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A METHOD FOR DETERMINING THE THERMOPHYSICAL PROPERTIES OF A CONSTRUCTION OBJECT

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A R T I C L E I N F O	A B S T R A C T
	Based on the analysis of the literature, a method was proposed for determining the actual thermophysical properties (thermal conductivity) of an object, according to which a portable automated installation was later developed to determine the thermophysical properties of an object using non-destructive testing using modern means of control and information processing for more a short period of time, non-stationary method. The developed installation is capable of determining the thermophysical properties of an object, as well as the spatial pattern of the distribution of heat flows inside the object, using non-destructive testing.

Disciplinary: Electronic Engineering, Thermal science.

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1. INTRODUCTION

Thermophysical properties (TPP) determine the discharge of fuel, electricity and materials temperature distributions. The analysis of the existing methods of determining the TPP of the object under study has shown that it is possible to develop an installation that will determine the TPP of the object NDTM using modern means of information handling and processing in a shorter period of time - in a non-stationary way (Ametistov, 2000; Bogoslovsky, 2013; Vavilov, 2009; Vidin et al., 2018; Fokin & Chernyshov, 2004; Kudinov, 2015; Fokin & Kovylin, 2009; Barilovich & Smirnov, 2014; Kabanov et al., 2014; Thermal protection of buildings, 2012). It should be noted that the non-stationary methods of TPP detection are the most promising due to their simplicity and short research time. According to the analysis performed, an algorithm (Malyavina, 2007; Kabanov & Panfilov, 2017) and an installation (Kabanov et al., 2017) were developed for the energy-efficient study of TPP of an NDTM object (Kabanov & Panfilov, 2017; Panfilov & Kabanov, 2016; Kabanov et al., 2016; Panfilov et al., 2019).

This study is devoted to the experimental studies of Thermo Physical Properties (TPP) of objects. The existing methods of TPP determination are analyzed. They presented the algorithm developed by the researcher for the TPP determination of the object under study. They described the operation of the unit for TPP (heat transfer coefficient, heat transfer resistance and specific thermal characteristic) determination of the object under study. The formulas are given required for TPP calculation. The experimental results of the study are presented. The main advantages of the developed unit are described.

2. METHOD

An installation block diagram is shown in Figure 1. The algorithm for assessing the thermal properties of the object is shown in Figure 2.
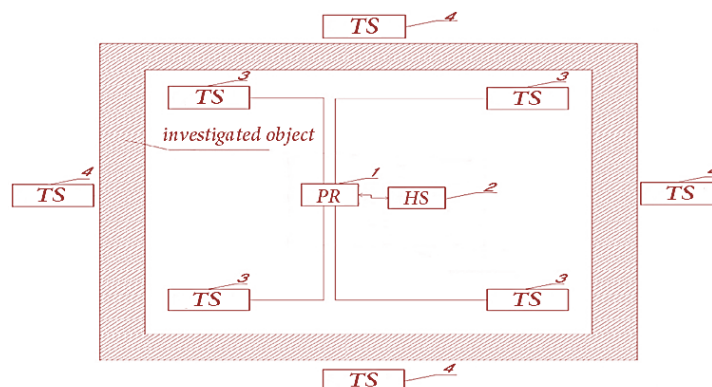

Figure 1: Block diagram of the designed portable unit.

The operating mode of the installation is as follows. Prior to the beginning of the object examination, temperature sensors 3 and 4 are installed along the internal and external perimeter of the object under study at an equidistant distance from each other. They determine the values to be used for further research: the power of the heat supply source $P_{ист}$, the total area of the object under study $S_{общ}$ on external measurement, V - the volume of the object under study on external measurement, the time of the study t, the temperature of the study $T_в$, as well as the delay time required for the study to be carried out. On reaching the temperature $T_в$, the programmable relay 1 fixes the time of the active functioning of heat supply source 2 for the whole duration of the study. While the study is being conducted, the ambient temperature readings are taken at a set time interval from the temperature sensors 4 for further calculation of the target values. By the end of the experiment, the thermophysical properties of the object under study are calculated according to the designed algorithm (Thermal protection of buildings, 2012; Malyavina, 2007; Kabanov et al., 2017).

