Malaysian Journal of Sustainable Environment
Vol.9.No.2 (2022) 1-20
doi: 10.24191/myse.v9i2.18825

ENERGY EFFICIENCY IN BUILDING AN ANALYSIS STUDY OF K-VALUE AND U-VALUE APPLICATION THROUGH GREEN BUILDING MATERIAL

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Received: 10 November 2021
Accepted: 9 December 2021
Published: 31 August 2022

ABSTRACT

The increasing energy consumption can have a long term effect in building. If it is not well managed, it can lead to a huge impact especially on costs due to energy wastage. There will be various problems when the use of energy efficiency is ignored, among them are wasteful use of energy in buildings from unplanned energy consumption costs, increase the cost of electricity thus giving a high impact on the cost of services. Most of the designers often ignore the basic requirements in building design, particularly in the selection of construction materials that do not suit with the local climate. Building always received a lot of heat because the construction of the wall surface do not use environmentally friendly materials which can absorb heat during the day. Therefore the objective of this research is to investigate alternative building materials as environmentally friendly building materials that can prevent the entry of high intensity heat into the building. This research is done through the study of k-value and U-Value of the material. This research is conducted by using The Hilton B480 Thermal Conductivity of Building & Insulating Materials Unit equipment based on International Standard for Steady State Measurement, ISO8301. From this study, it is *found that Brickool is a new alternative to green building material that is environmentally friendly and able to give an impact on the use of energy efficiency in building. Brickool has low thermal conductivity and a high insulation rate when compared with other conventional building materials.*

Keywords: *Energy Efficiency, Green Material, k-Value, U-Value*

INTRODUCTION

The wall of a building is the exterior finish or shade which functions as the main protection in reducing the absorption of heat from the sun into the building. Many materials can be used to construct walls for example concrete, clay brick, sand block, block, glass and so forth. Conventionally, concrete and bricks are the main materials for constructing walls in this country.

Concrete wall has a natural property of absorbing high amount of heat during daytime and releasing a high amount of heat during the night. This means that concrete has a low level of heat resistance. In the physics of thermal conductivity, the k-value of concrete is 1.0 – 1.8 W/m/K, where the k-value of concrete is high as compared to wood where its k-value is 0.15 – 0.17 W/m/K (Engineering ToolBox, 2003). This means that wood is a material of high heat resistance. Therefore, it is important to find a construction material that is suitable to the needs and climate of Malaysia which is hot and damp all year, where the walls will be exposed to sun radiation all day.

In the construction industry, heat resistance on walls is in the R-value (thermal resistance) in unit $K.m^2/W$ and the u-value (thermal transmittance) is in unit $W/K.m^2$. The R-value is an inverse to the U-value, where $R = 1/U$. The u-value is obtained depending on the wall thickness where $U = k/d$, d being the thickness (depth) of the wall and k is the k-value for that particular material (Irish Energy Centre, 2008). Besides that, the amount of heat absorption during daytime can be reduced by using finishes or materials that have good heat resistivity. Finishes with good resistivity help reduce the heat gain into the building. There are various finishes that have good heat resistivity including gypsum, perlite, and mineral wool among others (Roymech, 2013). Plastics have different characteristics where they are lightweight, and diverse in colour and shape. However, plastics are not the main material for building envelope. They may only be used as a form of finish.

Glass is widely used in our country. Most new buildings make use of glass facades. Glass actually has a high heat transmittance rate when used as a building envelope. Therefore, they will usually be layered with solar screen. This solar screen is used to avoid a high heat absorption into the inside of the building.

PROBLEM STATEMENT

Currently, global warming is becoming more serious as a result of the ozone layer depletion. High temperature from the surroundings affects internal temperature of the building due to excessive heat transferred into the building. This resulted in high energy consumption where air conditioner is forced to work harder by relying on compressor for heat exchange. As a result, utility cost increases and this may burden the occupants.

In addition, most of the air conditioners that are available in the market are non-green air conditioner. As most people can only afford to purchase cheaper air conditioners, the utilization of this type of air conditioner is popular. The use of non-green air conditioning system will cause an adverse effect to our environment as CFC gas may deplete the ozone layer. The use of green construction material especially for the building's walls that receive the most sunlight and heat absorption into the building is very timely and encouraged.

