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Research Article

Arduino Controlled Investigation and Thermal Simulation of One-Dimensional Stable Heat Transfer in Multilayer Plane Wall

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Abstract

There are innumerable events related to heat transfer that we experience or see in our daily lives. In this study, research and experimental calculations were made about multilayer plane walls, which are often made of different materials. There are so much application areas on heat transfer. In order to better understand heat conduction, we need to make an explanation of the thermal properties and heat transfer type of the materials used in the experiment. It is known that heat transfer occurs in three different ways (conduction, convection, radiation). In this study, a layered wall heat conduction mechanism was established by combining 6 different materials (Copper, St37 Steel, AISI 1050 Aluminum, Wood, Rock wool, Glass wool) with different pediments of 30*30 cm. Heat is produced by gradually applying voltage from the copper plate and the temperature between each plate is measured by temperature sensors with Arduino programming. In the Arduino assembly, one Arduino Unocard, 5 lm35 temperature sensors and 1 20*4 I2C LCD screen are used to take the measurement outputs. The LM35 temperature sensor produces a voltage between zero and 5 V from the analog output, and the temperature measurement is made by producing a value of 10mV for each degree Celsius. The right leg of lm35s with three legs is connected to GND on the breadboard for grounding, the middle leg is connected to the analog output on the uno board, the left leg is connected to the 5V input on the breadboard and 5 lm35s are connected in parallel on the breadboard. The sensors were placed in the middle of the plates and the measurements were printed and recorded on the LCD screen. The measurements in the experimental setup were analyzed by applying a stepped voltage of the same value to the layered wall designed from the same materials in the SolidWorks thermal program, the data were collected and compared with the theoretical calculations of heat transfer.

Keywords: Conduction, Insulation, Multilayer wall, Arduino.

1. Introduction:

The number of high-energy efficient appliances and furnaces (hence high heat efficiency) is increasing in the world in order to use energy more efficiently, and because the world's energy resources are limited and costly, we must conserve the energy we have. From the importance of this point, the insulation principle is very important in all studies related to heat, it is possible to see the insulation principle in many places in our lives (heat protection glasses, ovens, buildings, or large halls). To calculate the heat gains and losses of insulated walls, the Fourier equation, which is a second-order partial differential equation, must be solved under boundary conditions. There are many numerical methods for solving such problems, but it is generally considered a little difficult to find analytical solutions for multi-layered walls. Nowadays, finite difference methods are more preferred in our application to computer programs to find solutions to these problems. When we examine the studies related to this subject, in this investigation the temporary heat transfer in the walls numerically has finite differences [1]. Another study calculated the phase shift, damping ratio, internal surface temperature and heat fluxes by developing a computer program that calculates the thermal performance of the walls for the continuous periodic state [2]. According to another study that developed a method that calculates the amount of heat transfer in various structural elements in the transient regime and calculated the heat gains from walls and roofs in different regions of Turkey [3]. Another study that investigated the transient effects of heat transfer along three types of insulated walls with insulation on the outer surface, inner surface, and middle of the wall. In this study, the amount of heat passing through the multi-layered walls and the analysis of thermal insulation were made [4]. In the study, a system was designed, manufactured on various samples to measure the thermal conduction coefficients of the materials used in thermal insulation [5]. A mathematical model is presented to study the thermal response of multilayer building components. In this analysis, the harmonic analysis of meteorological data and the time-dependent variation of sunlight and outside temperature are considered [6]. Another study says, increasing the thickness of the insulation layer and reducing its thermal conductivity significantly reduces the energy consumption of a heating and cooling system [7]. In this study, they investigated the thermal response factors and conduction transfer functions of a multilayer wall based on polynomial s-transfer functions estimated by the theoretical frequency-to-frequency domain regression (FDR) method [8]. The temperature field in an air layer placed between two isothermal vertical plates with different temperatures was investigated with the aid of a Zehnder-Mach interferometer [9]. Another study, in order to limit the heat transfer through the wall as much as possible, the first step in this direction is to make sure that the convective heat transfer in the air layers is negligible. The studies provide boundaries between conduction and convection regimes as functions of air layer aspect ratio A and Grashof Number Gr (depending on the width of the gap) [10]. In this study, the amount of heat passing through the multi-layered walls and the analysis of thermal insulation were made. In order to get the most accurate result, three different calculations were used. This study was carried out in order to get the most accurate result and margin of error by comparing the results of the analysis by applying them to computer programs (SolidWorks thermal), theoretical calculations and the results of three different methods applied at room temperatures.

2. Materials and Methods

The following assumptions were made while creating the mathematical model.

1. There is no heat generation inside the building element.

2. Since the height and width of the building element are quite large compared to its thickness, it is assumed that the heat transfer takes place in one dimension only in the x direction.

3. It is assumed that there is excellent thermal contact between the layers and there is no interfacial resistance.

4. It is assumed that the thermal properties of the building element, such as the thermal conductivity coefficient, density, and specific heat, are not affected by temperature changes.

