# Theoretical Study of the Steady Time of Thermal Transmission in Materials That Have Engineering Uses

# Studi Teoritis tentang Waktu Tenang Transmisi Termal pada Material yang Memiliki Kegunaan Teknik

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***Abstract. General Background:*** *Understanding the time required to achieve steady-state heat transfer in construction materials is crucial for various engineering applications, including construction, architecture, and electronics.* ***Specific Background:*** *This study investigates the steady time of thermal transmission in engineering materials using both theoretical and experimental approaches. Knowledge Gap: Despite existing research on heat transfer, there is a lack of comprehensive studies that integrate both simulation and experimental validation for a wide range of building materials.****Aims:*** *The primary aim is to evaluate the steady-state time of heat transfer in fifteen construction materials through theoretical models and simulations using MATLAB and ANSYS, and to experimentally validate these findings with four selected materials.* ***Results:*** *The study finds that the steady time for heat transfer varies significantly among materials, with wood packaging requiring the longest time (32.49 hours) and aluminum the shortest (0.49 hours). Theoretical results, validated by simulations, show close agreement between MATLAB and ANSYS (0.087% deviation) and between numerical and experimental results (9.5% deviation). Brick demonstrated a 61.18% longer heat transfer time compared to concrete, while thermostone showed a 17.45% and 89.31% increase over brick and concrete, respectively.* ***Novelty:*** *This research provides new insights into the comparative stability of heat transfer times across a broad spectrum of materials, highlighting significant performance variations and validating simulation methods against experimental data.* ***Implications:*** *These findings are vital for optimizing material selection in construction to enhance thermal efficiency. The study's methodologies can aid in developing more accurate predictive models for heat transfer in construction materials, thereby contributing to improved design and energy performance in building applications.*

***Keywords –*** *thermal transmission, steady-state heat transfer, construction materials, MATLAB simulation, ANSYS validation*

***Abstrak*****.** ***Latar Belakang Umum:*** *Memahami waktu yang diperlukan untuk mencapai perpindahan panas kondisi tunak dalam bahan konstruksi sangat penting untuk berbagai aplikasi teknik, termasuk konstruksi, arsitektur, dan elektronik.* ***Latar Belakang Khusus:*** *Penelitian ini menyelidiki waktu tunak transmisi termal pada material teknik menggunakan pendekatan teoretis dan eksperimental.* ***Kesenjangan Pengetahuan:*** *Meskipun penelitian tentang perpindahan panas sudah ada, namun masih kurang studi komprehensif yang mengintegrasikan simulasi dan validasi eksperimental untuk berbagai macam bahan bangunan* ***Tujuan:*** *Tujuan utama penelitian ini adalah untuk mengevaluasi waktu tunak perpindahan panas pada lima belas bahan konstruksi melalui model teoritis dan simulasi menggunakan MATLAB dan ANSYS, dan memvalidasi secara eksperimental temuan-temuan ini dengan empat bahan yang dipilih.* ***Hasil:*** *Studi ini menemukan bahwa waktu stabil untuk perpindahan panas sangat bervariasi di antara material, dengan kemasan kayu membutuhkan waktu paling lama (32,49 jam) dan aluminium paling singkat (0,49 jam). Hasil teoritis, yang divalidasi dengan simulasi, menunjukkan kesesuaian yang erat antara MATLAB dan ANSYS (deviasi 0,087%) dan antara hasil numerik dan eksperimental (deviasi 9,5%). Batu bata menunjukkan waktu perpindahan panas 61,18% lebih lama dibandingkan dengan beton, sementara thermostone menunjukkan peningkatan 17,45% dan 89,31% dibandingkan dengan batu bata dan beton.* ***Kebaruan:*** *Penelitian ini memberikan wawasan baru tentang stabilitas komparatif waktu perpindahan panas di seluruh spektrum material yang luas, menyoroti variasi kinerja yang signifikan dan memvalidasi metode simulasi terhadap data eksperimental.* ***Implikasi:*** *Temuan ini sangat penting untuk mengoptimalkan pemilihan material dalam konstruksi untuk meningkatkan efisiensi termal. Metodologi penelitian ini dapat membantu dalam mengembangkan model prediktif yang lebih akurat untuk* *perpindahan panas pada material konstruksi, sehingga berkontribusi pada peningkatan desain dan kinerja energi dalam aplikasi bangunan*

