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Analysis of Soil Heat Propagation Properties for Determining the Optimal Soil Type in Passive Photovoltaic Cooling Systems

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ABSTRACT

Rising photovoltaic (PV) module operating temperature substantially reduces conversion efficiency, motivating passive, low-cost cooling strategies that avoid extra electrical energy consumption. Grounding-based passive cooling, using surrounding soil as a heat-dissipating medium, offers a promising alternative; however, prior studies have mostly characterized soil thermal properties in isolation rather than directly comparing soil types under a unified, real-time measurement protocol relevant to PV cooling. This study aims to analyze and compare the thermal conductivity of clay and coastal sandy soil as candidate passive-cooling media, while examining how moisture content and pH influence heat propagation. A quantitative experimental approach was employed using the Transient Line Heat Source (TLHS) technique, implemented through an ESP32 microcontroller integrated with a DS18B20 temperature sensor and a soil moisture/pH probe for automatic, real-time data acquisition. The system operated stably in an integrated manner, producing consistent temperature-time data for conductivity calculation. Results showed clay had an average thermal conductivity of 1.133 W/mK at 74.25% moisture content, while coastal sandy soil reached 1.595 W/mK at 81.25% moisture content, an increase of about 40.78%, indicating moisture content, alongside soil type, is a key determinant of heat propagation. These findings imply soils with higher natural moisture retention are more promising passive-cooling media, offering practical guidance for designing low-cost, energy-independent cooling solutions for tropical, ground-coupled PV installations.

Keywords: soil thermal conductivity; *transient line heat source*; ESP32; DS18B20; soil moisture

INTRODUCTION

The increasing global energy demand encourages various countries to accelerate the development of renewable energy sources that are more sustainable and environmentally friendly, one of which is solar energy through photovoltaic (PV) technology (Haegel & Kurtz, 2025). Photovoltaic technology is developing rapidly because it is able to convert solar radiation directly into direct current (DC) electrical energy that can be used for various modern energy needs (Saravanan et al., 2024). In addition to having abundant energy sources, PV systems are also considered more efficient, easy to implement, and able to provide electricity supply independently without relying fully on the conventional power grid (Jahan et al., 2025). The use of this technology is increasingly widespread, ranging from solar-based street lighting systems, household-scale power plants, to independent electricity systems in remote areas that have not been reached by the main electricity distribution network (Pongoh et al., 2025).

The use of photovoltaic is very suitable to be applied in tropical countries such as Indonesia which are located on the equator and receive exposure to sunlight almost all year round (Harianto & Karjadi, 2022). These geographical conditions make Indonesia have a huge potential for solar energy to be developed as a future energy source. The intensity of solar radiation in some regions of Indonesia even reaches 4.5–5.8 kWh/m² per day, thus providing a great opportunity in the

development of a more optimal and sustainable solar power generation system (Martin et al., 2022). With this potential, PV technology is one of the strategic solutions in supporting the national energy transition towards the use of clean energy and reducing dependence on fossil energy. However, the performance of solar panels still faces a major obstacle in the form of an increase in the operating temperature of the module which can significantly reduce the efficiency of the output power.

During the process of absorbing solar radiation, some of the energy received by the photovoltaic panel is not entirely converted into electrical energy, but rather converted into heat energy that accumulates on the surface of the module (Dada & Popoola, 2023). This heat accumulation causes the panel's temperature to increase as the intensity of solar radiation changes throughout the day (Al-Ghussain et al., 2023). The increase in temperature has a direct impact on the electrical characteristics of solar cells, especially a decrease in output voltage which results in a decrease in the efficiency of electrical energy conversion (Dubey et al., 2013). In monocrystalline silicon solar panels, a temperature increase of 1°C can reduce the output power by about 0.5%, so a temperature increase of up to 10°C has the potential to reduce the output power of the panel by about 5% (Libra et al., 2021). This condition shows that the working temperature is one of the most important parameters that affect the stability and performance of the photovoltaic system (Jo et al., 2024).

One potential approach is grounding-based passive cooling by utilizing soil as a heat-dissipating medium. The ability of soil to conduct heat is determined by the value of thermal conductivity which is influenced by various factors such as soil type, moisture content, density, soil structure, and chemical conditions such as pH (Majeed et al., 2023). Meanwhile, the characteristics of soil microstructure are also influenced by pH and moisture values which can affect the heat propagation process (Lunt et al., 2023);(Haas & Horn, 2018);(Wang et al., 2023). Therefore, the thermal characteristics of the soil cannot be determined based solely on the type of soil, but are the result of the interaction of various physical and chemical parameters of the soil.