In line with these assumptions, the temporary one-dimensional heat conduction equation in a multilayer wall is used to calculate the amount of heat transferred per unit time by conduction for each layer:

$$q = -k \cdot A \frac{dT}{dx} \quad \text{(W)} \qquad [1]$$

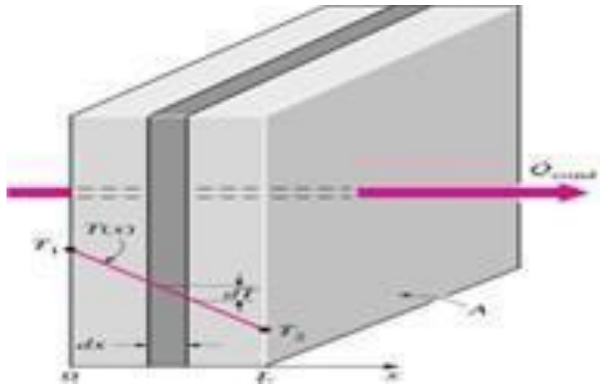


Figure 1. Heat conduction in solids

The heat transfer on the wall of the house can be modeled continuously and in one dimension. In this case, the temperature at the wall depends on only one direction (for example, the x direction) and can be denoted as T(x).[11]

$$Q_{in} - Q_{out} = \frac{dE_{duvar}}{dt} \quad [2]$$

The rate of heat transfer into the wall should be equal to the rate of heat transfer out of the wall. In other words, the heat transfer rate on the wall must be constant:

$$Q_d = -k \cdot A_x \cdot (dt - dx) \quad [3]$$

The concept of thermal resistance is the thermal resistance of the wall against heat conduction or simply the conduction resistance of the wall. The thermal resistance of a medium depends on the geometry and thermal properties of the medium.

$$Q_d = \frac{T_1 - T_2}{R_d} \quad [4]$$

$$R_d = \frac{L}{k \cdot A} \quad [5]$$

Temperature drop; $\Delta U = \frac{1}{R_{total}}$ [6]

U Total heat transfer Coefficient For example, after calculating Q, the surface temperature T_1 can be found from the equation:

$$Q = T_\infty - T_1 \quad [7]$$

Thermal resistance, which when the surfaces are pressed against each other, the protrusions provide good material contact, but air gaps remain in the recesses. As a result, an interface contains many air gaps of different sizes that act as insulation due to the low thermal conductivity of air. Therefore, an interface has some resistance to heat transfer, and this resistance per unit interface area is called the thermal contact resistance Rc. The value of the thermal contact resistance depends on the properties of the material and the smoothness of the surface, as well as the temperature, pressure at the interface and the type of fluid trapped at the interface.

$$Q = Q_{contact} + Q_{aperture} \quad [8]$$

$$R = \frac{L}{k} \quad [9]$$

For good conductors such as metals, thermal contact resistance is important and even determines heat transfer; but it is concluded that they can be neglected in bad thermal conductors such as insulations. Compound heat transfer often occurs in combination with various combinations of heat transfer types. The following equation is used to calculate the total heat transfer for flat surfaces.

$$Q = k \cdot A \cdot (T_1 - T_2) \quad [10]$$

Total heat transfer: It takes place by heat conduction on the wall and heat convection from the wall to the outside. According to this:

$$\text{Heat conduction: } Q = \frac{\sigma}{d \cdot A \cdot (t, - t_2)} \quad [11]$$

Calculation of surface temperatures can be easily performed with the help of the k value. On flat surfaces, the internal and external temperature is found as follows:

$$T_1' = \frac{t_1 + k}{\alpha_2 \cdot (T_1 - T_2)} \quad [12]$$

2.1. The Experimental setup:

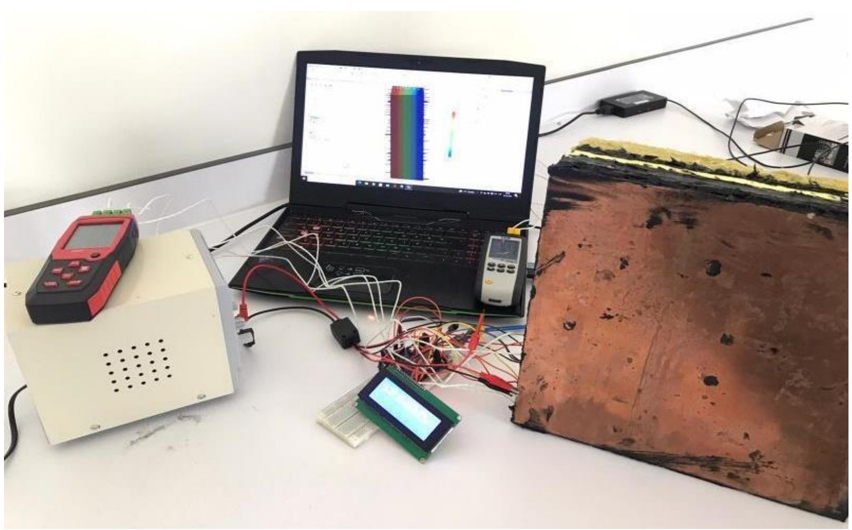


Figure 2. Heat conduction arrangement in the Layered Wall

The experimental setup consisted of copper, aluminum 1050, St37 steel, pine wood, glass wool and rock wool materials and an Arduino temperature measuring device. First, after ensuring the smoothness between the materials, thermal paste was applied between the materials in order to strengthen the temperature transmission between them. After the materials were combined in order, all the openings around them were closed with metal silicon. At the same time, lm35 temperature measurement sensors installed on the uno board are placed between the materials. Using the power supply, heat was given over the copper plate and observations of the temperature change were made on the I2C LCD display. Values taken from the LCD screen are indicated in the results section.

