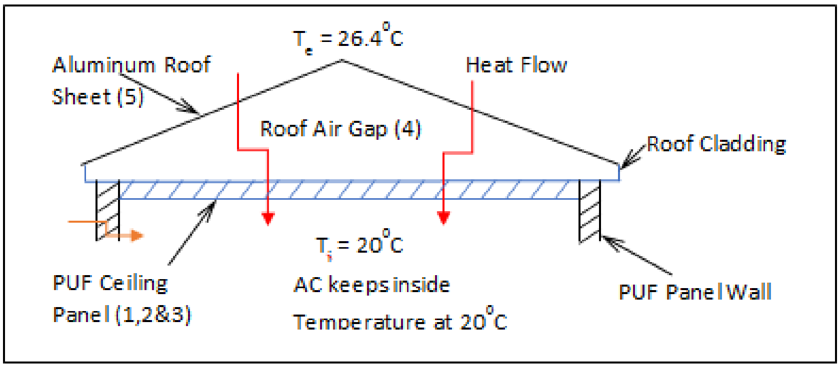


**Fig-5: A sketch showing the roof and ceiling thermal layers**

**Table-2: Porta Cabin Roof Thermal Layers and data**

| **CEILING** | | | | |
|---|---|---|---|---|
| **INNER LAYER (LAYER 1) – PAINTED RAL 9002 GALVANIZED STEEL SHEETS** | | | | |
| S/N | **Thermal Property** | **Value** | **Unit** | **Source** |
| 1 | Thermal Conductivity ($\lambda$) | 45 | W/mK | Izopanel (2020) |
| 2 | Specific Heat Capacity ($c$) | 480 | J/KgK | Izopanel (2020) |
| 3 | Density ($\rho$) | 7850 | Kg/m$^3$ | Izopanel (2020) |
| 4 | Thickness ($d$) | 0.4 | mm | Izopanel (2020) |
| MIDDLE LAYER (LAYER 2) – POLYURETHANE FOAM (PUF) | | | | |
| 1 | Thermal Conductivity ($\lambda$) | 0.022 | W/mK | Izopanel (2020) |
| 2 | Specific Heat Capacity ($c$) | 1000 | J/KgK | Izopanel (2020) |
| 3 | Density ($\rho$) | 40 | Kg/m$^3$ | Izopanel (2020) |
| 4 | Thickness ($d$) | 40 | mm | Izopanel (2020) |
| INNER LAYER (LAYER 3) – PAINTED RAL 9002 GALVANIZED STEEL SHEETS | | | | |
| 1 | Thermal Conductivity ($\lambda$) | 45 | W/mK | Izopanel (2020) |
| 2 | Specific Heat Capacity ($c$) | 480 | J/KgK | Izopanel (2020) |
| 3 | Density ($\rho$) | 7850 | Kg/m$^3$ | Izopanel (2020) |
| 4 | Thickness ($d$) | 0.4 | mm | Izopanel (2020) |
| ROOF AIR GAP WITH CLADING THERMAL RESISTANCE (LAYER 4) | | | | |
| 1 | Roof Air Gap Resistance (Ra) | Calculated | mK/W | ISO 6946 |
| ALUMINIUM ROOFING SHEET (LAYER 5) | | | | |
| 1 | Thermal Conductivity ($\lambda$) | 205 | W/mK | Ashiru (2011) |
| 2 | Specific Heat Capacity ($c$) | 900 | J/KgK | Ashiru (2011) |
| 3 | Density ($\rho$) | 2700 | Kg/m$^3$ | Ashiru (2011) |
| 4 | Thickness ($d$) | 0.7 | mm | Ashiru (2011) |

### 3.5 Input Data Used for Calculation of Floor Heat Transmission Coefficient

The Porta Cabin floor used in this study was constructed with 16 mm Particle Wooden Board, then, cover with tiles after 20 mm thick Cement Mortar covers. Thus, we have three layers of heat transfer on the floor, namely, layer 1 – tiles, Layer 2 – Concrete, and Layer 3 – Particle Board.