Building envelope is a critical component of a building as it plays an important role in protecting the buildings and the occupants in them. It is also a building component that protects the building from cold or hot weather, depending on the local climate. A building envelope consists of the exterior wall, roof, door, and window (MS 1525: 2007). Moreover, a building envelope controls the heat movement between the building's exterior surfaces to the interior surface.

In addition, it consists of structural elements and the enclosed space that separates the outdoor area from the indoor area of that particular building (Quorum Magazine, 2008). A good building envelope has to be able to balance temperature, thermal heat, and moisture between day and night time (Watt B, 1999). Therefore, the performance of the building envelope is important in increasing the thermal comfort and energy efficiency of the building.

The materials selection has to take into consideration the local climate in order to achieve a satisfactory building envelope besides prioritizing important factors which are safety, durability, and cost. Every building envelope may be made from different materials, suitable for the location it is used in. This research on building envelope is carried out based on the energy efficiency aspects with relation to steps in minimizing energy usage in the building and indirectly minimizing the introduction of heat into the building.

CONSTRUCTION MATERIAL AND U-VALUE

The conservation of natural resources, reduction of greenhouse gas emissions and protection of the environment have become important issues in modern construction development. These factors have urged the construction industry to shift their production methods toward sustainable models. To achieve this objective all stakeholders and parties involved should be encouraged to be creative and efficient in their use of materials. The careful design of appropriate eco-friendly building materials has an important role in helping builders or stakeholders to start integrating sustainable design concepts (Brenda & Vale, 1991).

However, price is still the primary consideration in selecting construction materials because it influences the profit of construction companies. This research seeks to explore the ways in which the quality of building materials can be improved with consideration to sustainability. Building material selection for its envelope is crucial to avoid excessive heat intrusion into the building. The needs and understanding towards heat flow through material is a must to match the building with the local climate. For the all-year hot and humid climate in Malaysia, materials that have high heat resistance is necessary to protect the building from excessive heat intensity.

Therefore, the thermal conductivity through material or better known as the k-value must be understood. Failure of the building designers in using suitable materials may result in faster heat introduction into the building. The k-value of insulation materials is the important property that is of interest when considering thermal performance and energy conservations measures (Adel A. Abdou & Ismail M Budaiwi, 2005). ASTM standards C168-97, define k-value (unit: W/mK) as the time rate of steady state heat flow through a unit area of homogeneous material induced by unit temperature gradient in a direction perpendicular to that area (ASTMC168-97, 1997). The physics of thermal conductivity or k-value is the ability of the material to conduct heat. There may be two situations when a certain temperature is introduced to a material (Wakefield-vette, 2016):

i.Heat sink (high thermal conductivity)
ii.Heat resistance (low thermal conductivity)

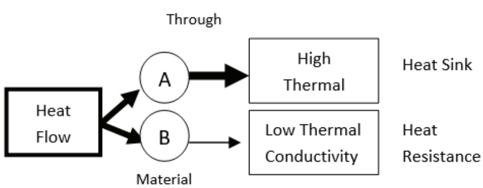


Figure **Heat Sink and Heat Resistance**

Source: Authors

Figure 1 shows the comparison of thermal conductivity between heat sink and heat resistance. Heat flows at a faster rate should a certain temperature be introduced to Material A, where the thermal conductivity rate is high. On the other hand, when heat of a certain temperature is introduced to Material B which is of low thermal conductivity, heat flows slower. This shows that Material B has a higher thermal resistance as compared to Material A. Therefore, it is known that a lower k-value means the material has a higher thermal resistance towards heat.

The better the quality of heat acquisition prevention, the better its resistive value (Darling D, 2007). It is preferable to have a low u-value in hot climates because it can substantially bring down the heat gain and hence the cooling load (M M Vijayalakshmi et, 2006). In the construction industry, suitable material selection for heat resistance is necessary to avoid heat introduction into the building. Usually, the R-value (thermal resistivity) unit: Km^2/W and U-value (thermal transmittance) unit: W/m^2K are used to calculate the rate of heat flow into the building (ASTMC168-97, 1997). For a wall of the building, the R-value is obtained when the thickness of materials and their k-values are available. This is because the R-value is:

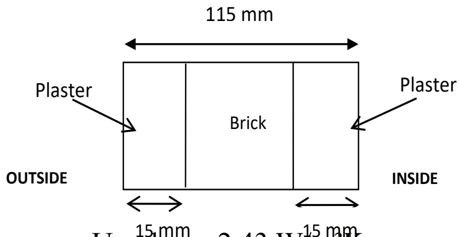
$$R = \frac{d}{k}$$

Where R = thermal resistivity Km^2/W
d= material thickness, in m
k= k-value, in W/mK

This means that the R-value of the wall is related to the thickness and k-value of the material. When the R-value is high, the thermal resistivity is better, or the prevention of heat introduction is working. The R-value is also related to U-value because the R-value is a reciprocal of the u-value:

$$R = \frac{1}{U} \text{ @ } U = \frac{1}{R}$$

The U-value is already known to be the reciprocal of R-value, where it is influenced by the thickness and k-value of the materials used. Thickness and k-value of the material will increase or decrease the U-value. The suggested limits for the U-values for walls and roofs of buildings in the warm climate countries are between 2.0 to 2.8 W/m^2K and 0.7 to 1.1 W/m^2K respectively (Anas Zafirol Abdullah Halim, 2006). Figure 2 shown in Malaysia usually, for a brick wall of 115mm thickness, the 15mm layer of plaster on the inside and outside each have a U-value of 2.43 W/m^2K (Anas Zafirol A H & Al-Hafzan A H, 2010).



U-value = 2.43 W/m²K

Figure 2. Typical U-value in Malaysia

Source: Authors

Therefore, it is necessary to reduce the U-value to produce a good and effective heat prevention (Rousseau D, 1999). Selection of building material with low k-value and high wall thickness will influence the u-value. The U-value equation is as follows:

$$U = \frac{1}{R_t}$$

$$R_t = R_o + \frac{d1}{k1} + \frac{d2}{k2} + \ldots\frac{dn}{kn} + R_i$$

Where

U= thermal transm

Ro= thermal resistivity of air outside, in Km²/W

Ri= thermal resistivity of air inside, in Km²/W

d= material thickness, in m

k= thermal conductivity (k-value), in W/mK

METHODOLOGY

The Hilton B480 Thermal Conductivity of Buildings & Insulating Materials Unit shown in Figure 3 was used to measure the thermal conductivity of the different manufactured specimens. The apparatus consists mainly of an insulated fiberglass hinged enclosure. The base section of the closure contains the heat flow meter and the cold plate assembly and mounted on four springs.

The plate is cooled with water to maintain it at a constant temperature. The enclosure lid houses the electrically heated hot plate, which is electronically controlled for setting the required temperature. A computerized system is used to determine and display the measured values of thermal conductivity. The faces of the enclosure are insulated to ensure adiabatic boundary condition and to ensure that all faces of the specimen are not in direct contact with the hot and the cold plates.

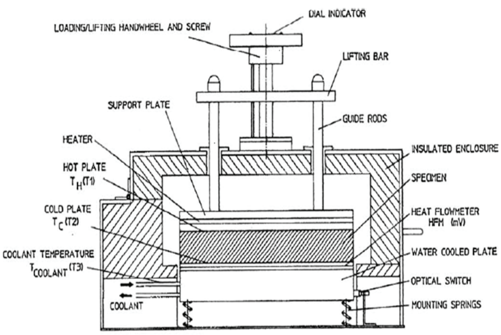


Figure 3. Cross-Sectional Diagram of the B480 Heat Flow Meter Apparatus (P.A. Hilton Ltd.).

Source: P.A Hilton LTD

Equipment: The Hilton B480 Thermal Conductivity of Buildings & Insulating Materials Unit. Test Standard: International Standard for Steady State Measurement, ISO 8301. For determination of the thermal conductivity, the specimen of 16.5mm is positioned between the hot and the cold plates and adjusted until the test position lamp illuminates to denote that the correct pressure has been applied. The determination of the thermal conductivity of the specimen requires the measurement of the following four parameters:

• The hot plate temperature TH, is set at 45°C

• The cold plate temperature TC in °C
• The heat flow meter (HFM) output in (mV)

The values of TH, TC and the heat flow meter output are taken after the steady state condition has been reached. This state is reached when the difference in five consecutive readings at sampling interval give values of thermal resistance to within (1%) without changing monotonically in one direction. The sampling interval is stated in, ISO8301, as ts=ρ.Cs. Ls. R or 300 s, whichever is the greatest, where ρ is the density in (kg/m3), Cs specific heat in (J/kg.K), Ls the thickness in (m) and R is thermal resistance in (m^2.k/W) of the specimen.

