Article

Measurement of Heat-Flux of New Type Façade Walls

Todorka Samardzioska [1,*] and Roberta Apostolska [2]

[1] Faculty of Civil Engineering, University Ss. Cyril and Methodius, blvd Partizanski odredi 24, 1000 Skopje, Macedonia
[2] Institute of Earthquake Engineering and Engineering Seismology - IZIIS, University Ss. Cyril and Methodius, 1000 Skopje, Macedonia; beti@pluto.iziis.ukim.edu.mk
* Correspondence: samardzioska@gf.ukim.edu.mk; Tel.: +389-71944825

Abstract: The building envelope has the most significant contribution in the reduction of the building energy consumption. Application of new, alternative and improved materials and systems has an important impact on the buildings performances. This paper is focused on the thermal transmittance, as an indicator of the thermal conductance of the construction element. It includes comparisons of the U-values, calculated by software, with those measured in situ on three representative façade walls. The walls have been constructed with the new wall system Fragmat NZ-1, a new product in Macedonian buildings. This research provides basic information on the thermal transmittance of the system. The results of the analysis show that the in situ measuring is a useful tool in validation of the precision of analytically calculated values, since it was difficult to obtain precise results from the analytical calculations only, especially when the layers are with non-uniform thickness.

Keywords: energy efficient building; heat flux; thermal transmittance; in situ measurement

1. Introduction

There is an imperative demand for low-cost, energy-efficient housing in Republic of Macedonia. Macedonia is not rich with energetic resources and the annual energy import represents 10% of the total energy consumption. The energy consumption in the domestic sector was 30% of the total energy consumption in the country (data 2010). The main part of this consumption goes to heating. In order to reduce the energy consumption and costs, as well as to improve the indoor environment, constructors have started to implement energy efficiency measures in the buildings. They aim for efficient structural design, reduction of use of high energy building materials such as glass, steel etc. and transportation energy, as well as use of low energy buildings materials.

The lack of National Regulations on energy performance of buildings has been an obstacle for the improvement of buildings in fYRoM for many years, together with education for certification of energy controllers. However, national Regulations were delivered in July 2013 and they enable improvement in the energy performance of buildings in the long term.

The assessment of materials for thermal insulation of the building envelope has the most significant contribution in the reduction of the building energy consumption, in general. The adequate placement and location of the insulation has a positive influence on the unsteady heat transfer in the external walls and the roofs. The results of the analysis of Kontoleon & Bikas, [1] showed that placement of three equal layers of insulation is optimal solution for the external walls and roofs. Usually, the best performances can be obtained if the insulation layer is near the entrance point of the heat flux. Due to this fact, the internal insulation layer is more appropriate for climate regions with dominant heating, while the insulation layer on the external side of the wall is better for climate zones with dominant cooling. Some practical experience of Papadopoulos, [2], refers that the best performance of the building envelope is achieved with an external layer of insulation material on the building.

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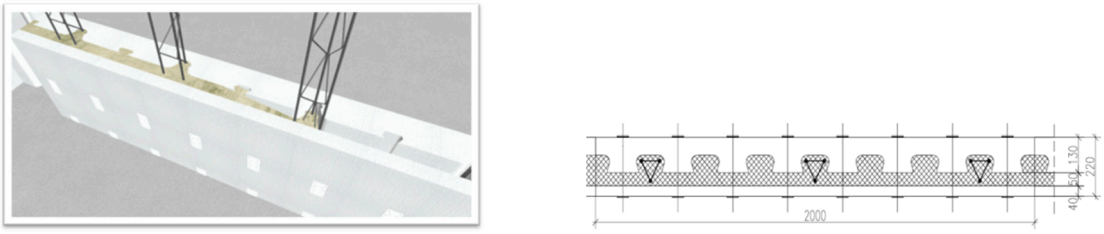
The application of new, alternative and improved materials and systems has an important impact on the buildings performances. An establishment of a correlation between the theoretical and practical analysis for determination of the preventive solutions for the building performance in exploitation is especially important. The deficit of analytical and experimental determined data for parameters which point to the efficiency of the measures for façade insulation is probably a key factor for their insufficient and inadequate application in the construction. Furthermore, the regulative, according to which the necessary steps for construction of an energy efficient building should be defined, is relatively new in many countries, in Macedonia as well.

