Electronic equipment measuring device for heat quantity through a flat wall

Krastin Yordanov[1], *Iliya* Hadzhidimov[1], and *Penka* Zlateva[1,*]

[1]TU Varna, Department of Thermal Engineering,1 Studentska Str., 9010 Varna, Bulgaria

Abstract. In the paper, an experimental study for calculation the heat quantity through a flat wall by electronic system has been presented. The aim is temperature measurement on outer and inner walls of a room for 20 days at 1-minute interval of measurement. A transient regime has been considered. The data measured has been collected on a non-insulated south wall of a Technical University of Varna campus building. The wall layers parameters have to be known for the choice of surrounding area. In order to reduce errors of the outer side of wall temperature measurement caused by the solar radiation, the temperature sensor has been painted grey. The experimental equipment for the heat quantity measurement consists of two plates, each with 4 temperature fixed in a rectangle. The sensors are situated in a flat area in order to obtaining more precise results of experimental study. The problem has been solved by finding decision of the classic heat conduction equation. The experimental temperatures are treated by microprocessor's platform based on Arduino board. As a result, the average temperature of each plate with sensors has been estimated.

1 Introduction

The problem of energy efficiency [1-3] of surrounding elements of new and renewed buildings in order to decrease power expenses for heating and cooling during different seasons [4, 5] is actual today. In present study a method and a measurement system for evaluation of the heat flux through a wall of an administrative building is presented.

Based on one-dimension steady state heat transfer equation and experimental data collected, the heat flux through the wall can be calculated [6-10]. The heat loses in the room during the winter and the cooling load during the summer can be found.

The results of the project may be used for obtaining total loses of different heated objects and for comparison with the standards which are necessary for certifying new and old buildings during the exploitation period.

The project is realized by a microcomputing unit (MCU) Arduino Nano [11] with parameters sufficient for the needs of current development. Eight identical digital thermometers are used in order to minimize the error of the temperature measurements.

Automatic registration of data collected has been achieved: the system is designed with a Data Logger equipped with a micro SD and all parameters of the process are recorded at the

---

[*] Corresponding author: pzlateva@tu-varna.bg

same time. The heat flux are also computed and recorded. The risk of electricity drop down has been avoided by the use of UPS equipped with a battery with capacity in range of 10000 mAh due to small energy consumption of the system [12].

Practically the equipment may be implemented for different surrounding elements, as during the mounting the measurement facility the entity of the walls remains untouched. For this purpose and in order to fix the right place of the thermometers a technology has been provided and explained below.

The aim of the present project is to make a picture of the heat transition in the room during the heating and cooling period after collecting the temperatures measured. Having in mind the integral ascendency of the outer wind over both regimes of heating/cooling a dynamic characteristic of the heat loses for a large period may be realized.

2 Method and material

2.1 Method

The mathematical background [13-15] for the heat flux behavior is based on the Fourier Law at two known temperatures on both sides of the wall (so called Dirichlet boundary condition) [16]:

$$q = \frac{t_i - t_e}{\sum_{i=1}^{n} \frac{\delta_i}{\lambda_i}}, \frac{W}{m^2}, \tag{1}$$

where:

t_i - average internal temperature of the wall, °C;
t_e - average outer temperature of the wall, °C;
δ_i - thickness of the layer "i" of the wall, m;
λ_i - thermal conductivity of the wall material, W/(m.K).

The calculation of the control area is as follows:

$$A = a \cdot b, m^2, \tag{2}$$

where:

a and b are the dimensions of the area limited by the thermal measurement.

The calculation of the loses (for heating or cooling) are described by the equation 3.

$$Q = A \cdot q, W \tag{3}$$

A 3-layer wall is presented on Fig. 1. The values of thickness and the thermal conductivity are shown in Table 1.

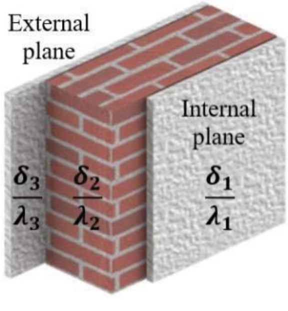


Fig. 1. A 3 layers wall, object of analysis.