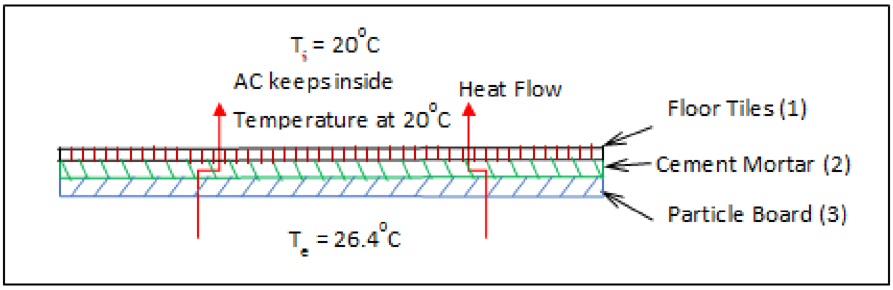


**Fig-6: A sketch showing the floor thermal layers**

**Table -3: Porta Cabin Floor Thermal Layers and data**

| FLOOR | | | | |
|---|---|---|---|---|
| INNER LAYER (LAYER 1) – FLOOR TILES | | | | |
| S/N | **Thermal Property** | **Value** | **Unit** | **Source** |
| 1 | Thermal Conductivity ($\lambda$) | 0.55 | W/mK | Ashiru (2011) |
| 2 | Specific Heat Capacity ($c$) | 837 | J/KgK | Ashiru (2011) |
| 3 | Density ($\rho$) | 1900 | $Kg/m^3$ | Ashiru (2011) |
| 4 | Thickness ($d$) | 6 | mm | Ashiru (2011) |
| MIDDLE LAYER (LAYER 2) – CEMENT MOTAR | | | | |
| 1 | Thermal Conductivity ($\lambda$) | 1.8 | W/mK | ISO 13786 |
| 2 | Specific Heat Capacity ($c$) | 1000 | J/KgK | ISO 13786 |
| 3 | Density ($\rho$) | 2400 | $Kg/m^3$ | ISO 13786 |
| 4 | Thickness ($d$) | 20 | mm | |
| INNER LAYER (LAYER 3) – 16mm PARTICLE BOARD | | | | |
| 1 | Thermal Conductivity ($\lambda$) | 0.067 | W/mK | Ashiru (2011) |
| 2 | Specific Heat Capacity ($c$) | 432 | J/KgK | Ashiru (2011) |
| 3 | Density ($\rho$) | 1260 | $Kg/m^3$ | Ashiru (2011) |
| 4 | Thickness ($d$) | 16 | mm | Ashiru (2011) |

## 4. CALCULATION RESULTS

ISO 13786: 2017 specify in Section 8 that calculation reports should include heat transfer matrix (Z) and the calculated thermal properties, which include Thermal Admittance, Periodic Thermal transmittance, Areal Heat Capacity (K), and Thermal transmittance (U).

### 4.1. Calculation Results of External Wall Heat Transmission Coefficient

#### 4.1.1 Heat Transfer Matrix

**Table-4: Wall Heat Transfer Matrix**

| S/N | PARAMETER | MODULUS | UNIT |
|---|---|---|---|
| 1 | Z11 | 10.5395 | - |
| 2 | Z12 | 3.7081 | $W/m^2K$ |
| 3 | Z21 | 37.5921 | $m^2K/W$ |
| 4 | Z22 | 13.2922 | - |

#### 4.1.2 Thermal Properties

**Table-5: Wall Thermal Property Value**

| S/N | THERMAL PROPERTY | MODULUS/UNIT | TIME SHIFT (MIN) |
|---|---|---|---|
| 1 | Internal Thermal Admittance | 2.8423 $W/m^2K$ | 8.3581 |
| 2 | External Thermal Admittance | 3.5846 $W/m^2K$ | 12.4813 |
| 3 | Periodic Thermal Transmittance | 0.2697 $W/m^2K$ | -44.2194 |
| 4 | Areal Heat Capacity -Internal ($K_1$) | 1.7571 $KJ/m^2K$ | - |
| 5 | Areal Heat Capacity -External ($K_2$) | 2.2060 $KJ/m^2K$ | - |
| 6 | Thermal Transmittance (U) | 0.4156 $W/m^2K$ | - |
| 7 | Decrement Factor | 0.6489 | - |