Table 1. Material Data

Materials	k [W/m.K]	L [mm]	A [m²]
Copper	390	1.5	0.09
Aluminum 1050	230	3	0.09
St37 Steel	38	3	0.09
Pine Wood	0.22	20	0.09
Glass wool	0.035	20	0.09
Rock wool	0.04	20	0.09

2.2. Temperature measurement with Arduino:

Arduino is a physical programming platform consisting of a G/C (I/O) board and a development environment containing an implementation of the Processing/Wiring language. In this study, an Arduino was used to record temperature measurements between materials. In the setup, lm35, Arduino uno board, 20*4 I2C LCD display, jumper cables are used for the connections on the breadboard.

Figure 3. Lm35 temperature sensor Figure 4. Arduino UNO board

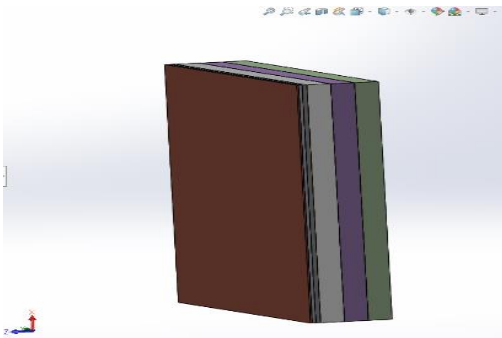
The LM35 consists of three legs; Pin 3 is used for grounding and is attached to the gnd pin. The 2nd leg is attached to the analog pins of the Ardunio uno board and information is received. Leg 1 is plugged into the 5-volt input. With Arduino UNO, physical information of lm35 sensors was received and this information was given to the LCD screen. The coding of the Arduino system is shown below.

```
// generated by mBlock5 for <your product>
// codes make you happy
#include "src/LiquidCrystal_I2C.h"
#include <Arduino.h>
#include <Wire.h>
#include <SoftwareSerial.h>
float gerilim = 0;
float sicaklik = 0;
LiquidCrystal_I2C LCD_I2C_0x27(0x27, 20,
4);
void _delay(float seconds) {
  long endTime = millis() + seconds * 1000;
  while(millis() < endTime) _loop(); }
void setup() {
  pinMode(A0+0,INPUT);
  LCD_I2C_0x27.init();
  LCD_I2C_0x27.backlight();
  pinMode(A0+1,INPUT);
  pinMode(A0+2,INPUT);
  pinMode(A0+3,INPUT);
  pinMode(A0+4,INPUT);
  while(1) {
 gerilim = analogRead(A0+0);
     sicaklik = gerilim * 0.488;
gerilim = analogRead(A0+1);
     sicaklik = gerilim * 0.488;
     LCD_I2C_0x27.setCursor(1 - 1, 2 - 1);
     LCD_I2C_0x27.print(String("T2=") +
String(sicaklik));
     _delay(1);
     gerilim = analogRead(A0+2);
     sicaklik = gerilim * 0.488;
     LCD_I2C_0x27.setCursor(10 - 1, 1 - 1);
     LCD_I2C_0x27.print(String("T3=") +
String(sicaklik));
     _delay(1);
     gerilim = analogRead(A0+3);
     sicaklik = gerilim * 0.488;
     LCD_I2C_0x27.setCursor(10 - 1, 2 - 1);
     LCD_I2C_0x27.print(String("T4=") +
String(sicaklik));
     _delay(1);
     gerilim = analogRead(A0+4);
     sicaklik = gerilim * 0.488;
     LCD_I2C_0x27.setCursor(10 - 1, 2 - 1);
     LCD_I2C_0x27.print(String("T5=") +
String(sicaklik));
     _delay(1);
     _loop();
  } }
```

LCD_I2C_0x27.setCursor(1 - 1, 1 - 1); LCD_I2C_0x27.print(String("T1=") + String(sicaklik)); _delay(1);	void _loop() { } void loop() { _loop( );

2.3. Layered wall thermal analysis with SolidWorks thermal:

Layered wall design was made with SolidWorks, and the design stages and analysis are evaluated below.



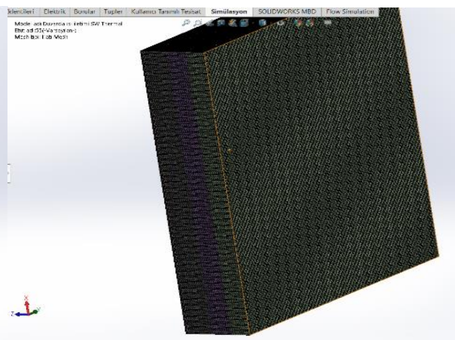


Figure 5. SolidWorks layered wall design Figure 6. Layered wall mesh application

6 different materials in 30*30 dimensions were used and mounted. Copper 1.5 mm, Aluminum 3 mm, St37 Steel 3 mm, Pine wood 20 mm, Rock wool 20 mm, Glass wool 20 mm. 2mm mesh is applied to the layered wall design and 1mm local mesh is applied for finer results. Analysis was done for five different temperatures.