Table 1. Wall layers and characteristic parameters

i	**Name**	***δ*, m**	***λ*, W/(m.K)**
1	Lime-sand plaster (internal)	0,025	0,7
2	Masonry from bricks (lattice)	0,25	0,52
3	Lime-sand plaster (external)	0,025	0,87

The realization of the experiment in correspondence with the sketch in Fig. 2 has been performed and the picture of equipment mounted on the wall is presented in Fig. 3.

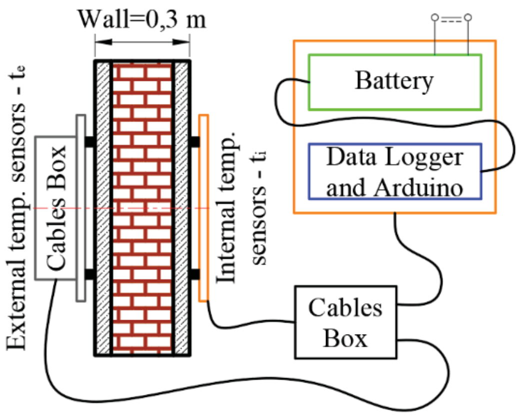
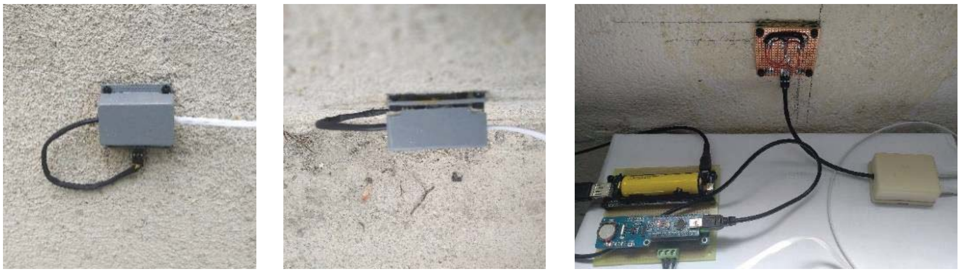


Fig. 2. Sketch of the equipment used for heat flux determination.

In Fig. 2 the internal and external temperature sensors can be seen. The sensors have been fixed on a plate distantly from the wall to avoid stopping the external air circulation in order to obtain conditions as much closer to the real.

The red line shows that all the sensors (external and internal) must be fixed oppositely to find the right temperatures, which is important to calculate correctly the heat flux. In addition, this is realized in horizontal and vertical direction. The sensors connection to the MCU is by cable.



a) View Front b) View Top c) Micro computing unit

Fig. 3. Experimental equipment with MCU, Data Logger and battery.

In Fig. 3 a) and b) the mounted wall sensor box for the registration of the external temperatures is shown in accordance with the sketch on Fig. 2. The sensor box for the internal temperatures, the MCU and the battery are presented in Fig. 3 c). The MCU compartment is close to the wall inside the room.

The temperature of the room has be maintained by an air conditioner at the heating and the cooling regimes. The air conditioner is fixed to provide temperature of +22°C during the heating regime and +25°C during the cooling one.

2.2 Materials

For temperature measurement 8 digital thermal sensors DS18B20 [17] are used due to their positives for the needs of the project characteristics (Fig. 4):

- The sensible area of the digital thermometer is a flat zone with area of 16,448 x 10^{-6} m². The thermometers are lying on the wall's surface;
- All the thermometers of this type may be connected in parallel due to their unique ID number and so called One Wire interface;
- The precision of measurement is ±0,5°C in the range of -10°C, +85°C;
- The sensitivity at using of 12 bits signal is 0,0625°C.

For date and time registration one piece of module RTC DS 1307 is used. The module saves on micro SD date the month, year, hour, minute and the second. A MCU Arduino Nano manages all these electronic components.

In Fig. 4 the principle sketch of the system is presented. The system is divided into 4 blocks – internal temperatures block, outer temperatures block, Data Logger block and the MCU. In a case of failure, the system can be very easy and fast repaired.