Figure 2, the block diagram consists of 17 blocks. The values for further research are entered in 1: nominal capacity of heat supply source, total area of the object under research according to external measurement, volume of the object under research according to external measurement, temperature of maintenance inside the object under research during the research, time of research. The study timeout timer starts in 2. The condition is checked in 3: "$t_1>t_2$, time of research execution is exceeding the current time of research execution", during which the control is transferred to block 4, where the heat supply is switched on to heat the temperature inside the object under research, then, in 5, the ambient temperature reading is recorded outside the object under research into the device memory. Then the run time of the installation is started in active mode in 6. In 7, the condition is checked: "$t_1>t_2$, time of research is exceeding the current time of research", if the condition in 8 is

observed, the following condition is checked: " $T_{inside.} < T_{inside\ the\ specified}$, the current temperature inside the object is higher than the set maintenance temperature", if the condition in 9 is observed, the heat supply is stopped, the ambient temperature reading outside the object under research is recorded in the device memory in 10, and then in 11, a stop is made for a pause in time of the calculation of the installation operation in the active mode for the set maintenance time. The condition is checked in 12: " $t_1 > t_2$, research time is exceeded or equal to the set research time", if it is performed, then in 13 the condition is checked: " $T_{inside.} < T_{inside\ the\ specified}$, the current temperature inside the object is less than the set maintenance temperature" when it is performed - return to 4, if it is not performed in 9, when the conditions in one of the blocks 7 or 12 are reached, the algorithm passes to block 14, where the calculation of the installation time is stopped in the active mode. The ambient temperature reading is recorded in 15 outside the tested object to the device memory, in 16 the required values are calculated, and in 17 data output.
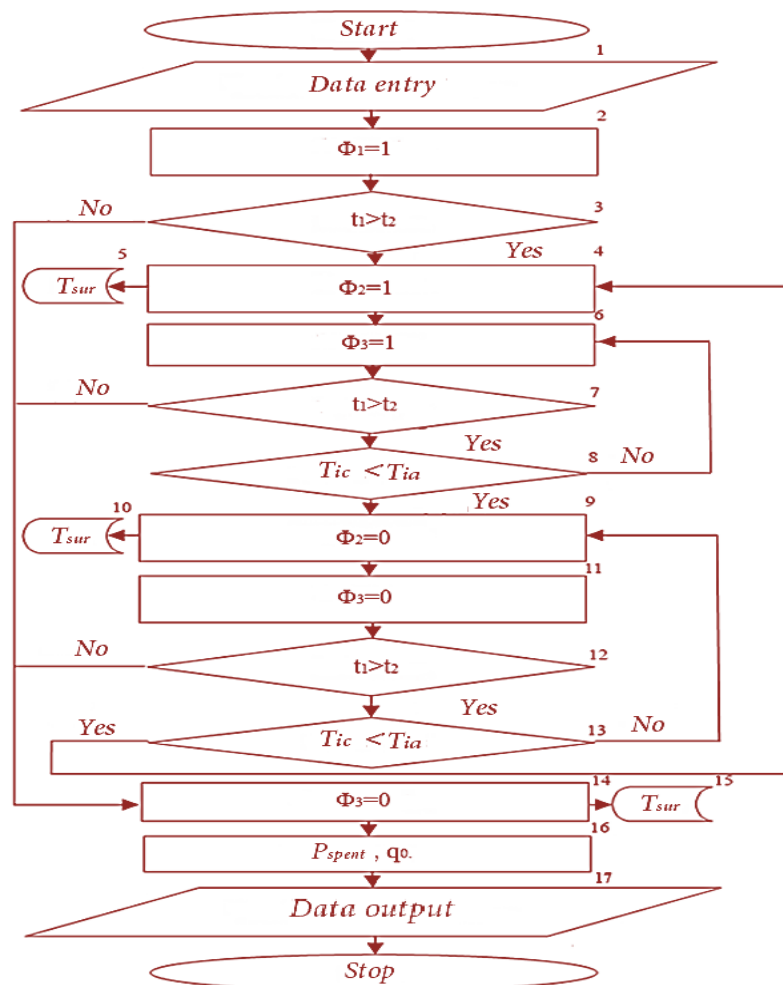

Figure 2: Block diagram of the algorithm for determining the TPP object

3. MATHEMATICAL MODELING

The needed mathematical formulas to determine the required values for the experiment are given below.