3. Results

Table 2. Temperatures at 50°C

Method	T_i	T_1	T_2	T_3	T_4	T_5	T_o
Ardunio	50	48	47.5	39.9	34.3	24	23
SolidWorks Thermal	50	47.750	43.250	38.750	34.250	25.250	23
Theoretical	50	49.98	49.97	49.94	28.37	24.30	20.40

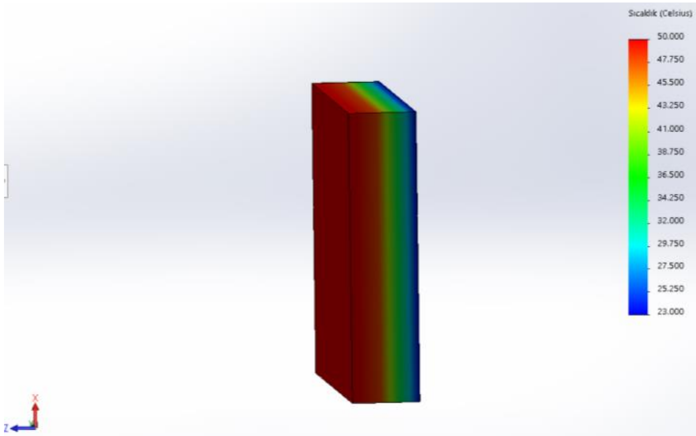


Figure 7. SolidWorks thermal analysis at 50°C

As can be seen in Figure 7, Copper, Aluminum, Steel materials transmitted in Red color (high temperature), that is, inlet temperature, without much temperature loss between the above-mentioned materials due to their high thermal conductivity coefficients. In the wooden plate, on the other hand, it is observed in the green part where there is a sudden decrease in temperature due to the low thermal conductivity coefficient. In glass wool and rock wool insulating materials, it is seen in the blue part where the temperature is equal to the temperature of the experimental laboratory.

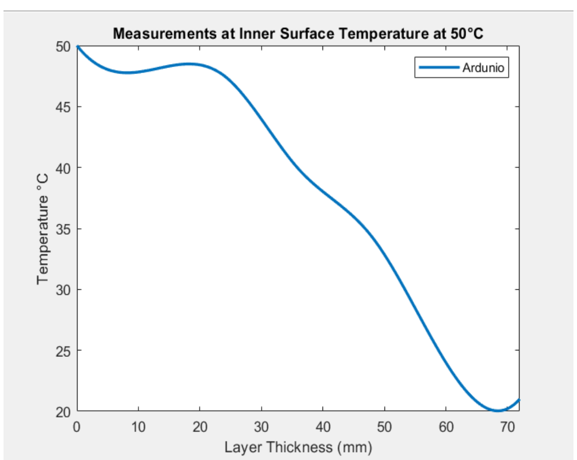


Figure 9. MATLAB Theoretical analysis at 50°C

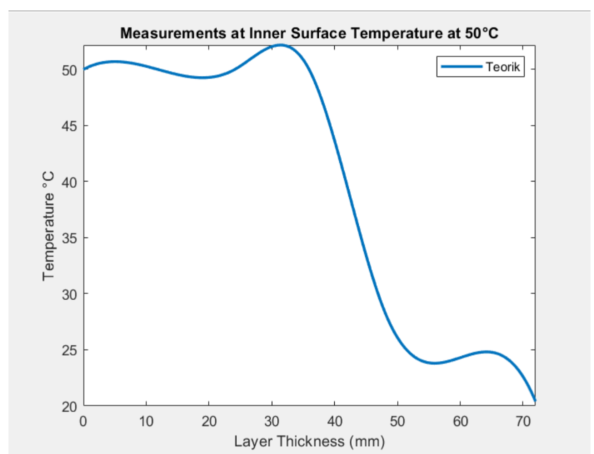


Figure 8. MATLAB Arduino analysis at 50°C

Table 2 shows the values measured in the experimental setup. In Figure 8. and Figure 9. the values are shown graphically in the MATLAB program. If Solidworks thermal analysis and graphics are examined, the Arduino values and analysis values confirm each other. Theoretical values, on the other hand, differed because of the assumptions made. The difference seen in the theoretical calculations is due to the assumption that there is no heat loss.