The k-value is calculated based on the Eq. 1 below:

$$k = \frac{t \times [(k1 + (k2 \times Tave)) + (k3 + (k4 \times Tave)) \times HFM + (k5 + (k6 \times Tave)) \times HFM^2}{dT} \quad \text{.........Eq. 1}$$

t is thickness,
Tave= (T2+T1)/2
dT= T1-T2
k1= -12.0723
k2= 0.0849
k3= 2.0949
k4= 0.0048
k5= 0.0022
k6= 0.0001

RESULT AND ANALYSIS

Table 1. Steady State Data

Time (min)	k-value	% different
130	0.227326	0.93721
135	0.226735	0.26086
140	0.224758	0.87945
145	0.223184	0.70502
150	0.223658	0.21176

155	0.225236	0.70044
160	0.225714	0.21175

Source: Authors

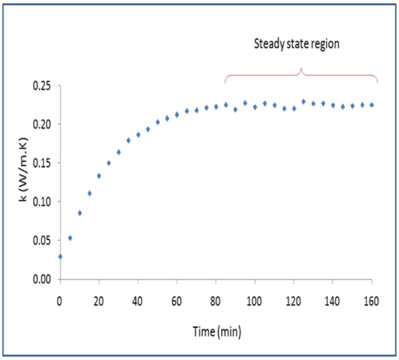


Figure 4. Result k-value vs. Time

Source: Authors

The steady state condition is achieved at the range of 90 to 160 min based on Figure 4, in which monotonically direction is observed. The data at 130min to 160min in Table 1 shows that the k-value obtained is in the 1% stability, where this is the region of acceptable k-value. The average k-value of obtained is 0.225 W/m.K.

Table 2 shows the comparison of this Brickool with other construction material. It is found that the Brickool is better than the other materials. And with this improvement k-value, the building built with this material should be less hot due to less heat transfer into the building.

Table 2. Comparison k-value of Brickool with other Construction Material

Material	k-value (W/m.K)
Brickool	0.225
Cement, mortar	1.01-1.73
Cement, portland	0.29
Brick dense	1.31 - 1.6
Brickwork	0.6
Sand	0.15-0.25

Source: Authors

From the k-value obtained, it is found that k-value of Brickool material is lower than other building materials with conventional building material. Brickool has low thermal conductivity and high insulation rate if compared with other building material. Brickool is three (3) times colder than ordinary clay brick. For normal tropical climate like Malaysia, building materials that been used must have high insulation rate to avoid excess heat absorption inside the building area. Excess heat inside the building will increase interior air temperature and will create a hot environment for the occupants. Therefore, low k-value's material is necessary to prevent the absorption of excess heat into the building and then cool the building. Hence, Brickool material has low k-value compared with other building material such as clay brick and concrete. The use of Brickool will be able to prevent the entry of large amount of heat through walls and then cool the interior part of a building.

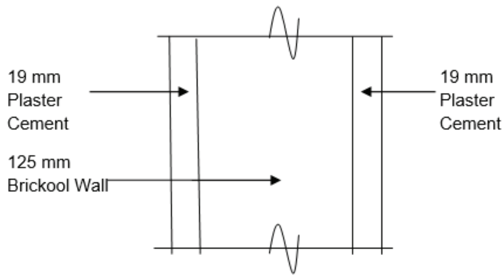


Figure 5. Cross-Sectional Detail of Brickool Wall

Source: Authors

Table 3. R-Value Brickool

Component	t/k	R
Outside Air Film		0.044
Plaster Cement	$\frac{0.019}{0.533}$	0.036
Brickool Wall	$\frac{0.125}{0.225}$	0.556
Plaster Cement	$\frac{0.019}{0.533}$	0.036
Inside Air Film		0.120
Total R		0.792

Source: Authors

R-Value = 0.792 m²K/W
U=1/R
=1/0.792
= **1.26 W/ m² K**

Note : R = t/k
U = U-Value (Thermal Transmission), W/m²K
R = R-Value (Thermal Resistivity), m²K/W
t = Thickness, m
k = k-Value (Thermal Conductivity), W/mK