Although previous studies have established that soil thermal conductivity is influenced by physical and chemical parameters such as moisture content, density, structure, and pH (Majeed et al. 2023; Lunt et al. 2023; Haas and Horn 2018; Wang et al. 2023), most of this work remains descriptive in nature: it characterizes individual soil properties in isolation rather than critically comparing how different soil types perform against one another under a controlled, real-time measurement protocol relevant to photovoltaic cooling. This represents a clear research gap, since selecting an optimal passive-cooling medium requires direct, side-by-side empirical evidence rather than inferences drawn from studies conducted for different purposes, such as geotechnical or agricultural soil characterization. Moreover, most previous studies have not specifically compared the heat propagation capabilities of distinct soil types while simultaneously accounting for both physical and chemical parameters within the context of photovoltaic cooling applications.

Therefore, research that provides more representative empirical data under actual conditions is needed, particularly to determine the most effective soil type as a passive cooling medium. Based on this gap, this study aims to analyze and compare the thermal conductivity values of clay and sandy soils using the Transient Line Heat Source method, as well as examine the influence of moisture content and pH parameters on the ability to propagate heat. The study also evaluated the reliability of DS18B20 temperature sensors in the measurement process to ensure the accuracy of the data obtained. Distinguished from earlier investigations that rely on either steady-state methods

or single-parameter soil characterization, this research combines a transient, real-time acquisition approach with simultaneous physical–chemical parameter monitoring, providing a more direct and reproducible basis for comparing soil media. With this microcontroller-based experimental approach, this research is expected to provide a scientific basis for selecting the optimal soil medium for passive cooling systems in photovoltaic modules.

Thus, the novelty of this research lies in the integration of thermal conductivity analysis of two types of soils by taking into account specific physical and chemical parameters, as well as the application of transient measurement methods based on real-time data acquisition systems to support the development of more effective and applicable passive cooling systems. From a practical standpoint, the resulting data are expected to provide engineers and PV system designers with an evidence-based criterion for selecting locally available soil media, particularly in tropical regions such as Indonesia where land-mounted or ground-coupled PV installations are common; from a scientific standpoint, the study contributes an empirically validated, low-cost, microcontroller-based measurement protocol that can be replicated or extended in future thermal-management research for renewable energy systems.

RESEARCH METHODS

This study adopts a quantitative method of system experimentation, where this approach is applied to the creation of measurement systems and data analysis. By comparing the heat propagation values of clay and sandy soils as well as moisture content and pH. This research involves the following steps and stages:

To improve methodological transparency and reproducibility, several procedural aspects are clarified as follows. Soil samples were taken from two contrasting sites representing clay and coastal sandy soil, and each sample was homogenized and placed in the test container prior to probe insertion so that the heater and temperature sensor were in direct, consistent contact with the soil matrix. Prior to data collection, the DS18B20 temperature sensor was checked against a calibrated reference thermometer, and the soil moisture/pH probe was verified using a known-value reference solution, to ensure that the recorded readings reflected the actual soil condition. For each soil type, the heating and data-logging procedure illustrated in Table 1 was repeated over multiple cycles (n = 10 heater-power readings, as summarized in Table 1) to evaluate the repeatability of the heat-flux output before the thermal conductivity measurement itself was performed; the mean and range of these repeated readings, rather than a single reading, were used to characterize the stability of the heating source.

Thermal conductivity values were then calculated from the temperature-time pairs using the transient equations described below, and the two soil types were compared descriptively based on their resulting conductivity, moisture, and pH values. Measurement points were selected at the depth at which the heater probe could be fully embedded with uniform soil contact, avoiding surface layers subject to rapid moisture loss. The authors acknowledge that a fully quantified uncertainty analysis (e.g., propagated instrument error and formal replication of the full TLHS measurement across multiple independent trials per soil type) was not performed in the original data collection; this is noted as a limitation of the present study and a direction for future refinement of the experimental protocol.