Table 3. Temperatures at 55°C

Method	Ti	T_1	T_2	T_3	T_4	T_5	T_o
Ardunio	55	53	50.6	44.9	39.3	28	23
SolidWorks Thermal	55	52.5	50	45	37.5	27.50	23
Theoric	55	54.98	54.97	54.94	29.47	24.93	20.95

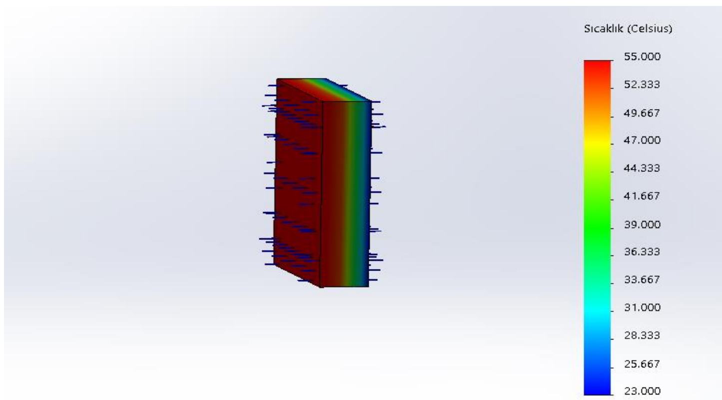


Figure 10. SolidWorks thermal analysis at 55 °C

As seen in Figure 10, due to the high thermal conductivity coefficients of Copper, Aluminum, and Steel materials, the inlet temperature was transmitted in Red (high temperature), that is, without much temperature loss between the above-mentioned materials. In the wooden plate, on the other hand, it is observed in the green part where there is a sudden decrease in temperature due to the low thermal conductivity coefficient. In glass wool and rock wool insulating materials, it is seen in the blue part where the temperature is equal to the temperature of the experimental laboratory.

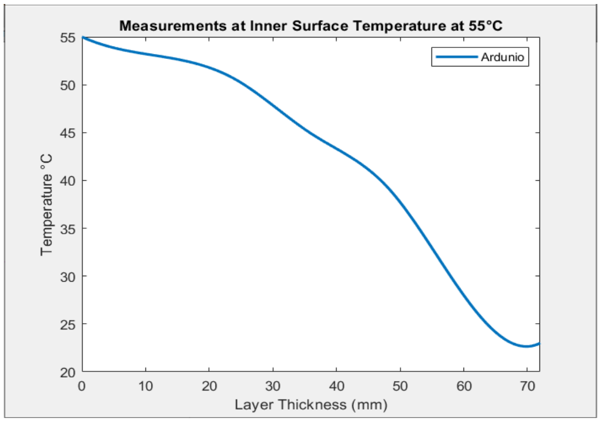


Figure 11. MATLAB Arduino analysis at 55°C

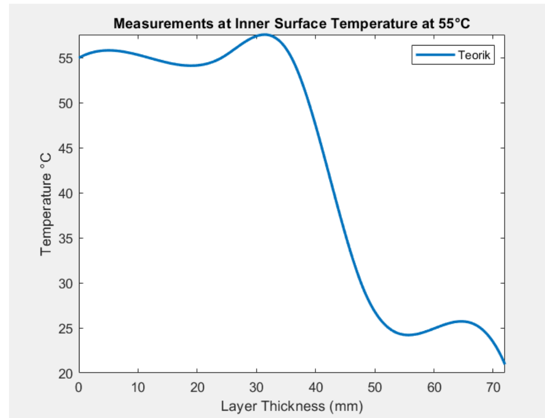


Figure 12. MATLAB theoretical analysis at 55°C

The values measured in the experimental setup are shown in Table 3. In Figure 11 and Figure 12. The values are shown graphically in the MATLAB program. If Solidworks thermal analysis and graphics are examined, the Arduino values and analysis values confirm each other. Theoretical values, on the other hand, differed because of the assumptions made. The difference seen in the theoretical calculations is due to the assumption that there is no heat loss.

Table 4. Table of Results at 60°C

Method	T_i	T_1	T_2	T_3	T_4	T_5	T_o
Ardunio	60	58	54.5	48.3	43.3	32	23
SolidWorks Thermal	60	56.917	50.75	47.667	41.50	27.50	23
Theoric	60	59.98	59.97	59.93	29.88	25.83	21.72

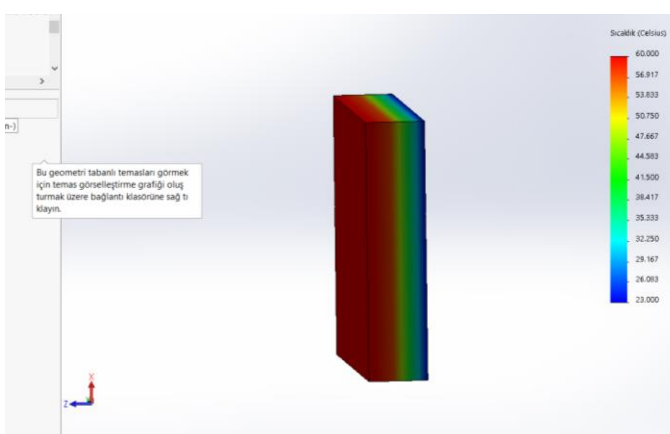


Figure 13. SolidWorks thermal analysis at 60 °C

As seen in Figure 13, due to the high thermal conductivity coefficients of Copper, Aluminum, and Steel materials, the inlet temperature was transmitted in Red (high temperature), that is, without much temperature loss between the above-mentioned materials. In the wooden plate, on the other hand, it is observed in the green part where there is a sudden decrease in temperature due to the low thermal conductivity coefficient. In glass wool and rock wool insulating materials, it is seen in the blue part where the temperature is equal to the temperature of the experimental laboratory.