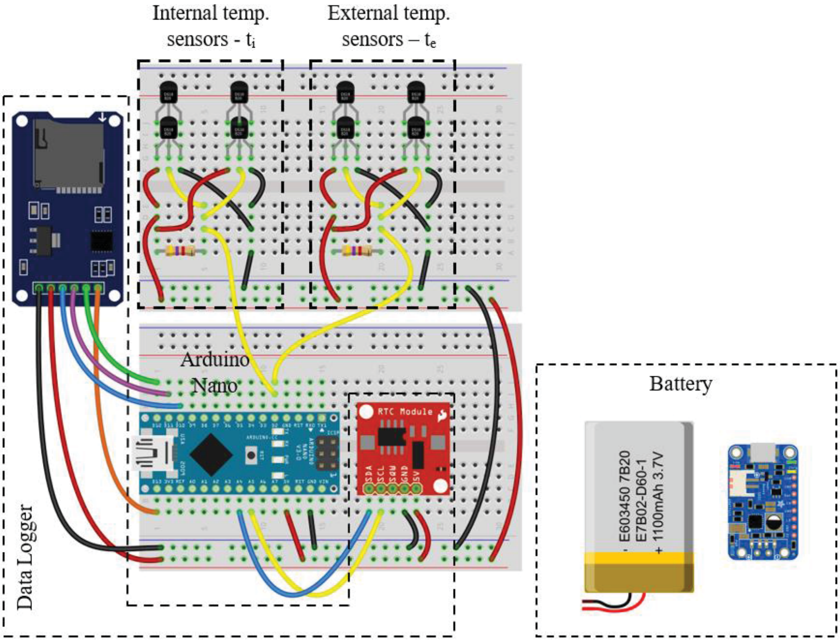


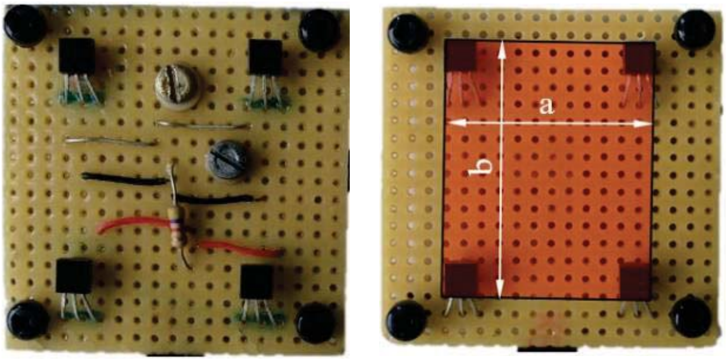
Fig. 4. Sketch of the measurement system – two temperature blocks, RTC with SSD, battery and MCU Arduino Nano.

The ground plates for the thermometers (Fig. 5) is made of glass fiber reinforced (fiberglass) epoxy resin with holes (experimental PCB) for better ventilation of the board and also with a convenient flexibility for the fixing in a vertical position. The sensors mounting position is in every plate's corner next to the polyamide screws in order to provide necessary pressure for the thermometer's contact area.

For precaution the soldering from oxidation when exposed on environment conditions, 4 layers polish for PCB are performed on the external plates and 2 layers on internal one. In order to keep thermometer's sensitivity they have not been polished.

The sensors plate (in red) with dimensions correspondently a=0,03 m, b=0,036 m and area A=0,00108 m² is shown on Fig. 5.

The MCU Arduino Nano and the battery for the data registration system are shown in Fig. 5 c). The battery module is with capacity of 9800 mAh, which is loaded by the AC net. When the battery is fully loaded, the loading stops. The consumption of the measurement system is small which provides independent work without external power within a period of 4 days.



a) External sensors b) Internal sensors

c) MCU

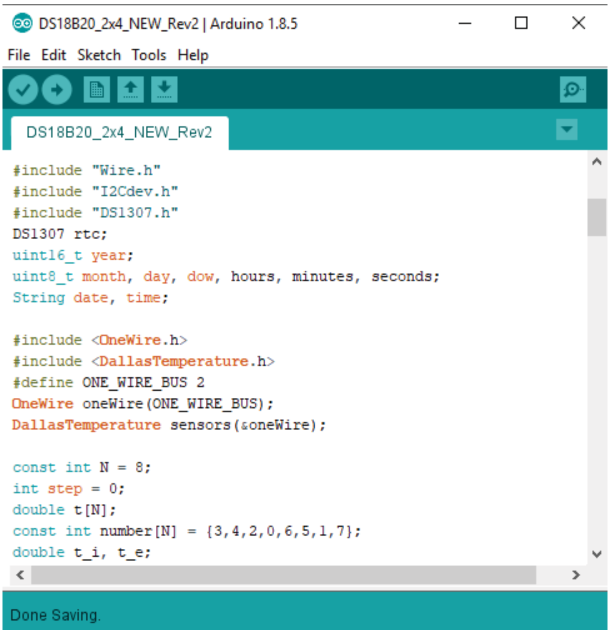
Fig. 5. Pictures of the measurement system with two temperature sensor blocks.