### 4.2. Calculation Results of Roof Heat Transmission Coefficient

#### 4.2.1Heat Transfer Matrix

**Table-6: Roof Heat Transfer Matrix**

| S/N | PARAMETER | MODULUS | UNIT |
|---|---|---|---|
| 1 | Z11 | 12.8300 | - |
| 2 | Z12 | 4.2245 | $W/m^2K$ |
| 3 | Z21 | 50.2407 | $m^2K/W$ |
| 4 | Z22 | 16.9982 | - |

#### 4.2.2 Thermal Properties

**Table-7: Roof Thermal Property Value**

| S/N | THERMAL PROPERTY | MODULUS/UNIT | TIME SHIFT (MIN) |
|---|---|---|---|
| 1 | Internal Thermal Admittance | 3.0370 $W/m^2K$ | 7.8793 |
| 2 | External Thermal Admittance | 4.0237 $W/m^2K$ | 11.7903 |
| 3 | Periodic Thermal Transmittance | 0.2367 $W/m^2K$ | -10.4753 |
| 4 | Areal Heat Capacity -Internal ($K_1$) | 1.8711 $KJ/m^2K$ | - |
| 5 | Areal Heat Capacity -External ($K_2$) | 2.4398 $KJ/m^2K$ | - |
| 6 | Thermal Transmittance (U) | 0.4134 $W/m^2K$ | - |
| 7 | Decrement Factor | 0.5726 | - |

### 4.3 Calculation Results of Floor Heat Transmission Coefficient

#### 4.3.1 Heat Transfer Matrix

**Table-8: Floor Heat Transfer Matrix**

| S/N | PARAMETER | MODULUS | UNIT |
|---|---|---|---|
| 1 | Z11 | 152.4544 | - |
| 2 | Z12 | 26.5710 | $W/m^2K$ |
| 3 | Z21 | 0.0012 | $m^2K/W$ |
| 4 | Z22 | 209.5906 | - |

#### 4.3.2 Thermal Properties

**Table-9: Floor Thermal Property Value**

| S/N | THERMAL PROPERTY | MODULUS/UNIT | TIME SHIFT (MIN) |
|---|---|---|---|
| 1 | Internal Thermal Admittance | 5.7376 $W/m^2K$ | 0.5977 |
| 2 | External Thermal Admittance | 7.8880 $W/m^2K$ | 7.4738 |
| 3 | Periodic Thermal Transmittance | 0.0376 $W/m^2K$ | 7.8076 |
| 4 | Areal Heat Capacity -Internal ($K_1$) | 3.3012 $KJ/m^2K$ | - |
| 5 | Areal Heat Capacity -External ($K_2$) | 4.5189 $KJ/m^2K$ | - |
| 6 | Thermal Transmittance (U) | 2.3224 $W/m^2K$ | - |
| 7 | Decrement Factor | 0.0162 | - |

## 4.4. DISCUSSION OF CALCULATION RESULTS

The calculation results show that the present construction of Porta Cabin shelter used in Nigerian Oil and Gas firms does not comply with the Part L of European Union Building Regulations 2019 and Approved Document L1A of the English Building regulations 2013. To remedy the non-compliance, further analysis was undertaken in this study to determine the element that should be altered. Analysis for possible compliance of porta cabin shelter. Possible compliance where determined by plotting the thermal parameters over a range of thickness of the layers of the roof, wall and floor components. Plotting the thermal parameters gives us insight on the thermal performances of the components of the Porta-Cabin shelter and how it affects energy conservation of the Porta Cabin as a dwelling place.