Average ambient temperature during the survey:

$$\overline{T}_{surrounding} = \frac{\sum T_{surrounding\,i}}{n} \tag{1},$$

where $T_{\text{surrounding}i}$ is the ambient temperature at the "i" moment of the study.

n - quantitative $T_{\text{surrounding}}$ readings during the study.

Average $P_{\text{spent.}}$ power consumption to maintain the set temperature during the survey (W):

$$P_{\text{spent}p.} = P_{\text{source.}} \cdot \frac{t_{\text{work}}}{t_{\text{maintenance}}} \tag{2}$$

where $P_{\text{source.}}$- rated power of a heat supply source, $t_{work.}$- time of active operation of a heat supply source, $t_{maintenane.}$- set time of maintenance of the set temperature $T_\text{в}$.

The ratio [28] is available from references:

$$q_0 V (T_{i\text{inside}} - T_{\text{surrounding}}) = P_{\text{spent}} \tag{3}$$

where q_0 is the specific thermal characteristic of the object W/(m3· º C));

Specific thermal characteristics of the object:

$$q_0 = \frac{P_{\text{spent.}}}{V \cdot (T_{\text{inside}} - \overline{T}_{\text{surrounding}})} \tag{4.}$$

To determine the required capacity of the heat supply system to maintain the optimal temperature inside the facility, considering the coldest five-day period:

$$P_{\text{source}} = q_0 V (T_{\text{within nominal}} - T_{\text{average ambient}}) \tag{5,}$$

where $T_{Bн}$ - is the optimal air temperature inside, according to the normative papers for this type of facilities; $T_{Oкрн}$ - is the average ambient temperature, considering the coldest five-day period for this location, as determined by the normative documents; P_{ucm} is the power of the heat supply source to maintain the optimal temperature inside the facility.

4. RESULT AND DISCUSSION

Based on the analysis of the literature presented in this article, a method was proposed for determining the actual thermophysical properties of an object, according to which a portable automated installation was later developed to determine the thermophysical properties of an object using non-destructive testing using modern means of control and information processing for more a short period of time - non-stationary way. The installation on the basis of the carried-out analysis and theoretical data to determine the TPP of the object under study. Figure 3 represents a block diagram of the installation.
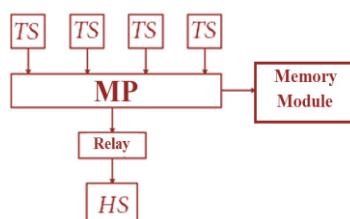

Figure 3: Block diagram of mobile installation for TPP detection.

Figure 4 provides a schematic diagram of the mobile automatic installation running on the Arduino Mega 2560 microcontroller. It should be noted that the Arduino MEGA 2560 is designed for projects that require more I/O lines, more sketch memory and more RAM.
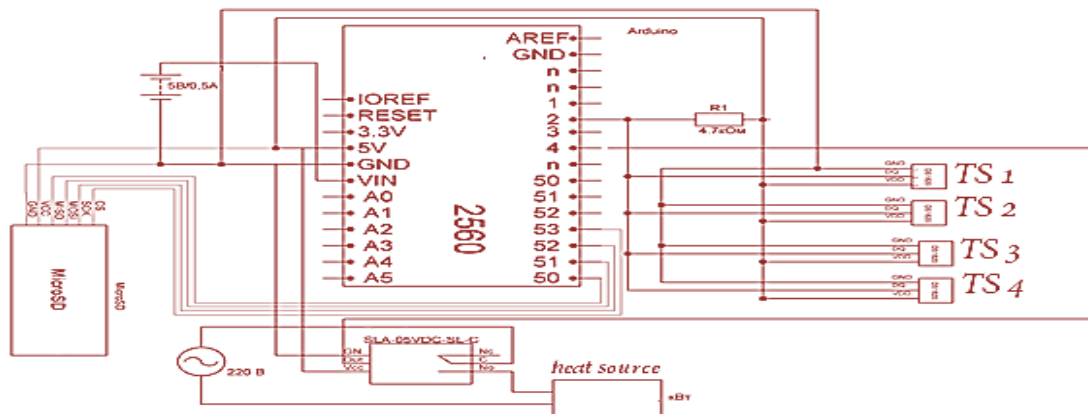

Figure 4. Schematic diagram of the portable automated installation to determine the FPS of the object