***Kata Kunci –*** *transmisi termal, perpindahan panas kondisi-mantap, bahan konstruksi, simulasi MATLAB, validasi ANSYS*

# I. INTRODUCTION

The direct transfer of heat, in part, from the external surroundings of buildings to the immediate interior of buildings is a global problem, as it combines it together with the use of more energy to serve the removal of this heat with various known cooling and air conditioning methods. This leads to an increase in the consumption of fossil fuels and increases the phenomenon of global warming, which is now one of the problems of the current era that affects the Earth and all the life on it. Through studying and calculating heat transfer, it leads to rationalization of energy and fuel consumption in order to avoid what was mentioned later.

A recent study by the Carbon Atomic Energy Agency (IEA) showed that air conditioning is responsible for the emission of nearly one billion metric tons of carbon dioxide, out of a total of 37 billion targets worldwide[1].

According to a New York Times article in the New York Times, on May 15, 2018, the number of air conditioners in the world has increased from about 1.6 billion currently, to 5.6 billion in 2050, according to economic growth rates [2].

A study from the National website indicated that the amount of energy used for cooling in the Gulf region between 1990 and 2016 jumped about 5-fold, from 25 terawatt-hours to 125 terawatt-hours. According to World Bank Figures, air conditioning in the UAE, for example, represents about 70 percent of electricity consumption [3]

Thermal steady is the resistance to irreversibility of changes of a substance due to rise in temperature. The notion of an effective time constant was applied to study the time which it takes a variable to reach steady-state value of a single measure. The time constant for first-order processes was estimated to capture the dynamic systems represented by partial differential equations. The advantage of this method is highlighted by the frequency-domain solution of the governing equation. The applications of this technique will be through deriving analytical expressions for the time constant after representing the process with a system of partial and ordinary differential equations to arrive at an accurate calculation of the time required for heat transfer to stabilize.

Past studies compared the model with other numerical methods[4]. The ease of the method and the good fitting observed suggest that the protocol we have used here may be used for the characterization of the thermal behavior of bricks and the steady time of thermal transmission via the straightforward determination of the thermal resistance and the thermal diffusivity using our proposed model. A literature survey of this paper can be summarized by these paragraphs.

a. **Jose´ -Luis Vivancos**, [4]: The heat flux evolution on different types of clay and concrete bricks has been studied using a guarded hot-plate. The model allows the determination of the thermal resistance (RB), the heat flow for a finite wall thickness in the steady-state and the time necessary to achieve. It has proposed a model that allows determining in a very simple way the value of that has been found to show a linear correlation with the square root of the product between the thermal diffusivity and the geometric characteristics of the brick. The equation was used to calculate steady-time heat transfer for brick was $t_{brick} = m.(\alpha.\sigma)^{-1/2} = m.(\frac{\rho.C_p}{K.\sigma})^{1/2}$ …(1).
b. **MCNABB,** [5]: The specific time and temperature were calculated in this research, which is related to time difference constants. The average working time was determined by a linear solution. It was readily found that a useful comparative time was given to the process of heat transfer, which gave a measure for its adoption.
c. **L.P. Thomas,** [6]: The researchers conducted an analytical study to calculate and compare both steady-state heat flows and time-dependent heat flows through the building. They concluded that W1' reduces u to 70% of the W1 corresponding value, and qviN max and qviS max decrease to the same extent. In this way, the decrease in the heat flux qvi is so significant that the time lags τqvi 10 and τ qvi 20 of W1' can be irrelevant all year round.
d. **P. Munoz**, [7]: The researchers studied the effect of paper pulp as a brightening agent on the thermal and mechanical properties of baked clay and improved the thermal properties without the mechanical properties falling below the required levels. This improved the conductivity by 39.69%, at 10°C K was 0.45 W/m-K. This reduction results a 16% improvement in thermal transmittance of brick walls.