Mounting both plates for internal and external thermometers is on a vertical wall. For oppositely fixing of one external to another internal thermometer with minimal deviation a level meter with crossing laser beams is used, as it is shown in Fig. 6 a). The laser level meter has been positioned and fixed tightly. In addition, during the process of fixing the laser level meter should not to be switched off when setting the markers on both sides of the wall (Fig. 6 b and c). The sensors are fixed with glue on the bolt's heads at a proper angle of the marks on the wall – Fig.3 c.

For the purpose of the development the source code for the measurement and the recording is combined (Fig. 7). The results obtained are recorded in a text format, tabulation separated for convenient import to other software. The source code is changing the file name for data recording every 24 hours on a single file and the file name contains the date and month.


a) Laser level meter b) Level meter c) Markers

Fig. 6. Temperature sensor blocks montage on the wall – inner and outer side.



```
#include "Wire.h"
#include "I2Cdev.h"
#include "DS1307.h"
DS1307 rtc;
uint16_t year;
uint8_t month, day, dow, hours, minutes, seconds;
String date, time;

#include <OneWire.h>
#include <DallasTemperature.h>
#define ONE_WIRE_BUS 2
OneWire oneWire(ONE_WIRE_BUS);
DallasTemperature sensors(&oneWire);

const int N = 8;
int step = 0;
double t[N];
const int number[N] = {3,4,2,0,6,5,1,7};
double t_i, t_e;
```

Done Saving.

Fig. 7. Part of the source code for data acquisition.

3 Results and discussion

In Fig. 8 the average temperature distribution can be seen. The average inside and outside temperatures for the heating season are 20°C and 19°C. The average temperatures for cooling are as follows: 22°C inside, 23°C outside. The small difference of 1°C observed during the two regimes is caused by the transient season conditions when the measurements were performed. The value of the average outside temperature shows that 36°C is reached for a short period of the heating regime and 40°C is reached at the cooling regime due to the south orientation of the wall.

The heat flux values are presented in Fig. 9. The axe has negative direction for a better visualization of its distribution during the period of measurement. As can be seen, the graphic interpretation in Fig. 9 corresponds to the average outside temperature in Fig. 8.

The values of the heat flux in Fig. 9 for the heating regime varies from -28 W/m² to +10 W/m². During this regime, the air conditioner was in operation more often during the night hours. In the cooling regime, the heat flux varies from -32W/m² to +12W/m². Then the air conditioner was in operation more often during the day time.

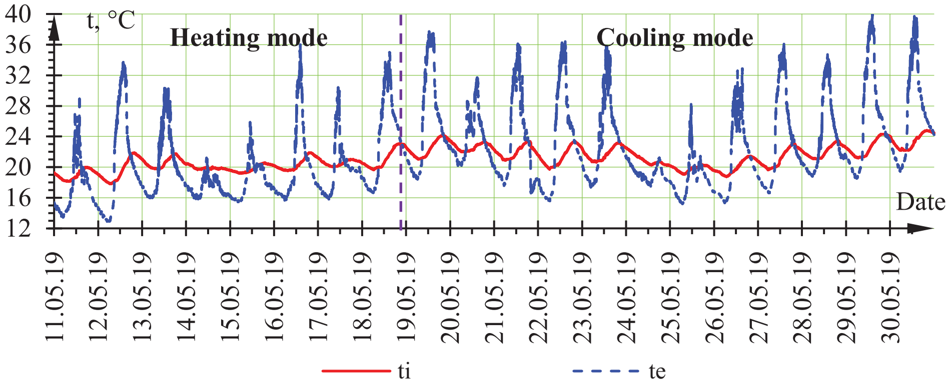


Fig. 8. Average inside and outside temperatures of the wall based on measurements for 20 days.