The code for the mobile automated system control program is written in the C++ programming language (Kabanov et al., 2018). We also used the complex assembled on the programmable relay PR200. The schematic diagram of the portable automated installation working on the programmable relay PR200 is provided in Figure 5.
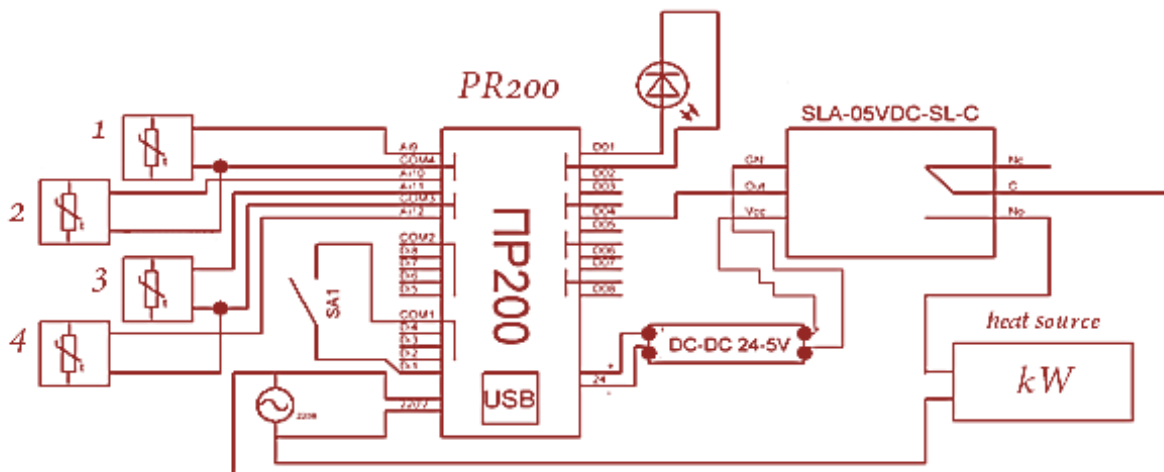

Figure 5: Schematic circuit diagram of mobile automated installation on programmable relay PR200.

The control program code developed in the Owen Logic programming environment to be used for controlling the mobile automated installation with the PR200 programmable relay (Panfilov et al., 2016) is provided in Figure 6.

It works in the following way: setting the necessary values - the time of examination, temperature maintaining period inside the examined object. After entering the necessary data the installation set in the running mode compares the obtained temperature readings inside the object, then checks the required condition to fulfill the task, once all the conditions are reached, the installation completes the process, and according to the resulting data we estimate the TPP of the object of study. The designed model of the automated mobile installation to define the valid FPS of the construction object is provided in Figure 7.
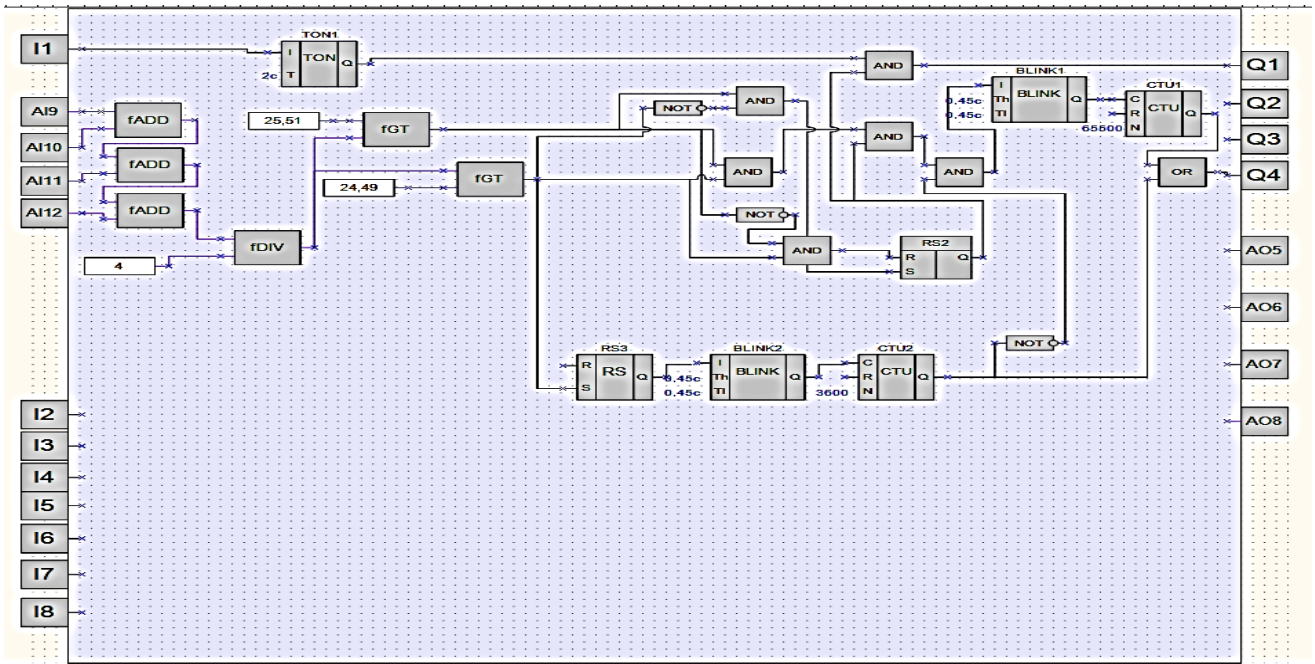
Figure 6: The program for implementing actions algorithm to control automated mobile installation