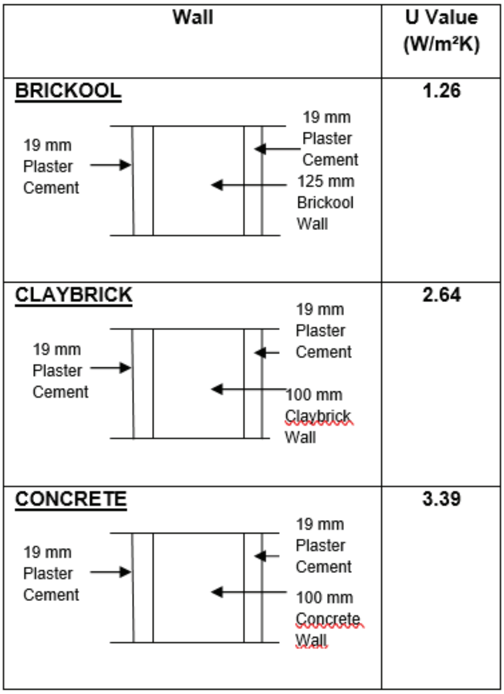


Figure 6. Comparison of U Value For Brickool Wall Against the Clay Brick Wall and Concrete Wall

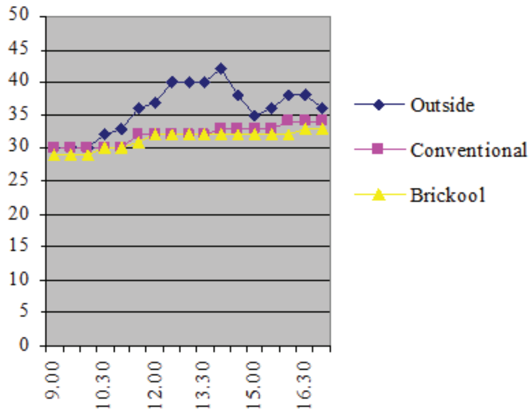
Source: Authors

Based on Figure 6 the application of wall building, U-Value obtained for Brickool is lower than clay brick wall and concrete wall. It shows Brickool has high insulation rate towards heat absorption inside the building. The requirement on heat resistivity is very important for a building to prevent the building from becoming hot and uncomfortable. U-value for Brickool wall is very low and it can block the entry of large amounts of heat and thereby cool the building as compared to the clay brick wall and concrete wall.

Therefore, the heat that absorbs through the building wall element will give an impact to the temperature in the building. Conventional usage of concrete will affect the rising usage of energy in the building. Looking deeper, the thickness of the construction materials in the building may cause the reduction of the U-Value of the building. See Figure 6 about the low usage of the U-Value. The U-Value of the Brickool is lower than the U-Value of other conventional materials. If we look at the value of the U-Value where the maximum value is 2.0W/m², it can be said that the level of insulation is good.

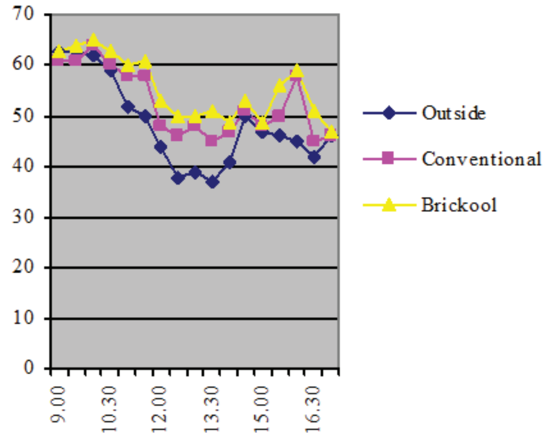
The low U-Value of Brickool will be achieved by providing enough insulation at the wall building. Thus, wall insulation is very important to reduce U-Value. The lower the U-Value of certain materials and constructions, the better the insulation value and the quality of the heat entry preventation will also be improved. The sensitivity of building architect is vital in understanding the need of insulation material in a building. It is important to reduce massive heat absorption in a building.

TEMPERATURE & HUMIDITY DATA OF BRICKOOL BUILDING



Graph 1. Comparison of Temperature between Brickool Building with Conventional Building

Source: Authors



Graph 2. Comparison of Humidity between Brickool Building with Conventional Building

Source: Authors

Time 9.00 am, outside air temperature was 30 ºC with 63% of relative humidity, indoor air temperature for conventional building was 30 ºC with 61% relative humidity while Brickool building's indoor air temperature was 29 ºC with 63% of relative humidiy. Outside air temperature increased to 32 ºC at 10.30 am and it further increased to 42 ºC at 2.00 pm. Temperature decreased between 2.30 pm until 5.00 pm at the rate 36 ºC.