Hardware Design

The main instrument used in this study is a measurement system based on the Transient Line Heat Source method which is integrated with the ESP32 microcontroller. The system consists of a temperature sensor DS18B20 to measure temperature changes continuously, a heating element (heater) as a linear heat source, and a power supply to maintain power stability. All components are integrated through programming using the Arduino IDE, allowing real-time data acquisition.

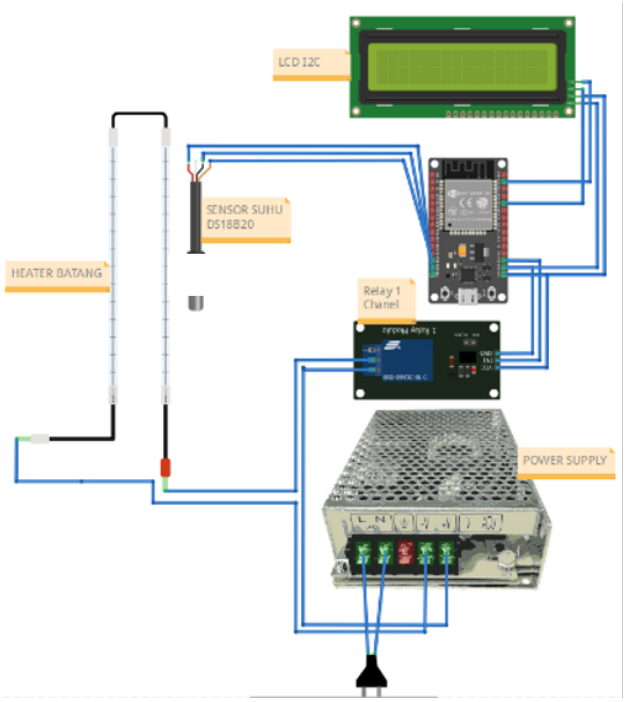


Figure 1. Wiring System Diagram

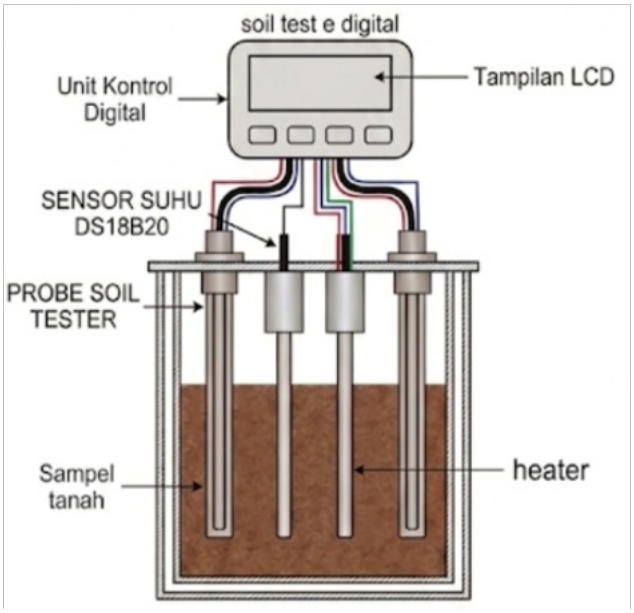


Figure 2. Measurement Setup

Figure 2 shows the design of a soil measurement probe based on the Transient Line Heat Source (TLHS) method consisting of a heater as a heat source and a DS18B20 temperature sensor connected to an ESP32 microcontroller for real-time acquisition of thermal conductivity data. Soil moisture and pH measurements are carried out using a 2 in 1 soil moisture tool that is integrated by itself.

Diagram Block System

The system block diagram consists of three main parts, namely inputs, processes, and outputs that are integrated with each other in measuring soil thermal conductivity. In the input section, there are two main components, namely the heater and the temperature sensor DS18B20. The heater serves as a linear heat source that is planted inside the soil medium to generate heat flow. When the heater is activated, the heat will propagate to the surrounding soil environment. Meanwhile, the sensor DS18B20 functions to measure changes in soil temperature due to the warming. The resulting temperature data is a function of time (T to t), which is the main parameter in the transient method.