Figure 7: Mobile automated installation for the TPP defining

The heat source controller module is provided in Figure 8. The heat source controller is connected to the heat source machine control device on the heat source side and to the load equipment side.
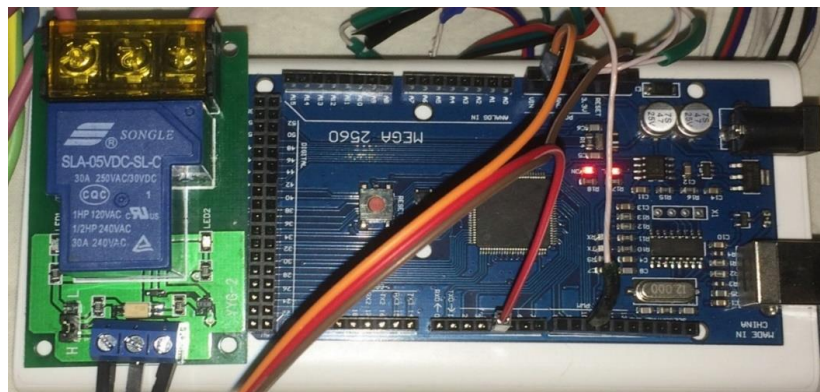

Figure 8: The heat source controller module.

The heat source controller module is designed as an Arduino Mega 2560 unit on the basis of an ATmega2560 microcontroller. The DS18D20 temperature sensors, the SLA-05VDC-SL-C relay, and the TF Cardreader module are integrated into the microcontroller via the connection wires to save the data obtained during the experimental study. The equipment is presented in Figure 9.
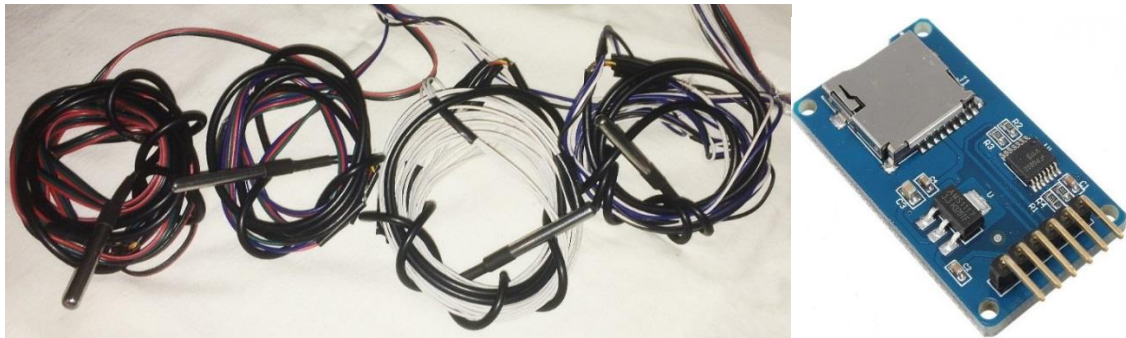

Figure 9: Temperature sensors DS18D20 and TF Cardreader.