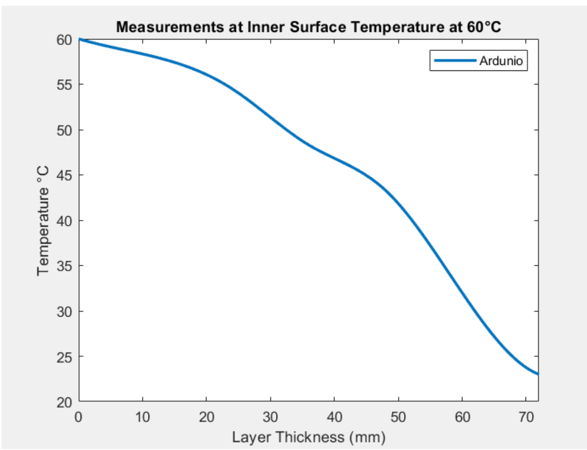


Figure 14. MATLAB Arduino analysis

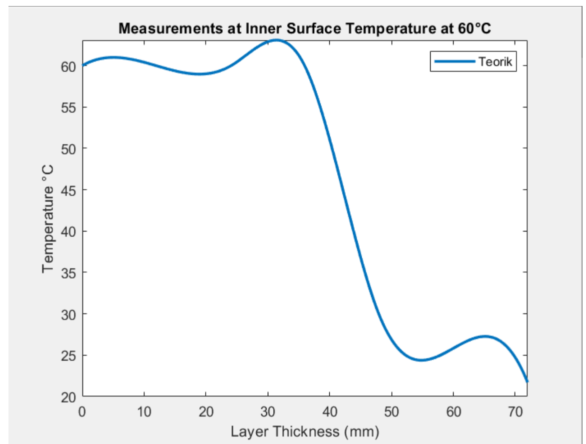


Figure 15. MATLAB Theoretical analysis

The values measured in the experimental setup are shown in Table 4. In Figure 14. and Figure 15. the values are shown graphically in the MATLAB program. If Solidworks thermal analysis and graphics are examined, the Arduino values and analysis values confirm each other. Theoretical values, on the other hand, differed because of the assumptions made. The difference seen in the theoretical calculations is due to the assumption that there is no heat loss.

Table 5. Results Table at 65°C

Method	T_i	T_1	T_2	T_3	T_4	T_5	T_o
Ardunio	65	63	59.8	52.3	47.4	37.6	23
SolidWorks Thermal	65	61.50	58	51	47.500	37.1	23
Theoric	65	64.97	64.96	64.91	32.54	26.94	22.90

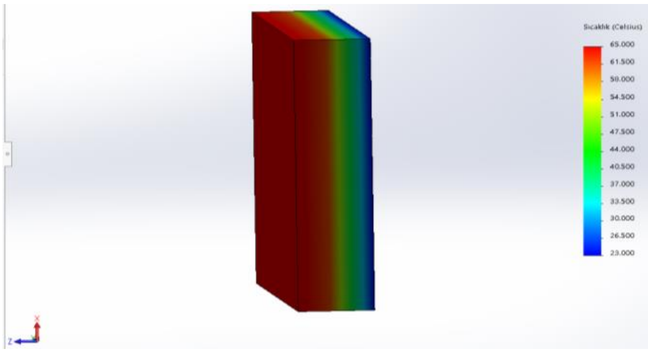


Figure 16. SolidWorks thermal analysis at 65 °C

As can be seen in Figure 16, Copper, Aluminum, Steel materials are transmitted in red color (high temperature), that is, the inlet temperature, without much temperature loss between the above-mentioned materials, due to their high thermal conductivity coefficients. In the wooden plate, on the other hand, it is observed in the green part where there is a sudden decrease in temperature due to the low thermal conductivity coefficient. In glass wool and rock wool insulating materials, it is seen in the blue part where the temperature is equal to the temperature of the experimental laboratory.

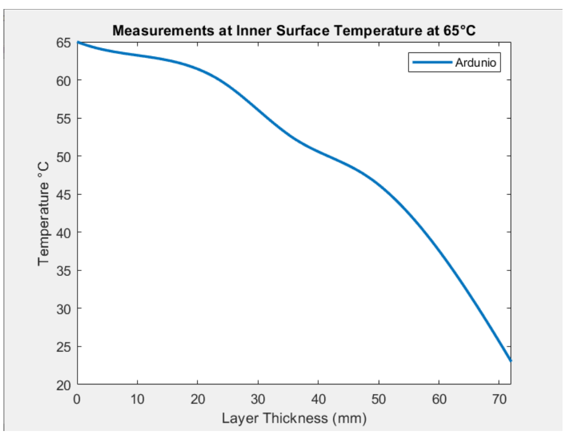


Figure 17. MATLAB Arduino analysis

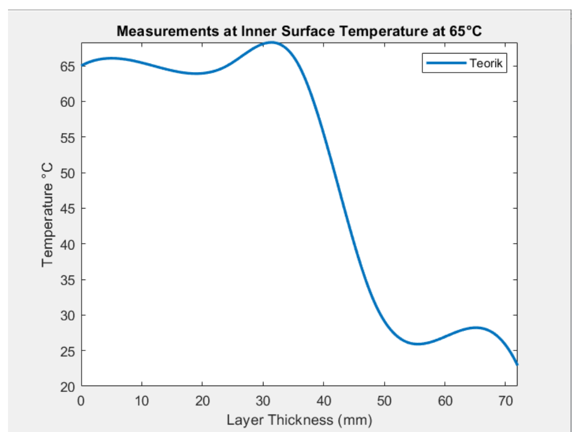


Figure 18. MATLAB Theoretical analysis

The values measured in the experimental setup are shown in Table 5. In Figure 17 and Figure 18, the values are shown graphically in the MATLAB program. If Solidworks thermal analysis and graphics are examined, the Arduino values and analysis values confirm each other. Theoretical values, on the other hand, differed because of the assumptions made. The difference seen in the theoretical calculations is due to the assumption that there is no heat loss.