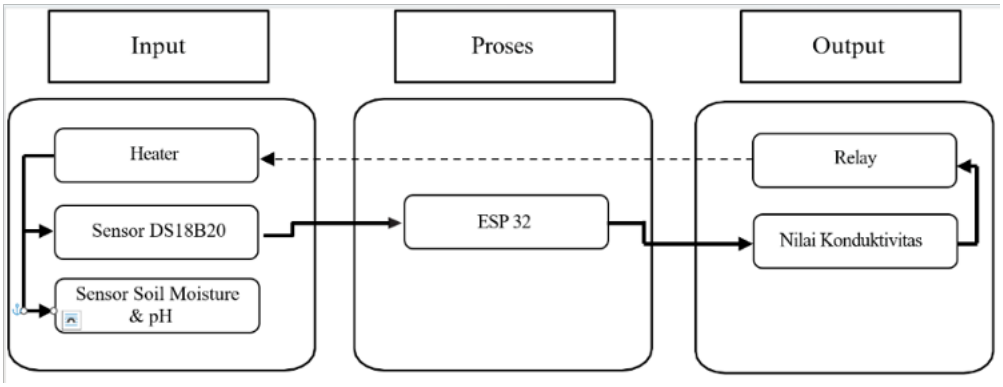


Figure 3. System Block Diagram

System Flowchart

System flowchart in Drawing. 4 describes the workflow starting from the initialization of all components, then the system activates the heater as a heat source to heat the ground medium, the temperature sensor continuously reads the temperature change over time (T and t), then the system checks the condition until the temperature reaches the desired state, after which the temperature and time data obtained are processed by ESP32 using the transient method to calculate the thermal conductivity value (λ).

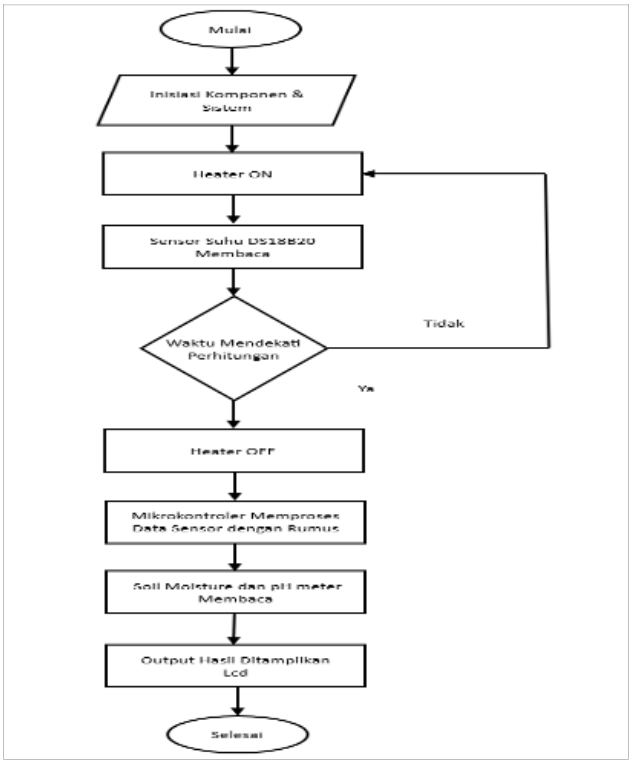


Figure 4. *System Flowchar*

Implementation of Measurement System

Data collection is carried out automatically by the system through the recording of temperature (T) and time (t) value pairs in certain intervals. The data collected is then analyzed using transient method equations to determine the value of thermal conductivity. In the analysis, two data points (beginning and end) are used to describe temperature variations over time. To maintain the validity of the data, the system only processes data that has a positive temperature difference ($\Delta T > 0$), thus avoiding miscalculations. The measurement system uses the following equations:

$$\lambda = \frac{Q}{4\pi(T_2 - T_1)} \ln\left(\frac{t_2}{t_1}\right) \quad (1)$$

In the equation, λ expresses the value of the thermal conductivity of the soil (W/mK), Q is the heat rate per unit length of the heater (W/m), while T_1 and T_2 are the temperature at the time of measurement t_1 and t_2. The value of π is a mathematical constant of 3.14. This equation shows that the conductivity value is obtained from the relationship between heat flux, temperature changes, and time changes during the heating process. This conservation implementation is directly embedded in the ESP32 program which first calculates the temperature difference ($\Delta T = T_2 - T_1$) to ensure that the data is valid before the results are displayed on the serial monitor or LCD as the output system.