Figure 9 shows the temperature sensors DS18D20 which are configured to work with maximum accuracy (tenths of a degree), the effective value is averaged by 10 measurements, which allows you to accurately track temperature changes. The module shown in Figure 10 was designed to estimate the ambient temperature and save the obtained values.
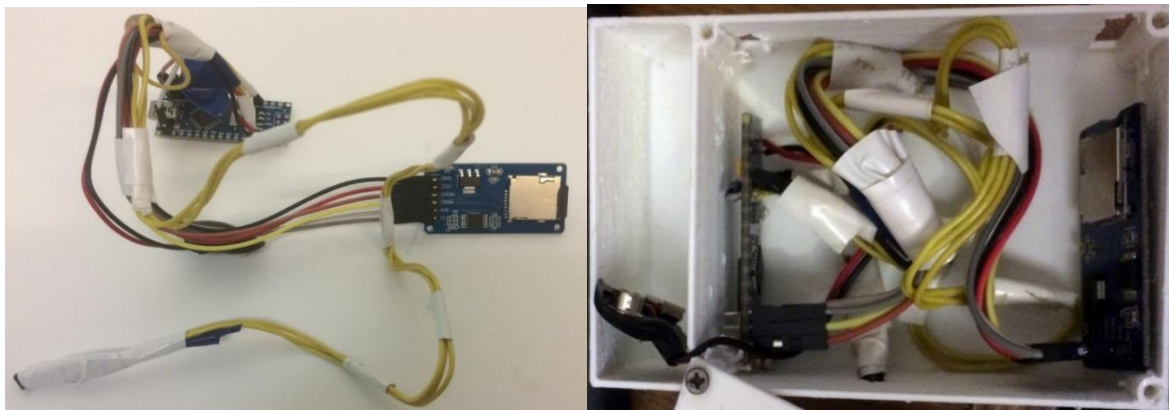

Figure 10: Module for ambient temperature measurement on the outer side of the object of study

It should be mentioned that the ambient temperature is measured with a thermometer while room temperature is based more on feeling. The ambient temperature of an environment may vary greatly from its accepted room temperature, such as when an air conditioner or heater malfunctions. Figure 11 shows the schematic circuit diagram of the ambient temperature measurement module.

The code of the ambient temperature module control program is provided in (Kabanovet al., 2018). It should be mentioned that the ambient temperature measurement module comprises an ArduinoNano 3.0 microcontroller (ATmega328), a DS1820 temperature sensor that connects to the microcontroller, and a TF Cardreader module for recording and storing the data obtained in the experiment (Panfilov & Kabanov, 2017).

The Wi-Fi module shown in Figure 12 was also used as a module for recording ambient temperature readings for objects with large overall dimensions.
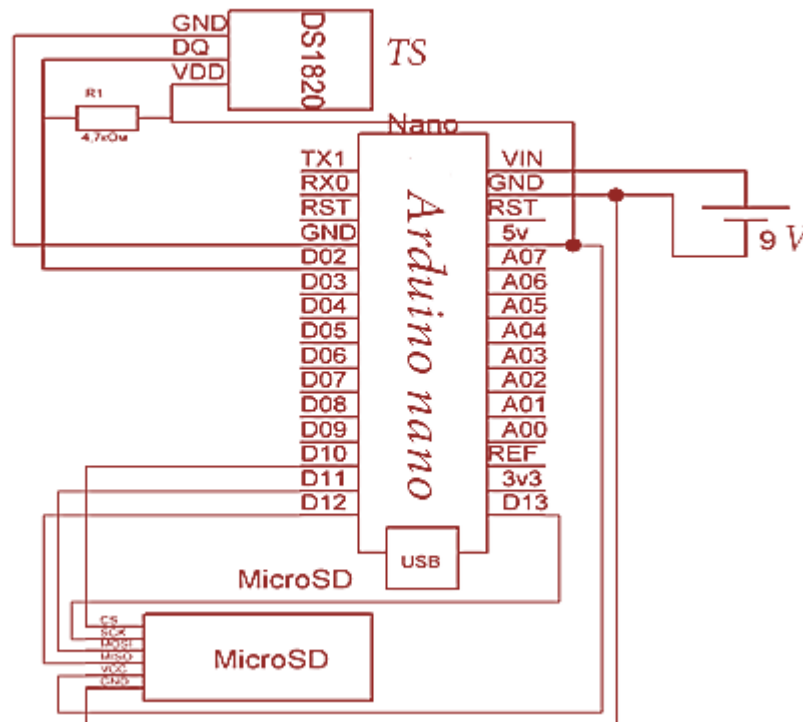
Figure 11: Schematic circuit diagram of the ambient temperature measurement module
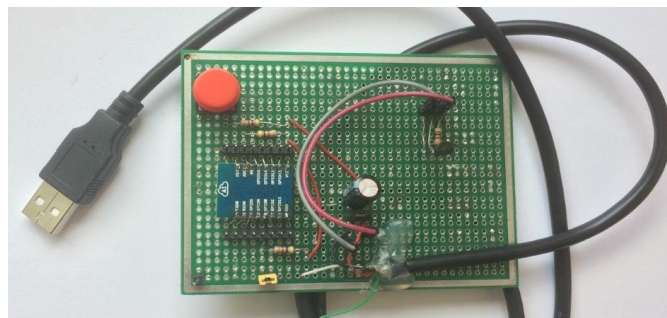