Table 6. Results Table at 70°C

Method	Ti	T_1	T_2	T_3	T_4	T_5	T_o

Ardunio	70	67.7	61.8	54.1	49.4	40.6	23
SolidWorks Thermal	70	66.083	62.167	54.33	46.50	38.667	23
Theoric	70	69.97	69.96	69.91	33.84	28.01	23.34

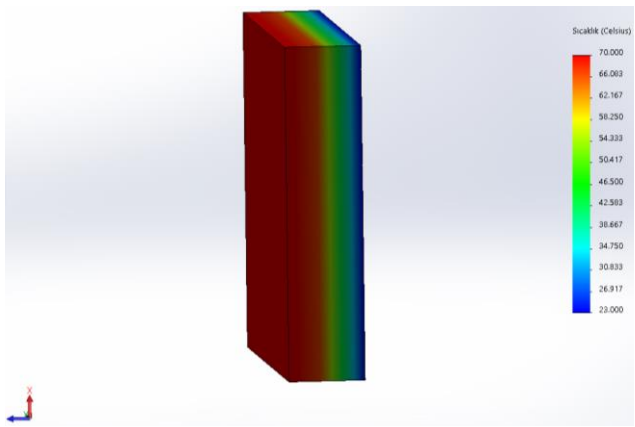


Figure 19. SolidWorks thermal analysis at 70°C

As can be seen in Figure 19, due to the high thermal conductivity coefficients of Copper, Aluminum, and Steel materials, the inlet temperature is transmitted in Red (high temperature), that is, without much temperature loss between the above-mentioned materials. In the wooden plate, on the other hand, it is observed in the green part where there is a sudden decrease in temperature due to the low thermal conductivity coefficient. In glass wool and rock wool insulating materials, it is seen in the blue part where the temperature is equal to the temperature of the experimental laboratory.

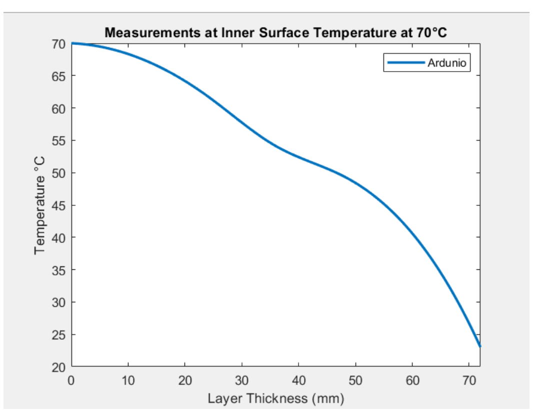


Figure 20. MATLAB Arduino analysis 70°C

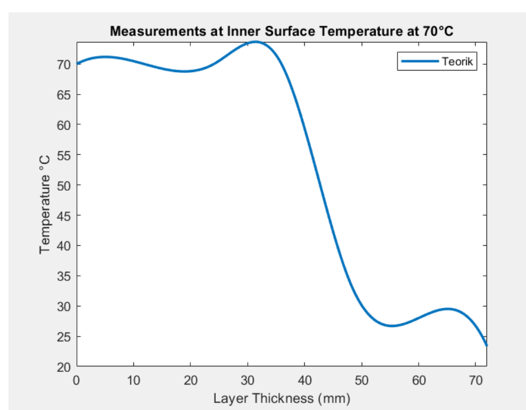


Figure 21. MATLAB Theoretical analysis at 70°C

The values measured in the experimental setup are shown in Table 6. In Figure 20. and Figure 21. the values are shown graphically in the MATLAB program. If Solidworks thermal analysis and graphics are examined, the Arduino values and analysis values confirm each other. Theoretical values, on the other hand, differed because of the assumptions made.

4. Discussion and Conclusion

If an inference is made with graphics and collected data, it is seen that SolidWorks analysis values and Arduino temperature measurements confirm each other. If a comparison is made with theoretical values, there are differences in the values due to the accepted assumption that there is no heat loss.