For conventional building, the temperature increased to 32 ºC while the relative humidity showed 58% at 11.30 am and it was further increased to 33 ºC meanwhile the relative humidity decreased to 47% at 2.00 pm, and the temperature increase at 4.00 pm was 34 ºC with 58% of relative humidity. At noon, humidity and air temperature occur inversely until evening. The effect of air temperature increase and reduction of indoor humidity had caused building occupants to feel uncomfortable in the afternoon and evening.

For Brickool building, increase in air temperature to 30 ºC with 63% realtive humidity, 32 ºC with 53% of relative humidity, 33 ºC with 51% of relative humidity at 10.30 am, 12.00 pm and 4.30 pm respectively.

With 32 ºC air temperature at noon was insignificant with high humidity until 4.30 pm. Although the rising temperature occur in the afternoon and evening, the rate is still high for relative humidity in the building causing the building occupants to be comfortable in the building. Lower rate of heat flow in brickool building have caused a slow temperature increase in the afternoon and evening, while the rapid heat flow in a conventional building would lead to a higher temperature in the afternoon and evening.

CONCLUSION

k-value and U-value are two matters which are closely related, a thicker material will yield a lower U-value of a certain material. The lower the U-value of certain construction materials, the better the value of insulation and its quality of heat absorption prevention.

Based on the application of wall building, U-value obtained for Brickool is lower than clay brick walls and concrete walls. It shows Brickool has high insulation rate towards heat absorption inside the building. The requirement on heat resistivity is very important for a building to prevent the building from becoming hot and uncomfortable. U-value for Brickool wall is very low, and it can block the entry of large amounts of heat and thereby cool the building as compared to the use of clay brick wall and concrete wall.

Thus, Brickool is an important green material that needs to be considered by any building designer for efficient energy usage of a building and the achievement of good usage of low-energy indoor eco-friendly and which will lead to a positive impact on the aspect of air-conditioning choices, operation in the building and finally continuous maintenance will create efficient energy usage in a building.

From the k-value obtained, it is found that k-value of Brickool material is lower than other building materials upon conventional building material. Brickool has low thermal conductivity and high insulation rate if compared with other building material. Brickool is three times colder than ordinary clay brick. For normal tropical climate like Malaysia, building materials that have been used must have high insulation rate to avoid excess heat absorption inside the building area. Excess heat inside the building will increase interior air temperature and will create a hot environment for the occupants. Therefore, low k-value's material is necessary to prevent the absorption of excess heat into the building and then cool the building. Hence, Brickool material has low k-value compared with other building material such as clay brick and concrete. The use of Brickool will be able to prevent the entry of large amount of heat through wall and then cool the interior part of building.

A good wall is a wall that can prevent the entry of excess heat into the building. Materials that are used to build the wall also influence the heat entry rate into a building. Construction materials and U-Value are two matters which are closely related, a thicker material will yield a lower U-Value of a certain material. The lower the U-Value of certain construction materials, the better the value of insulation and its quality of heat absorption prevention. Looking at the construction materials that are using the conventional building materials like concrete, plaster, brickwall and also wall tiles as wall foundation. This conventional construction may reduce the cost of construction materials of a building without considering the factor of efficient energy usage.

Although we are looking at the short-term effects of the cost, with the usage of conventional construction materials it has contributed to high rate of heat intensity inside a building. Consequently, the energy capacity that will be used increases together with the increase usage of air-conditioning in the building. If we look at the usage of concrete where the natural characteristic of concrete wall is absorbing heat at a high rate during the day and releasing high heat at night.

ACKNOWLEDGEMENT

The authors would like to acknowledge the financial support from Syarikat Brickool Sdn Bhd. management. The authors hope that this article will help for further research in the field of green building material.

FUNDING

No funding for this research.

AUTHOR CONTRIBUTIONS

All authors contributed to the design of the research, the questionnaire, and the write-up. The on-line survey, data cleaning and tabulation was undertaken by researcher. All authors have read and approved the final manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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