#### 4.4.1. Effect of thickness of the ceiling layer on Thermal Performance of Porta Cabin Shelter

Varying the thickness of the PUF ceiling board, the following plots where obtained. From Fig 7, the compliant thickness of the PUF ceiling layer was obtained to be 120mm and 100mm respectively for the Part L of European Union Building Regulations 2019 and Approved Document L1A of the English Building regulations 2013. Fig 8 and Fig 10 show that the internal areal heat capacity and the internal admittance were both minimum at 100mm thickness of ceiling layer. Minimum value of internal areal heat capacity translates to minimum release and accumulation of heat in the shelter, thereby economizing the energy consumption of the Air Conditioner used in the shelter and enhances indoor comfort. Fig 8 shows a higher K values at thickness lower than 70 mm and construction within this range should be regarded and major non-compliant structures as heat buildup within the shelter will pose more load on the Air conditioner leading to high energy losses. Lower values of the internal admittance can be interpreted to mean lower release of heat into room at any constant outside temperature, this also favoured energy conservation which is the main aim of the Part L of the Building regulations. Fig 9 shows a near zero periodic thermal transmittance which translates to reduced external heat load. Thus, the ceiling layer thickness range of 100 mm to 120 mm will minimize energy losses in any thermal regulating equipment (such as Air Conditioners) used in the porta Cabin shelter.