Heat flux conversion

The value of the heat power generated by the heating element is then converted into a linear heat flux to represent the distribution of the heat source throughout the test medium. This conversion is carried out by comparing the heat power to the length of the heating element, so that the heat flux parameters are obtained which are the basis for the analysis of the Transient method.

$$q = \frac{Q}{L} \tag{2}$$

With as a linear heat flux (W/m), as a heat power, and as the length of the heating element. This value is used as a key parameter in the calculation of thermal conductivity because it reflects the rate of heat distribution along a linear heat source.$q = Q/L$

RESULTS AND DISCUSSION

System Design Results

The results of the system design in this study are the implementation of the Transient-based soil thermal conductivity measurement method. The system design is carried out by integrating hardware and software so that it is able to produce a measurement system that works automatically, accurately, and stably in recording temperature change data against time.

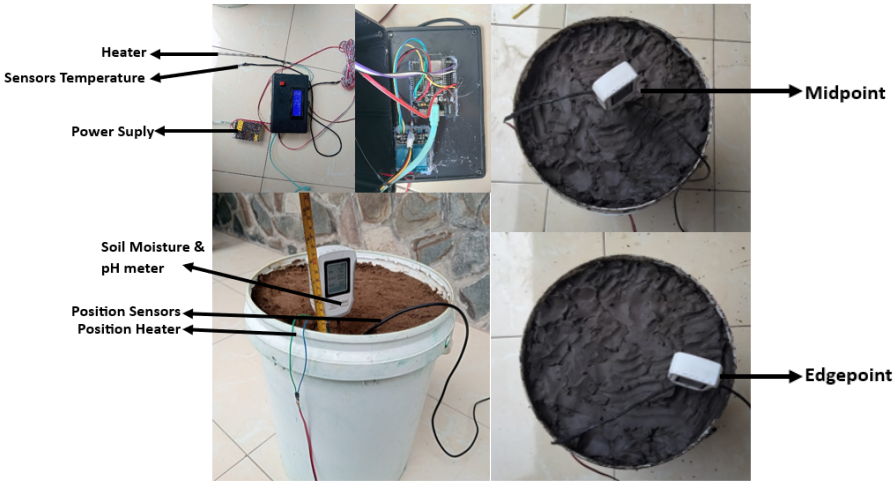


Figure 5. *Conductivity* Measurement System Prototype

The system consists of an ESP32 microcontroller as the control center, a temperature sensor DS18B20 as a temperature gauge, a heating element (heater) as a heat source, a relay as an electrical contactor on the heating element and a soil tester sensor to measure soil moisture and pH. In its implementation, the system is used to measure the thermal characteristics of clay and sandy soils. The heater serves as a heat source that generates heat propagation in the soil, while the sensor DS18B20 read temperature changes over time. The data obtained was then processed to determine the value of thermal conductivity using the Transient method. Overall, the system has been designed to work well, where all components can be integrated and work automatically. The system is also capable of recording temperature data continuously and generating thermal conductivity values. Shows the measurement setup of edge and midpoint points in thermal conductivity measurement testing.

Transient Conduction Test Results

Based on the results of the analysis of temperature graphs over time, it can be concluded that the heat transfer process that occurs in clay and coastal sandy media shows the characteristics of heat transfer in a transitory manner. This is indicated by the appearance of a significant increase in

temperature at the beginning of warming, which is then accompanied by a decrease in the rate of temperature increase over time.