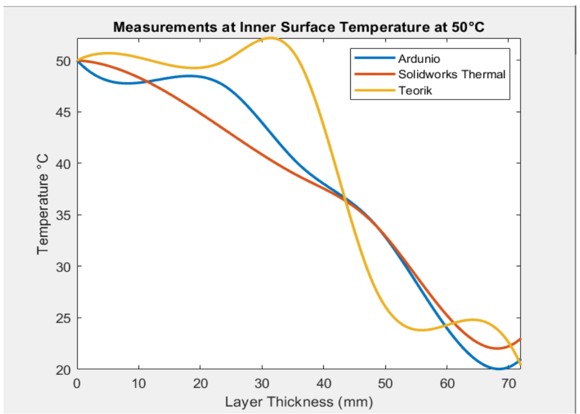


Figure 22. Temperature and layer thickness at 50°C (By MATLAB)

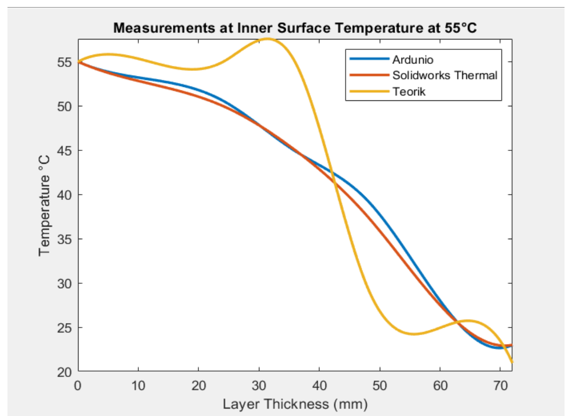


Figure 23. Temperature and layer thickness at 55°C (By MATLAB)

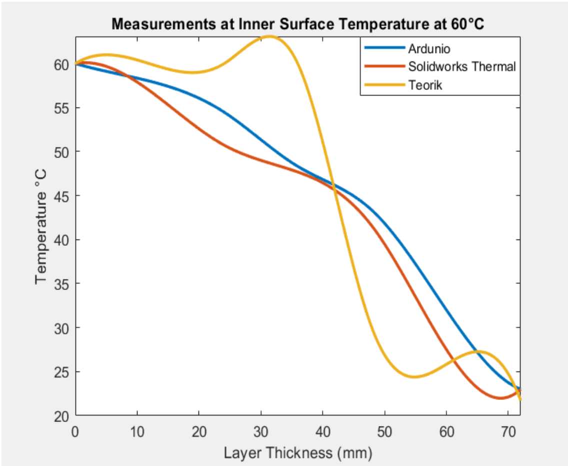
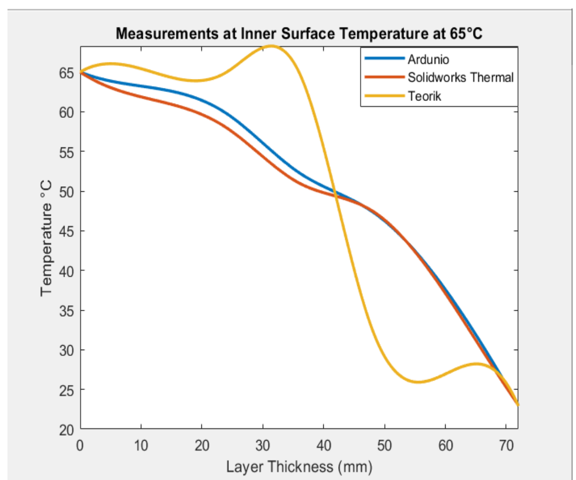


Figure 24. Temperature and layer thickness at 60°C Figure 25. Temperature and layer thickness at 65°C



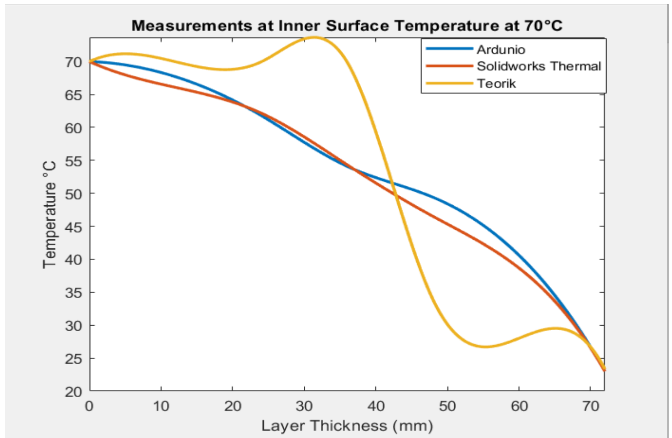


Figure 26. Temperature and layer thickness at 70°C

A layered wall assembly was established using 6 different materials and the heat transfer in the wall was examined in detail. As seen in Figure 22-26 graphics, Arduino temperature measurement, SolidWorks thermal values and theoretical results confirm each other.

In the study, a multi-layer heat conduction mechanism was created with 6 different materials. The Arduino temperature system was created, and the interlayer temperatures were measured. The temperature variation between the layers was recorded for the inner surface temperatures of 50 55 60 65 70 degrees. Multi-layer wall design was made from Solidworks thermal program and analysis was made for the same interior surface temperatures. Theoretical calculations have been calculated because of the determined method and acceptance. The data collected for the 3 measurement methods were compared and presented in graphs.

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Symbols:

Q: amount of heat (w)

k: coefficient of thermal conductivity (W/mK)

A: surface area (m^2)

dT: temperature difference (C)

dx: position change (m)

R: thermal resistance of the medium (Ω)

U: coefficient of total thermal conductivity (W/mK)

L: length (m).