e. **I-Shih Liu et.al,[**8]: The researchers studied the linear theory that contains internal density gradients. They explained how temperature is influenced by Fourier's law of thermal conduction. They represented the first linear gradient theory time where $q_i = k_2(\frac{\partial \varepsilon}{\partial x_i} - \frac{\partial \varepsilon}{\partial \varphi}\frac{\partial \varrho}{\partial x_i}) = k_2\frac{\partial \varepsilon}{\partial T}\frac{\partial T}{\partial x_i}$ …(2).

f. **P. H., et.al** [9]: The researchers used the derivation of the steady condition that was introduced. They derived a condition of stability by using a new method to applied on the stability of the solution. The obtained results were compared with Von Neumann's method where applicable and agreed with him and then compared the result of the problem (steady time at distance X) by Crank Nicolson method $T = t + \frac{X^2}{2}$,
$T = t^2 + x^2 t + \frac{x^4}{12} + (\delta x)^2(\frac{1}{6} - \gamma)(a^2 - x^2)/2$ …(3).

## II. METHODS

Heat transport through Brick is simulated using the finite element analysis software package. The simulation model was a rectangular block of material with an insulated barrier and a constant temperature at one end.

**Theoretical Background:**

The heat conduction equation expresses heat flux density using Fourier's law for thermal conduction:
q conduction = −kA dt/dx (4).

The general equation for heat transfer states that at any point in a homogeneous body, the net rate of heat transfer in a part is added to the homogeneous rate. The net rate of heat transfer in a part plus the volumetric rate of heat generation in this part must be equal to the rate of change in energy. stored in this part. There are many simplified forms of the general equation for heat transfer in Cartesian coordinates that can be obtained by performing some appropriate assumptions. For example, if we assume that the thermal conductivity coefficient is constant and does not depend on temperature, then the general equation can be written in the form [6]:
$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} + \frac{q^-}{K} = \frac{1}{\alpha}\frac{\partial T}{\partial \tau}$ …(5).

The thermal diffusivity (α) of the building material can be used to define thermal mass $\frac{\partial T}{\partial \boldsymbol{t}} = \alpha\frac{\partial^2 T}{\partial x^2}$ And sine α =k/ρ*Cp …(6).

The quantity of heat required to raise the temperature of a given mass by one kelvin is known as its heat capacity, or HC. HC = m*cp …(7).

The total of the heat capacities of all the parts that make up a building element is its heat capacity. When a substance has a high thermal diffusivity, heat can transfer quickly. The material retains a minuscule amount of heat and responds quickly to temperature changes. To calculate the stability time of heat transfer from the bottom base to the top base of the brick, a law can be used, heat transfer by thermal conduction through the material, which is expressed by the following equation:

$Q = \frac{KA\Delta T}{d}$…(8).

The following formula can be used to get the constant time of thermal transmission:

t = (ρ*Cp L^2) / (4α^2) ….(9).

A material's ability to transport heat through it fast is measured by its thermal diffusivity, or α. The calculation involves dividing the thermal conductivity by the sum of the specific heat capacity and density of the material.

- Linking Conduction and Diffusion:

Combining the heat conduction equation with the diffusion equation, we can express the transient thermal conduction along with diffusion as [7]:

$\rho c\frac{\partial T}{\partial t} = \nabla.(K\nabla \mathrm{T}) - \mathrm{KA}\frac{\mathrm{dT}}{\mathrm{dx}}$ …(10).