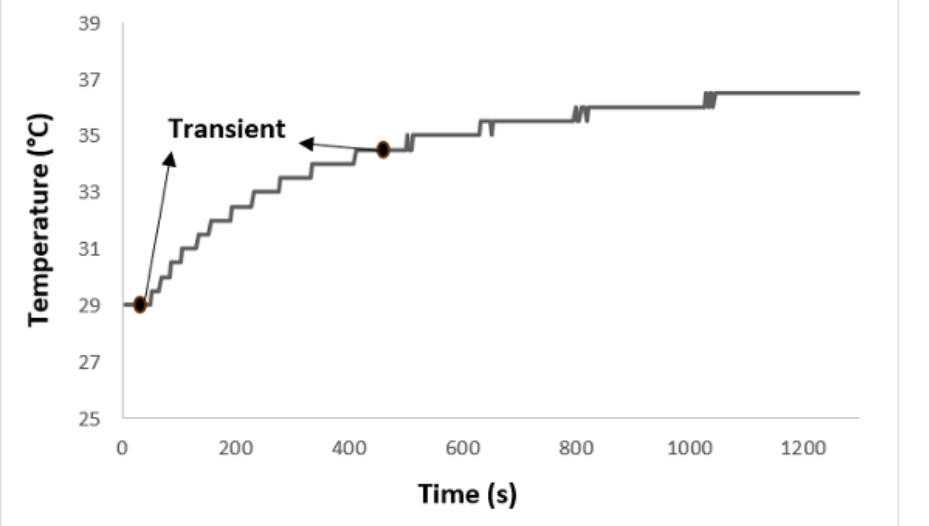


Figure 6. Transient Conduction Measurement Graph

The most representative time range to describe the transient conditions of both types of soil is at intervals of about 37 seconds to 556 seconds. At this range, temperature changes still occur significantly so that the data obtained reflect the heat propagation process that has not yet reached a stable condition. Therefore, such time intervals can be considered as ideal conditions in data capture for transient heat transfer analysis.

Heater Power Test Results

The stability test of the heater power in this study was carried out to determine the accuracy level of the heater power used for 10 minutes, to obtain a stable heat flux value to maintain the reliability of the system, by dividing the heating power by the length of the heater element by 0.15 meters. For the collection of power values by measuring the voltage and current of the heater element.

Table 1. Heat Flux Heater Results

No	Tegangan(V)	Current(A)	Power(W)	Q (W/m
1	11.91	0.35	4.16	27.7
2	11.91	0.35	4.16	27.7
3	11.91	0.35	4.16	27.7
4	11.93	0.35	4.17	27.8
5	11.91	0.35	4.16	27.7
6	11.91	0.35	4.16	27.7
7	11.91	0.35	4.16	27.7
8	11.93	0.35	4.17	27.8
9	11.95	0.35	4.18	27.8
10	11.91	0.35	4.16	27.7

No	Tegangan(V)	Current(A)	Power(W)	Q (W/m
	Average		4.16	27.7

Source: Data Processed

Based on Table 1, the voltage during the test was in the range of 11.91–11.95 V and the current remained constant at 0.35 A. This condition resulted in an almost unchanged power, which was 4.16-4.18 W with an average of 4.16 W. The heat flux value (Q) was also relatively uniform, being in the range of 27.7–27.8 W/m with an average of 27.7 W/m. The very small difference between the data is thought to be due to slight fluctuations in the voltage source. However, a power that tends to be constant indicates that the heater is working stably. This is important because the stability of power has a direct effect on the uniformity of the heat flux, so that the temperature distribution within the material can be observed more consistently.

Temperature Sensor Accuracy Test Results DS18B20

The sensor accuracy test in this study was carried out to determine the accuracy of the reading level of the temperature sensor used, namely the DS18B20 sensor, by comparing the measurement results to a reference tool in the form of IR Thermography. These tests aim to ensure that the temperature data used in thermal conductivity analysis is of good reliability.

Table 2. Temperature Sensor Accuracy DS18B20

No	DS18B20	IR Thermography	Error (%)	Accuracy (%)
1	32	32.4	1.23%	98.77%
2	36	36.4	1.09%	98.91%
3	38	38.8	2.06%	97.94%
4	39	39.5	1.26%	98.74%
5	42	42.2	0.47%	99.53%
6	44.5	45	1.11%	98.89%
7	49	49.8	1.60%	98.40%
8	50.5	51	0.98%	99.02%
9	52.5	53.3	1.50%	98.50%
10	53.5	53.9	0.74%	99.26%
		Average	1.20%	98.79%

Source: Data Processed

Based on Table 2, the temperature sensor measurements DS18B20 compared to IR Thermography showed fairly close results, with a small difference at each point. The error value was in the range of 0.47%–2.06% with an average of 1.20%, where the highest error occurred in the 3rd measurement and the lowest in the 5th measurement, the difference is suspected to be influenced by the characteristics of the sensor response and environmental conditions during the measurement process. In terms of accuracy, DS18B20 showed good performance with values between 97.94%–99.53% and an average of 98.79%. The sensor also remains consistent over higher temperature

ranges. In general, the deviations that occur are still within reasonable limits, so these sensors can be considered sufficient for use in temperature measurements in heat transfer studies.