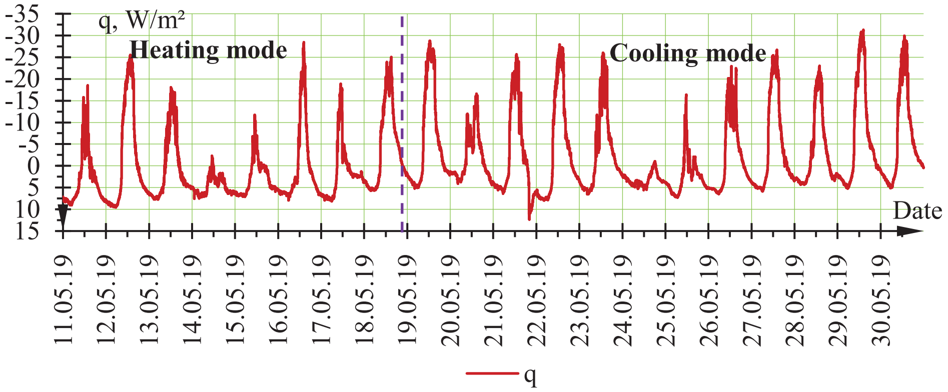


Fig. 9. Heat flux distribution through the wall for 20 days.

4 Conclusions

1. The system for temperature measurement, data recording and results treatment works in real time in order to obtain heat through a 3 layers wall with known thermal parameters during a large period of time.

2. The analysis of the results leads to conclusion, that it is possible to find a correct behaviour of the heat flux concerning ambient temperature during a specific working regime of the air conditioning installation intended for heating and cooling.

3. The project may be improved and developed including the other internal and external walls and the nonlinear temperature stratification from the bottom to the ceiling.

The investigations in that paper have been implemented with the financial support of National Programme “Young scientist and postdoctoral students”, funded by Bulgarian Ministry of Education.

References

1. F. G. N. Li, A. Z. P. Smith, P. Biddulph et. al., Buld. Res. & Inf. **43**, 238 (2015)
2. G. Valtchev, N. Kalojanov, V. Rasheva, M. Minchev, S. Tasheva., Bulg. Chem. C. **48**, 283 (2016)
3. N. Penkova, K. Krumov, I. Kassabov, L. Zashkova, Eng. Tr. Gl. in Arch. and Str. Eng., 373 (2016)
4. T. J. Sauer, D. W. Meek, T. E. Ochsner, A. R. Harris, R. Horton, Vad. Z. J. **2**, 580 (2003)
5. F. Kreith, R. M. Manglik, M. S. Bohn, *Principles of Heat Transfer* (Seventh Edition, Cengage Learning, 2012)
6. W.S. Janna, *Engineering Heat Transfer* (Third Edition, Taylor & Francis, 2009)
7. K. S. N. Raju, *Fluid mechanics, heat transfer, and mass transfer: chemical engineering practice* (John Wilely and Sons, 2011)
8. M. Favre-Marinet, S. Tardu, *Convective Heat Transfer: Solved Problems*, (John Wilely and Sons, 2013)
9. A. Terziev, 8th Int. Conf. TE-RE-RD, E3S Web of Conf. 112, Code 151155, (2019)
10. P. Prodanov, D. Dankov, 20th ISPE (Ee), IEEE Art. Num. 8923317, (2019)
11. Arduino, https://www.arduino.cc, (2020)
12. T. Papanchev, A. Georgiev and J. Garipova, IEEE XXVIII Int. Sc. Conf. El.-ET, (2019)
13. J. G. Myers, V. K. Yerramilli, S. W. Hussey, G. F. Yee, J. Kim, Int. J. of H. and M. T. **48**, 2429 (2005)
14. F. Kreith, R.F. Boehm et. al., *Heat and Mass Transfer: Mechanical Engineering Handbook*, CRC Press LLC, Ed. Frank Kreith. (Boca Raton, 1999)
15. R.W. Powell, C.Y. Ho, P.E. Liley, *Thermal Conductivity of Selected Materials* (Part 2, Government, 1968)
16. M. J. Moran, *Introduction to thermal systems engineering: thermodynamics, fluid mechanics, and heat transfer* (John Wilely and Sons, 2003)
17. Maxim Integrated, www.maximintegrated.com/en/products/sensors/DS18B20.html, (2020)