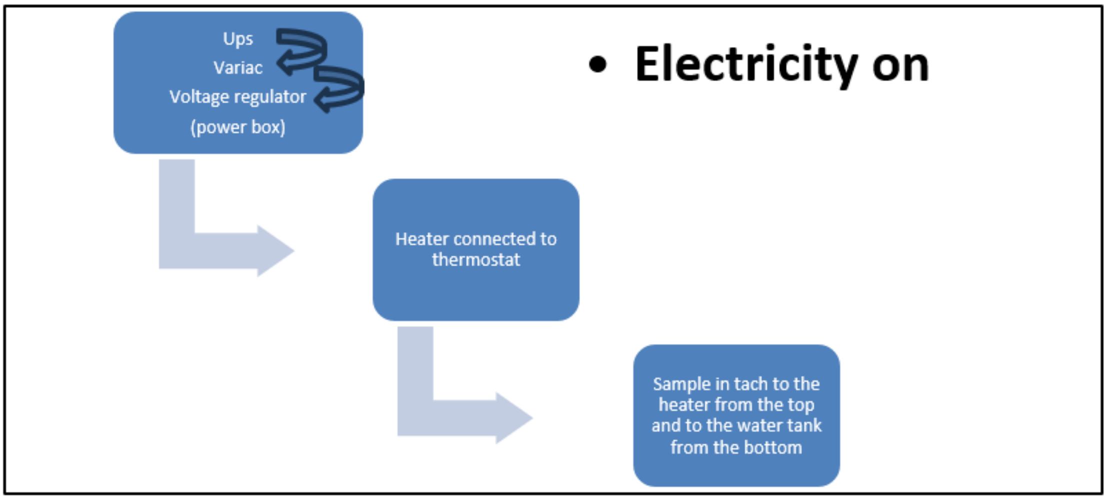
This equation represents the comprehensive model for studying the constant time of heat transfer, considering the processes of thermal conduction and diffusion in the material. We can incorporate specific applications and boundary conditions based on the properties of the engineering material and the system being analyzed. And for this case that studded in this research and by considering the boundary condition, the dimensions and properties of the sample this equation was used to calculate the steady time of the solid brick. $Time\ to\ steady\ state = \frac{L^{2\rho c}}{2k}$ …(11).

**Experimental Work**

An experimental was conducted to determine the effect of heat transfer on materials that have engineering uses. The materials tested was 4 samples only . We also conducted a test on a concrete block, in addition to conducting another test on pure cement mixed with water only. Finally, a test was conducted on a piece of thermostone, a thermal stone. These materials are the most used materials in construction, whether the construction is for residential homes, rooms, large residential buildings, or commercial buildings. We manufactured the device manually by, and also for the samples used, we made a mold in order to ensure that the geometric dimensions were uniform in all sample that were tested theoretically that specified in (Table 1) for the purpose of achieving the goal of this research. The device type was steady state method, while the technique was guarded hot plate method[8]. Below is Figure (1) explain experiential work.

(Table 1) shows all samples dimensions

| Sample dimensions | | |
|---|---|---|
| Length 4 cm | Width 4 cm | Hight 20 cm |



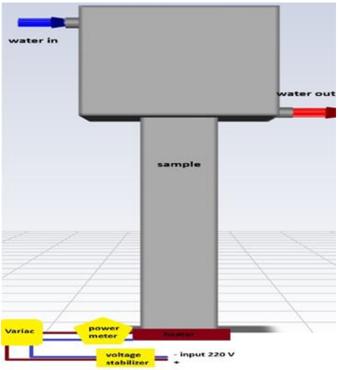

(Figure 1) shows how the rig work.

**Experimental equipment and procedure**

(Figure 2) shows a schematic diagram of the components of the test device that was designed in (Figure 3) Which shows the shape of the device that was designed and used to examine models. The device consists of the following parts:

1. water tank as shown in (Figure 4) with 20 cm length, 20 cm width and 20 cm height.
2. Flowmeter device as shown in (Figure 5) from (0.5-5 gallon/ M).
3. An electric heater as shown in (Figure 6) (5 cm length, 5 cm width).
4. Metal structure to cover the sample as shown in (Figure 7) with 25 lengths.
5. Variac as shown in (Figure 8) that has range from (0-1000) watt.
6. Voltage regulator as shown in (Figure 9) with input voltage 160-240v.
7. Temperature sensors and temperature readers as shown in (Figure 10) thermocouple type K.
8. Uninterrupted Power Supply (UPS) as shown in (Figure 11) The capacity of this device is 3KVA.
9. The insulation of tank insulation and the insulation of cylindrical metal shell of the sample.
10. Thermal grease as shown in (Figure 12).