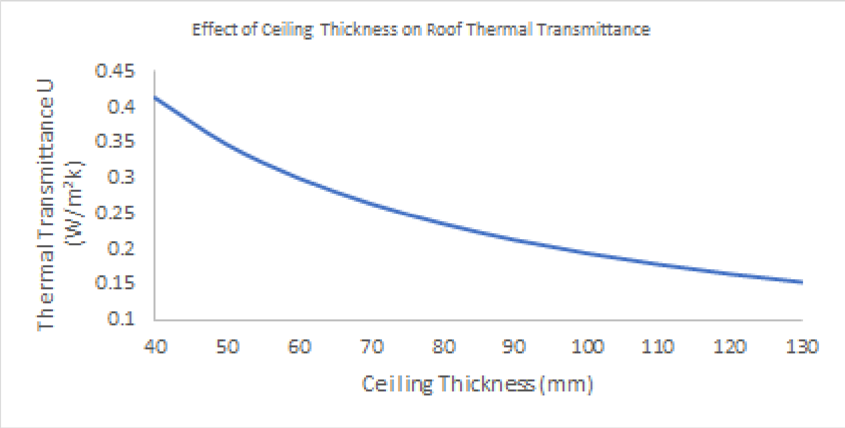


**Fig-7: Effect of Ceiling Layer Thickness on Roof Thermal Transmittance**

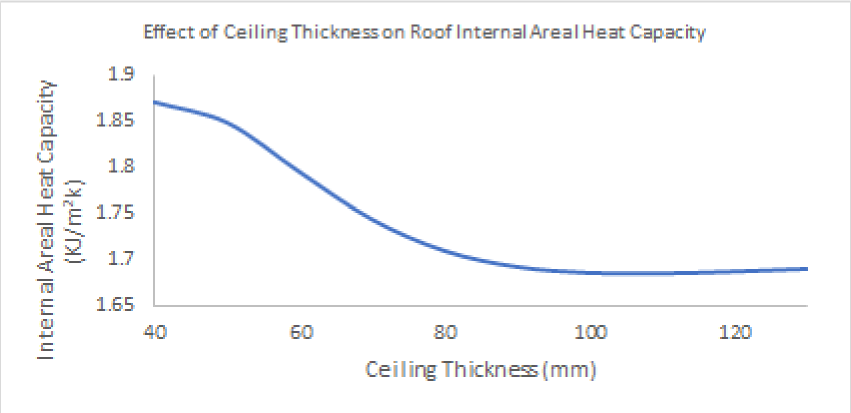


**Fig-8: Effect of Ceiling Layer Thickness on Roof Areal Heat Capacity**

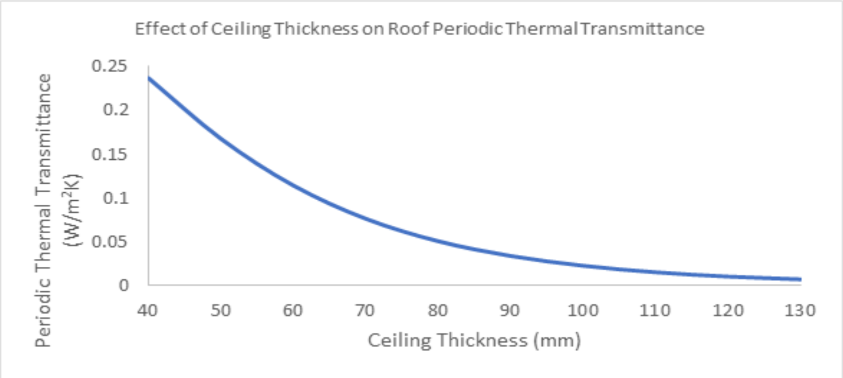


**Fig-9: Effect of Ceiling Layer Thickness on Roof Periodic Thermal Transmittance**

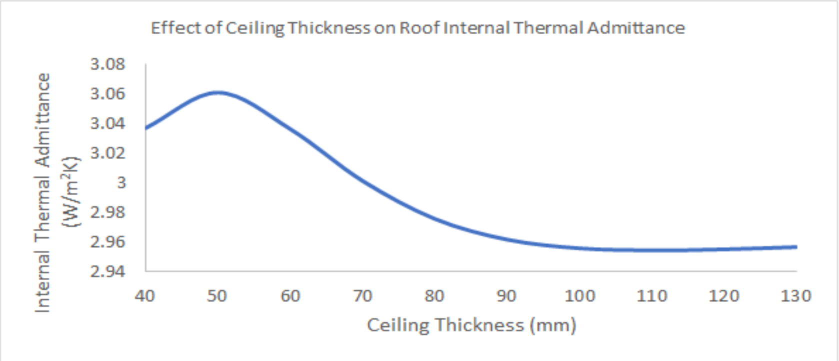


**Fig-10: Effect of Ceiling Layer Thickness on Roof Thermal Admittance**

**4.4.2 Effect of External Wall thickness on Thermal Performance of Porta Cabin Shelter**

To determine the effect of wall thickness, the thickness of the PUF wall layer was varied from 40mm to 130mm and the results plotted. From Fig 11, the thickness of the PUF external wall layer that comply with regulations considered in this work were found to be 120 mm and 72 mm respectively for the Part L of European Union Building Regulations 2019 and Approved Document L1A of the English Building regulations 2013. Fig 12 and Fig 14 show that the internal areal heat capacity and the internal admittance have lower values at 80mm to 130mm thickness of wall layer. These lower values show that constructions within this layer thickness will amount to economizing the energy consumption of the heat exchangers used in the shelter. The internal admittance shows uniform values from 80 mm to 130mm meaning that increase in the thickness beyond 80mm has no effect on the heat admitted into the shelter at any temperature fluctuation. To economize energy and materials, 80 mm to 100mm thickness of the PUF wall layer is recommended. Fig 13 shows periodic thermal transmittance of values less than 0.1 $W/m^2K$ for the range of wall layer thickness greater than 76 mm, Thus, the wall layer thickness equal or greater than 76mm (80 mm recommended) will minimize energy losses in any thermal regulating equipment used in the porta Cabin shelter.