Experimental Test Results

Experimental tests were carried out on clay and sea sand for 9 minutes under transient conditions, with depth variations of 10 cm and 20 cm at the center and edge measurement points. The data obtained included test time, pH, humidity, temperature change, heat flux, and thermal conductivity values.

Clay Test Results

The results of the system design and test data that have been carried out on the soil thermal conductivity measurement system based on the transient method are an important part of this study. The process includes several stages, from hardware design, integration of components such as temperature sensors and heaters, to testing on different soil types and conditions. Each stage is done in stages to ensure the system can work properly and produce consistent data.

The test results data were used to determine the thermal conductivity value of the soil based on the temperature response to the application of heat flux during transient conditions. The analysis is carried out by observing temperature changes over time, so that the relationship between heat distribution and the thermal conductivity of the material can be known (Yang et al., 2025). The consistency of the data obtained is also an indicator that the system is able to produce relatively stable conductivity values.



Figure 7. Clay Testing

Table 3. Clay Testing

No	Time (minutes)	Point & Depth (cm)	pH	Humidity (%)	Temperature Change (C)	Heat Flux	Conductivity (W/mK)
1	9	Midpoint - 10 cm	5.3	73%	6°C	27.8	1.077
2	9	Edge point - 10 cm	6.1	84%	4°C	27.8	1.481
3	9	Midpoint - 20 cm	5.3	70%	6°C	27.7	0.987
4	9	Edge point - 20 cm	6.3	70%	6°C	27.8	0.987
Average			5.7	74,25%	5,5°C	27.7	1.133

Source: Data Processed

This table shows the results of measuring the thermal conductivity of clay based on point and depth variations. The value is in the range of 0.987–1.481 W/mK, with an average of 1.133 W/mK. This condition is influenced by soil moisture in the range of 70%–84% and pH values of 5.3–6.3, in addition to the temperature change that occurs in the range of 4–6°C with an average of 5.5°C, and the heat flux is relatively stable at around 27.7–27.8 W/m with an average of 27.7 W/m. The results of the thermal conductivity are still in accordance with the literature, where the thermal conductivity of clay soils is in the range of 0.85–1.4 W/mK (Rasimeng, 2020).

The variation in the value obtained is related to the moisture content and structure of the soil. Increased humidity tends to increase the soil's ability to conduct heat (Liu et al., 2022), in line with previous research that mentioned moisture content as a major factor in thermal conductivity. In the test, higher humidity results in a greater conductivity value because water acts as a heat-conducting medium. In contrast, at low humidity, the conductivity value decreases. In addition, the difference in measurement point and depth (10 cm and 20 cm) also affected the results. The middle point tends to show a more stable value, while at the edges the results are more varied which is influenced by humidity.

Results of Coastal Sand Soil Testing

The results of observations on coastal sandy soils in this study were carried out to analyze the characteristics of soil thermal conductivity by considering moisture and pH parameters. This analysis aims to determine the relationship between the physical condition of the soil and the ability of the soil to conduct heat based on the test results data that have been obtained. In addition, observations are carried out in stages by paying attention to changes in temperature values over time during the heating process, so that a clearer picture can be obtained about the mechanism of heat propagation in the soil medium. The resulting data is then processed using the thermal conductivity calculation method to obtain a representative value (Lambrou & Gergidis, 2024). The results of this analysis are expected to show how soil conditions vary, especially humidity and pH levels.



Figure 8. Coastal Sand Soil Testing

Table 4. Coastal Sand Soil Testing

No	Time (minutes)	Point & Depth (cm)	pH	Humidity (%)	Temperature Change (C)	Heat Flux	Conductivity (W/mK)
1	9	Midpoint - 10 cm	5.8	86%	3°C	27.8	1.786
2	9	Edge point - 10 cm	6.1	79%	4°C	27.7	1.48
3	9	Midpoint - 20 cm	6.0	80%	4°C	27.8	1.55
4	9	Edge point - 20 cm	5.9	80%	4°C	27.8	1.566
Average			5.9	81.25%	4°C	27.7	1.595

Source: Data Processed

This table displays the results of measurements of the thermal conductivity of coastal sandy soils based on variation in point and depth. The value is in the range of 1,480–1,786 W/mK, with an average of 1,595 W/mK. Soil moisture is in the range of 79%–86%, while pH ranges from 5.8–6.1 in addition, the temperature change that occurs is in the range of 3–4°C with an average of 4°C, and the heat flux is relatively stable at around 27.7–27.8 W/m with an average of 27.7 W/m. The results of the thermal conductivity are still in accordance with previous research, where the thermal conductivity of granular soil is in the range of 1–3 W/mK. This condition shows that the data obtained is still in line with the general characteristics of the sandy soil, so that it can support the reliability of the research results (Musei et al., 2024).