Electricity is turned on to the electric heater and water pipes are connected to ensure that water reaches the tank. Water enters the flow meter device. The flow rate of water entering the tank is controlled by a control valve. A device was installed to measure the temperature before the water entered the tank, and a device was also installed to measure the temperature after the water left the tank. It is worth noting that all types of thermocouples used in this test were type K, where in addition to a gauge for the water inlet and outlet temperatures, a thermocouple was installed on the electric heater for the purpose of ensuring its temperature stability, despite the presence of a device to adjust the temperature. "The heater." Eight thermocouples were distributed over the sample and installed after puncturing the sample and attaching it with the material used to install the thermocouple.




(Figure 2) shows schematic diagram of the device

(Figure 3) shows a picture of the device used in the experimental work

(Figure 4) shows the water tank.

(Figure 6) shows the electrical heater.

(figure 7) shows the Metal structure to cover the sample.

(Figure 8) shows the Vatiac


(Figure 9) shows the Voltage regulator

(Figure 10) shows Temperature sensors and temperature readers.

(Figure 11) shows Uninterrupted Power Supply (UPS).

(Figure 12) shows thermal grease

## III. RESULT AND DISCUSSION

MATLAB and ANSYS simulation result: - After determining the properties of materials (15) sample as mentioned in (Table 2), the same thermal conditions for all samples, dimension and properties of samples heater temperature were took in the experimental work, MATLAB and ANSYS programs. The steady time of each sample shows in (Table 3).

Experimental Results: The experimental work was done for (4 samples) only as shown in (Table 3). When starting to measure the heat transfer stabilization time, the room temperature was 22.1°C, an electronic air thermometer was used. The initial reading was 22°C, and the temperature of the water entering and exiting the water Tank was 22.12°C, while the water flow rate was 6 liters/m. then began to measure the temperature distribution in the sample that move from the bottom of the sample to the highest point in the sample (since the top of the sample is in contact with the water tank) until the time constant for heat transfer stability is reached. The water temperature readings (inlet and outlet) were taken from the tank using thermocouple, all readings were taken (every quarter hour), the result of steady time for all samples shows in (Table 3)

| Material | Thermal conductivity K (Watt/m c) | Specific heat CP (KJ/KG K) | Density P (KG/m$^3$) | Heat capacity ρC |
|---|---|---|---|---|
| **Plaster** | 0.464 | 1.08 | 1280 | 1382.4 |
| **Cement** | 1.16 | 0.92 | 2000 | 1840 |
| **Bricks** | 0.812 | 0.8375 | 2000 | 1675 |
| **Concrete** | 1.58 | 0.8794 | 2300 | 2022.6 |
| **Asphalt** | 1.23 | 0.92 | 2240 | 2060.8 |
| **Soil** | 1.2 | 0.8375 | 1536 | 1286.4 |
| **Sand** | 1.298 | 0.9211 | 2242 | 2065.1 |
| **Concrete tiles** | 1.5 | 0.8375 | 2200 | 1842.5 |
| **Thermostone** | 0.388 | 1.175 | 800 | 940 |
| **Polystyrene** | 0.04038 | 1.214 | 16 | 19.5 |
| **Plastic wrap** | 0.837 | 0.865 | 1952 | 1689.2 |
| **Asbestos boards** | 0.6923 | 0.8374 | 1922 | 1609.6 |
| **Packing wood** | 0.1212 | 1.3817 | 513 | 708.2 |
| **Aluminum metal casing** | 45 | 0.5024 | 7832 | 3934.8 |
| **Polyurethane** | 0.0398 | (1.08-0.71) | (64-96) | (20.3-45) |