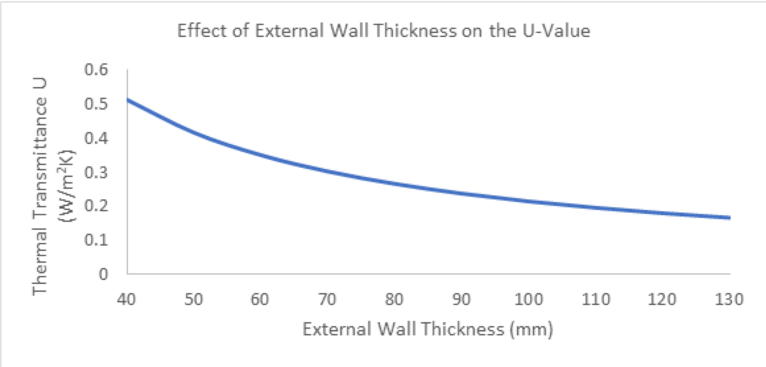


**Fig-11: Effect of Wall Layer Thickness on Wall Thermal Transmittance**

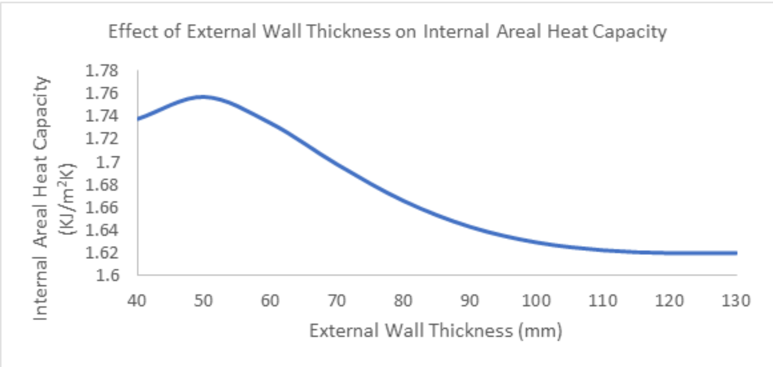


**Fig-12: Effect of Wall Layer Thickness on Wall Areal Heat Capacity**

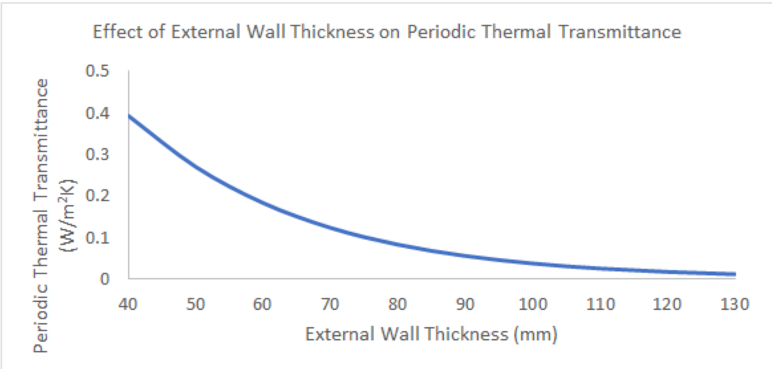


**Fig-13: Effect of Wall Layer Thickness on Wall Periodic Thermal Transmittance**

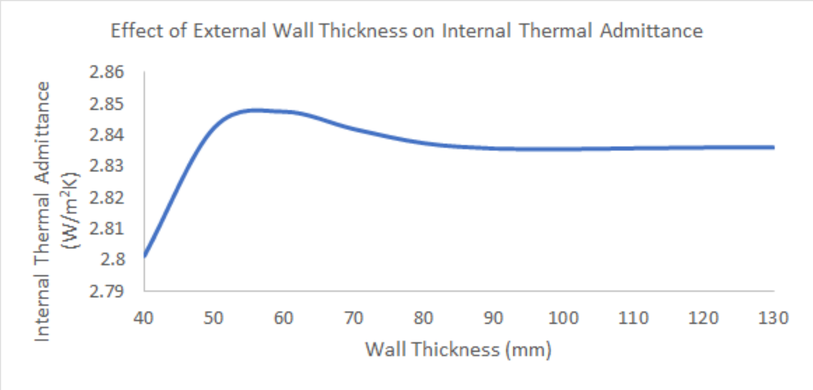


**Fig-14: Effect of Wall Layer Thickness on Wall Thermal Admittance**

**4.4.3 Remedy to the Major Non-compliance in the Floor Construction of Porta Cabin Shelter**

The calculation results show major non-compliance in the floor construction with regard to the Part L of European Union Building Regulations 2019 and Approved Document L1A of the English Building regulations 2013. A value of 2.3224 $W/m^2K$ was obtained against the required 0.18 $W/m^2K$ and 0.25 $W/m^2K$ of Part L of European Union Building Regulations 2019 and Approved Document L1A of the English Building regulations 2013 respectively. Increasing the thickness of the mortar layer and particle board layer never yield any better result. Therefore, to remedy this non-compliance, we adopt an alternative construction method.

The alternative construction of Porta Cabin floor should have four layers with PUF panel occupying the outmost layer of 50 mm thickness, then, followed with 16 mm Particle Wooden Board, cover with tiles after 20 mm thick Cement Mortar cover. Thus, we have four layers of heat transfer on the floor, namely, layer 1 – tiles, Layer 2 – Concrete, Layer 3 – Particle Board, and Layer 4 – PUF. The PUF should not be a load bearing layer, rather, it should be slotted into already prepared and coupled steel structure of 500mm x 500mm. The steel structures provide support to the PUF panel and bear the load of the floor as well as the entire structure.