Figure 12: The WiFi module to measure the ambient temperature with input to Mega 2560

Previous technical data (TD) lists have enclosed thermal features for numerous materials that are used to the packaging of electronics. The TD for the mentioned subject is broader in the area and addresses commonly used materials. Understanding of heat capacity and thermal conductivity (THC) of things that used to create or support a test set is required to understand the consequences.

Table 1: Construction Material Thermal Properties at Room Temperature (Incropera et al. 1996; Wilson 2008).

Material	THC	Specific Heat	Density
Concrete – cast dense	0.4	1000	1200
Concrete – cast light	1.4	840	2100
Brick	0.7	840	1600
Glass (window)	0.8	880	2700
Granite	1.7-3.9	820	2600
Hardwoods (oak)	0.16	1250	720
Softwoods (pine)	0.12	1350	510
Polyvinyl chloride	0.12–0.25	1250	1400
Acoustic Tile	0.06	1340	290
Paper	0.04	1300	930
Particle board (low density)	0.08	1300	590
Particle board (high density)	0.17	1300	1000
Fiberglass	0.04	700	150

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Table 1, some famous materials and their thermal features were listed. It should also be mentioned that some materials absorb water and for this reason, their features are changed. For instance, the THC of some materials such as wood may increase by 15% when wet. Some materials which used as insulators that rely on air, such as fiberglass blankets, exhibit a greater change in features when wet. It is worth noting that the range of THCs for these materials is rather modest (about two orders of magnitude).

Table 2, calculated values of THC and specific heat properties by the proposed method were provided for listed materials in Table 1.

Table 2: Calculated values construction Material Thermal Properties at Room Temperature.

Material	THC	Specific Heat
Concrete – cast dense	0.46	1125
Concrete – cast light	1.24	983
Brick	0.63	837
Glass (window)	0.91	964
Granite	2.37	796
Hardwoods (oak)	0.21	1421
Softwoods (pine)	0.14	1596
Polyvinyl chloride	0.24	1190
Acoustic Tile	0.05	1254
Paper	0.06	1470
Particle board (low density)	0.10	1364
Particle board (high density)	0.21	1404
Fiberglass	0.04	805

By comparing Tables 1 and 2, it can be seen that the proposed model has a good efficiency for calculating the thermophysical properties of an object. The developed installation is capable of determining the thermophysical properties of an object, as well as the spatial pattern of the distribution of heat flows inside the object, using non-destructive testing.

5. CONCLUSION

It is composed of a breadboard mock-up board, a DS18D20 temperature sensor coupled via connecting wires and passive electrical circuit elements (resistors and capacitors) onto the ESP8266 chip to transmit readings to the Arduino Mega 2560 microcontroller and other equipment fitted with a Wi-Fi signal receiver.

The INTERSKOL TP-5 mobile automated installation for detecting the object's FPS data on the basis of the heat source has the following specifications:

- defines the effective heat loss by nondestructive testing;

- power supply parameters of the plant 220 ±10% V, frequency of power supply network 50 Hz;

- thermal capacity from 3 kW to 5 kW;

- designed specifically for indoor research up to 400 m3;

- continuous-time of research for up to 24 hours;

- measurement error ± 3%.

The main outcome of the study is introducing a procedure to determine the thermophysical property of the mechanical system using nondestructive methods. In this regard, a code using C++ language has been written for the mobile automated system. It works in setting the necessary values -

the time of examination, temperature maintaining period inside the examined object.

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