| Material | Steady time in experimental work | Steady time in MATLAB simulation | Steady time in ANSYS simulation |
|---|---|---|---|
| Brick | 12.55 | 11.46 | 11.47 |
| Concrete | 9.15 | **7.11** | **7.12** |
| Thermostone | **15.30** | **13.46** | **13.47** |
| Cement | **10** | **8.49** | **8.50** |
| Plaster | **-----** | **16.55** | **16.55** |
| Asphalt | **-----** | **9.31** | **9.32** |
| soil | **-----** | **5.57** | **5.57** |
| sand | **-----** | **8.50** | **8.50** |
| concrete tiles | **-----** | **6.49** | **6.50** |
| Polystyrene | **-----** | **2.40** | **2.40** |
| Plastic wrap | **-----** | **11.21** | **11.22** |
| Asbestos boards | **-----** | **12.55** | **12.55** |
| Packing wood | **-----** | **32.49** | **32.49** |
| Aluminum metal casing | **-----** | **0.49** | **0.49** |
| Polyurethane | **-----** | **6.34** | **6.35** |

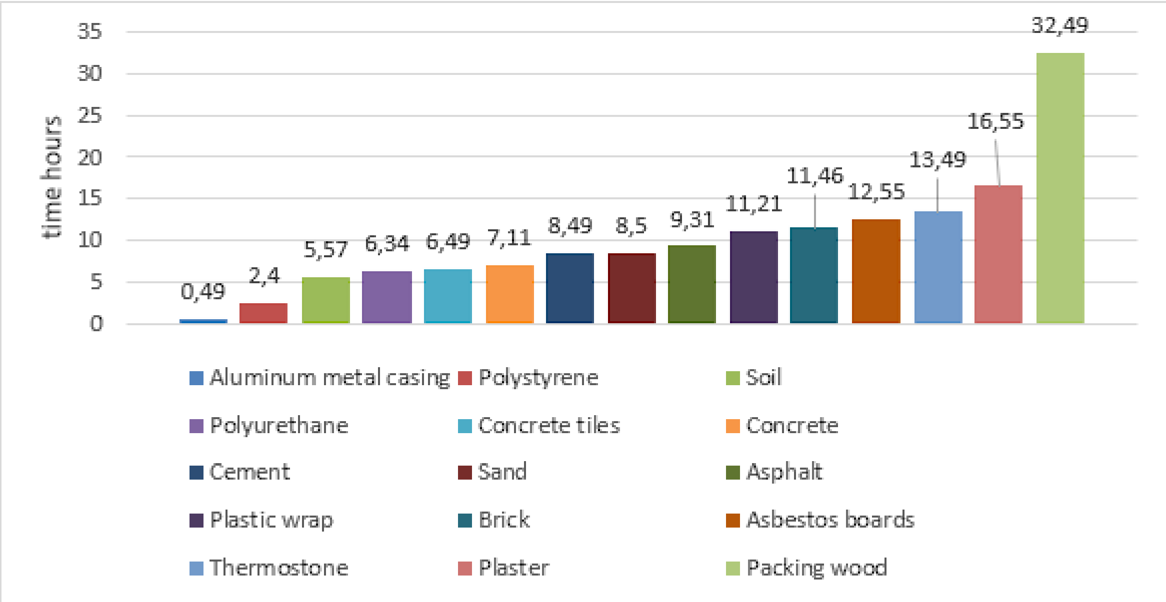
## IV. CONCLUSION

The main aim of this study is to determine the stability time of heat transfer in many materials that normally utilize in the construction of buildings. This aim could be achieved by developing an experimental rig using steady state method and guarded hot plate technique to calculate the heat transfer rate in one dimensional of single specimen. Four building materials have been investigated by using the experimental rig. Furthermore, MATLAB and ANSYS are used to numerically simulate the effect of different parameters on the stability time based on the finite difference method. Fifteen building materials including the four mentioned above have been simulated by both software's.