Given these findings, it is evident that humidity has a major impact on thermal conductivity values. Under the conditions of a maximum humidity of 86%, a peak conductivity value of 1,786 W/mK is achieved. This shows that the higher the moisture content in the soil, the ability of the soil

to conduct heat also increases. In addition, the relatively stable soil pH value in the range of 5.8 to 6.1 indicates that pH does not exert a significant influence on changes in thermal conductivity values. Nevertheless, pH remains a supporting parameter in describing soil conditions during testing. The difference in measurement point and depth also shows variations in conductivity values, but these changes are not very significant compared to the influence of humidity. This shows that the main factor that affects the test results is the moisture content in the soil. Overall, the test results show that coastal sandy soils have good heat transfer ability under high humidity conditions.

Comparative Analysis of Clay and Coastal Sand Soil Test Results

Comparative analysis of test results on two types of soil media (clay and coastal sand) showed a significant difference in heat transmission ability, where the thermal conductivity values obtained reflected the influence of material characteristics and water content on the heat propagation process in each medium.

In addition, the characteristics of the internal structure of the soil also affect the speed of heat transfer, so that each type of soil has a different response to the given heating process. Soils with better heat-conducting capabilities will show faster and more stable temperature increases, while soils with lower heat-transmitting capabilities tend to experience slower heat propagation processes.

Table 5. Comparison of the Two Soils

No	Data	Clay	Coastal Sand Land
1	pH	5.7	5.9
2	Humidity	74.25%	81.25%
3	Conductivity (W/mK)	1.133	1.595
4	Remarks	It tends to have low humidity so that it affects its conductivity value, the pH value also decreases	It tends to have higher humidity than clay so it affects a higher conductivity value, the pH value also increases

Source: Data Processed

Based on the test results in Table 5, it was obtained that the thermal conductivity value (k) in clay soils was 1,133 W/mK, while in coastal sandy soils it was 1,595 W/mK. This value shows that coastal sand soils have better heat conductivity than clay. To determine the degree of difference in heat transmission ability between the two media, a percentage increase in thermal conductivity was used. with the formula:

$$\% \text{ Difference} = \frac{\text{New value} - \text{Reference value}}{\text{Reference value}} \text{ x100\%}$$

$$\% \text{ Difference} = \frac{k_{sand} - k_{clay}}{k_{clay}} \times 100\%$$

Value substitution:

$$= \frac{1.595 - 1.133}{1.133} \times 100\% = 40.78\%$$

The calculation results show that the thermal conductivity of coastal sandy soils is about 40.78% higher than clay. This difference is influenced by the material characteristics of each soil and the water content in it. Coastal sandy soils have a higher moisture value (81.25%) than clay soils (74.25%), thus accelerating the heat transfer process. The water content in the soil acts as a good heat conduction medium, so the higher the humidity, the higher the thermal conductivity value, the thermal conductivity value tends to increase. In contrast, clay soils show lower conductivity values because the heat propagation process takes place more slowly in the medium, so the ability to conduct heat is not as good as coastal sandy soils.

CONCLUSION

Based on the design and test results, the microcontroller-based soil thermal conductivity measurement system is able to work in an integrated manner and perform automatic temperature data acquisition well. The sensor DS18B20 responsive in recording temperature changes in real-time so it can be used to accurately calculate thermal conductivity. The test results showed that coastal sandy soils had a higher thermal conductivity (1,595 W/mK) than clay soils (1,133 W/mK), an increase of about 40.78%. This shows that in addition to soil type, humidity levels also play an important role in heat transmission ability. The higher water content in the sandy soil accelerates heat propagation so that it has the potential to be used as a passive cooling medium in photovoltaic systems. Further research is suggested to add porosity and soil density parameters, multiply measurement points, calibrate sensors periodically, and integrate the system with the Internet of Things (IoT).

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