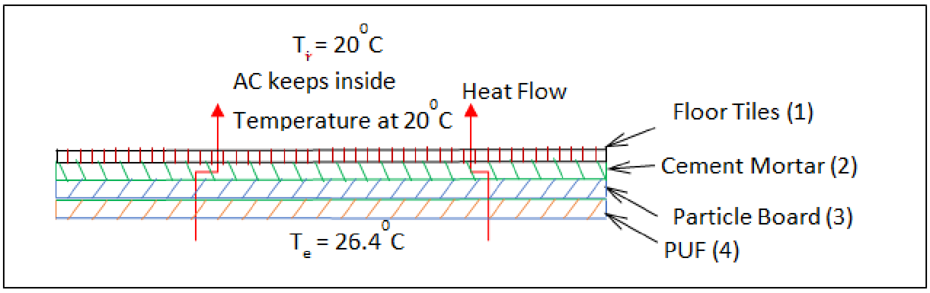


**Fig-15: A Sketch of modified Floor Construction and thermal layers**

Running a compliance test calculation on the proposed construction method with the thickness of PUF layer as 50mm gives the results on the thermal performance of the Porta-Cabin floor in the table below. Though there is still a minor non-compliance, varying the thickness of the PUF from 40mm to 130mm and plotting the result as in Fig 16, 17 and 18, the compliant thickness of the PUF layer was obtained to be 110mm and 80mm respectively for the Part L of European Union Building Regulations 2019 and Approved Document L1A of the English Building regulations 2013.

**Table-10: Floor Thermal Property Value of Alternative Construction**

| S/N | THERMAL PROPERTY | MODULUS/UNIT | TIME SHIFT (MIN) |
|---|---|---|---|
| 1 | Internal Thermal Admittance | 5.7364 $W/m^2K$ | 0.5970 |
| 2 | External Thermal Admittance | 1.2069 $W/m^2K$ | 7.6243 |
| 3 | Periodic Thermal Transmittance | 0.0083 $W/m^2K$ | 10.6888 |
| 4 | Areal Heat Capacity -Internal ($K_1$) | 3.2886 $KJ/m^2K$ | - |
| 5 | Areal Heat Capacity -External ($K_2$) | 0.6899 $KJ/m^2K$ | - |
| 6 | Thermal Transmittance (U) | 0.3750 $W/m^2K$ | - |
| 7 | Decrement Factor | 0.0222 | - |