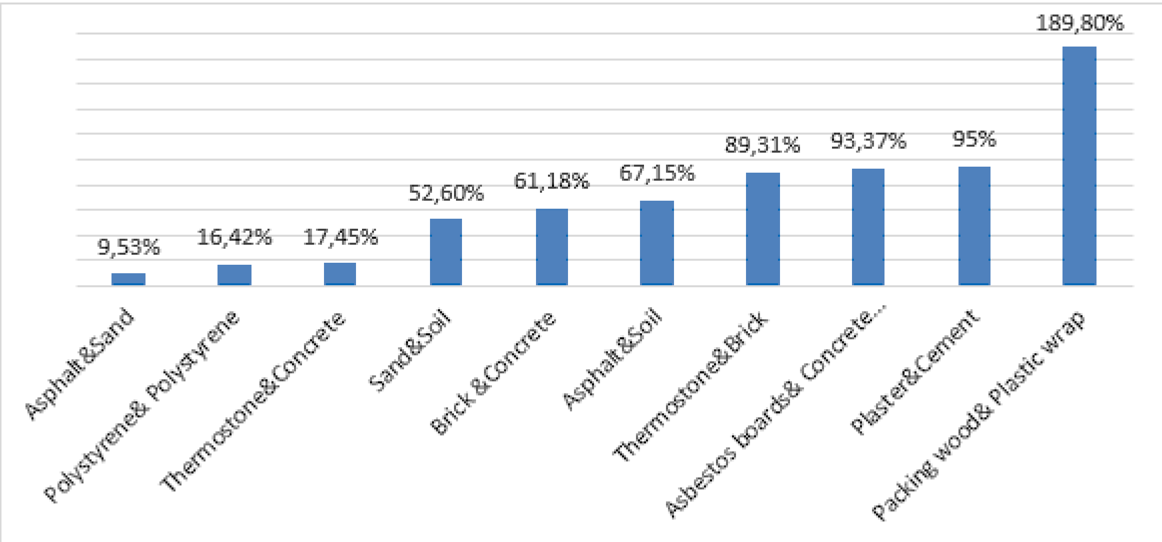
It is clear from this study that there are three factors effecting on the stability time of heat transfer, which are temperature, the surface area of the material exposed to heat, and the properties of the material (the heat transfer coefficient K, the specific heat CP, and the density of the material ρ). The results of this study as shows in Figures (13 and 14) could be summarized as follows,

a. The numerical results of the MATLAB and ANSYS have been compared for all materials to have verification in the accuracy of both programs which have been chosen to simulate a wide range of materials with more boundary conditions. The results for both mentioned software show very good validations of 0.087% for brick material. The validation has also achieved between the numerical and experimental results with a percentage of 9.5%.
b. Regarding the highest and minimum values of the steady time of heat transfer, the numerical results record 32.49 hours and 0.49 hours for the wood packing and aluminum materials, respectively.
c. Based on the materials normally used in the building of walls, there is an increment in the steady time of heat transfer through brick material with percentage of 61.18% by comparing with concrete one. The steady time of heat transfer through thermostone material increases by 89.31% and 17.45% compared to the brick and block, respectively.
d. A remarked increase in the steady time of heat transfer through plaster (as materials used to cover walls or other surfaces) up to 95% compared to cement material.
e. Regarding the materials that normally used in construction of floors, asphalt, soil and sand have been investigated; the results show the increment in the steady time of asphalt to transfer heat with percentage of 67% and 9% compared to soil and sand material, respectively. The sand is compared with soil in term of the steady time of heat transfer with an increasing of 52.6%.

f. When talking about the stabilization time of heat transfer between asphalt, soil and sand, it will increase by a remarkable amount of up to 67% when using asphalt over using soil, and the increase will reach a rate of more than 9% when using asphalt instead of sand. When comparing Sand and soil. Here it will notice that the percentage will reach more than 52.6% when using sand than when using soil. These percentages are amazing for identifying the optimal choice between these materials. And when using asbestos boards instead of concrete tiles, the percentage will exceed 93%.
g. A dramatically increase in steady time for polyurethane and wood up to 164.2% and 189.8% has been highlighted by comparing with polyurethane and plastic cover materials.




(Figure 13) Steady time for materials by MATLAB results.




(Figure 14) shows the comparison between the percentage of steady time for materials.

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