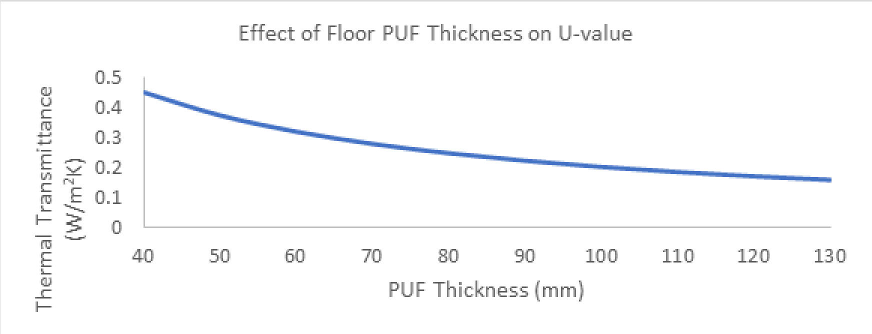


**Fig-16: Effect of Floor PUF Layer Thickness on Floor Thermal Transmittance**

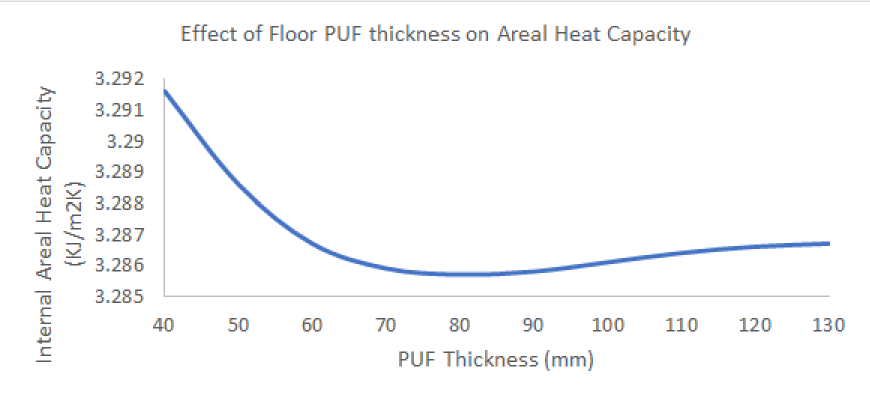


**Fig-17: Effect of Floor PUF Layer Thickness on Floor Areal Heat Capacity**

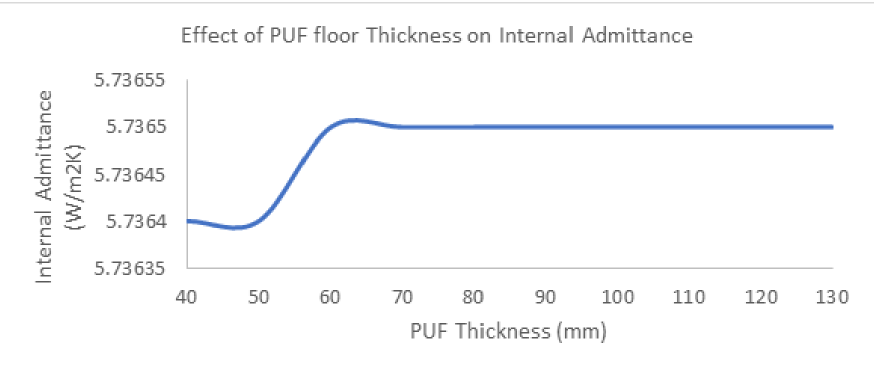


**Fig-18: Effect of Floor PUF Layer Thickness on Floor Thermal Admittance**

## 5. CONCLUSION

The thermal compliance and comfort of a porta cabin shelter were analyzed employing the calculation methods and procedures specified by ISO 13786:2017 and ISO 6946:2017. The calculations results were compared with the provisions of Part L of European Union Building Regulations 2019 and Approved Document L1A of the English Building regulations 2013 were used for compliance. The flowing conclusions were drawn from the analysis:

1. The Porta Cabin shelters used in Nigerian industries were non-compliant with the provisions of the Part L of the European Building Regulations.
2. Minor Non-compliance was discovered in the roof and wall constructions and major non-compliance was found in the construction of the floor.
3. The thickness of ceiling layer that comply with the provisions of the Part L of the European Building Regulations were found to be within the range of 100mm and 120mm respectively; and the wall thickness was found to be within 72mm and 100mm respectively for the Approved Document L1A of the English Building regulations 2013 and the Part L of European Union Regulations 2019.
4. Further analysis shows that adding about 80mm to 110mm thickness of insulator layer to the floor thermal layers will correct the major non-compliance in the floor construction and enhance thermal comfort of the shelters.
5. The recommended floor construction has the thickness of PUF layer that is compliant with the Part L of the European Building Regulations are 80mm and 110mm respectively for the Approved

Document L1A of the English Building regulations 2013 and the Part L of European Union Regulations 2019.

Summarily, thickness of PUF layers equal or greater than 120mm in any part of the Porta Cabin shelter will make the construction of the shelter to be compliant with the provisions of Part L of European Union Regulations 2019 and thickness of PUF layers equal or greater than 100mm will make the construction of the shelter to be compliant with Approved Document L1A of the English Building regulations 2013. The analysis of thermal admittance and internal area capacity which is measure of thermal comfort shows that thermal comfort can secure at less cost and reduced thermal pollution if Port Cabin Shelters are constructed with insulation layer thickness in the range of 80mm to 120mm.This research is of great importance to oil and gas industries and other industries that manufacture or use Porta Cabin shelters as dwellings and offices.

**Declaration of Conflicting Interests**

The authors declare that there is no potential conflict of interest with respect to the research, authorship, and/or publication of this article.

**Funding**

The authors received no financial support for the research, authorship, and/or publication of this article.

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