The U-values are usually calculated with adequate software, which are based on a simplified calculation, using a database of technical data for the common used building materials and systems. In situ measurements in England housing confirm findings in some works that the measured U-values of solid walls are significantly below the calculated ones [3]. Often, in a case of non-standard structures, or when analysing new, unexplored building elements or systems, a necessity of more precise determination of the thermal transmittance may appear, due to the limitations of the software in the material choice. When historical buildings have to be measured, difficulties appear due to the unknown internal wall structure, which make the calculation imprecise. In that case, in situ measurements are the most favourable. The study of Baker [4], found that different software codes for calculation of the U-value tend to over-estimate the U-values of the traditional building elements in historical Scottish buildings. The measurement of non-homogeneous walls is especially important, because the numerical calculation of their U-value is not precise due to the unknown thickness of the different layers and materials that should be input parameters in the calculation. The new research of Li et al, [5], also confirms that heat flux measurements are difficult to undertake in occupied properties and possible sources of error could lead to under-predictions of the U-value.

A practical comparison of two useful tools for determination of the thermal transmittance has been made in this paper: using software calculation and by in situ measurements in real conditions on a building in exploitation phase. The U-values are commonly calculated or well known for the types of walls which are often used. Nevertheless, the fact that the measured and analysed façade walls were constructed of the system Fragmat NZ-1, which is a relatively new product on the Macedonian market, leads to conclusion that its thermal performances are not well-known. This system has specific geometrical properties that differ from the most usually performed facades in Macedonia. This research provides basic information on the thermal transmittance of the system.

2. Description of a new façade wall Fragmat NZ-1

The system Fragmat NZ-1 presents a complete three-layer structure for construction of façade walls and building envelope, presented in Fig. 1. Functionally, it is an innovative and relatively new method for construction of the building envelope, significantly different from the widely accepted ceramic-block wall. It consists of two layers of expanded polystyrene and a mid-layer of concrete, reinforced with reinforcement trusses, [6]. The integrated thermal insulation simultaneously presents a formwork for the concrete layer, which on the other hand, provides the mechanical strength of the wall. The total width of the system is 220 mm. The internal layer is a flat slab of EPS with thickness of 40 mm and density of 25 kg/m^3. The external layer is with thickness of 130 mm and has a socket of 75 mm at each 250 mm, providing a connection with the internal concrete column, strengthened with reinforcement trusses, Fig. 1. The external layer has a density of 17 kg/m^3. One of the advantages of this system is that it does not need any formwork for placement of the concrete, and therefore the expenses for its construction are much lower than for the traditional reinforced concrete walls.



(a) (b)

Figure 1. Fragmat NZ-1; (a) Forming a mid-layer with concrete filling, (b) cross section, [6]

3. Thermal transmittance

The thermal transmittance, or the U-value, of a building element is defined in IS0 7345 as the "Heat flow rate in the steady state divided by area and by the temperature difference between the surroundings on each side of a system", [7].

The thermal transmittance represents an indicator of the thermal performances of the building elements. Calculation of the U-values is necessary for validation the energy efficiency of the building, according to the actual rules for construction of new buildings, as well as for repair and reconstruction of the existing buildings in order to improve their energy efficiency.

In principle, the U-value can be obtained by measuring the heat flow rate through an element with a heat flow meter or a calorimeter, as well as the temperatures on both sides of the element under steady state conditions. However, since steady state conditions are never encountered on a site in practice, such a simple measurement is not possible. Nevertheless, there are several ways of overcoming this difficulty:

- Imposing steady-state conditions by the use of a hot and a cold box. This method is commonly used in the laboratory (IS0 8990), but is cumbersome in the field.
- Assuming that the mean values of the heat flow rate and temperatures over a sufficiently long period of time give a good estimate of the steady state. This method is valid if the thermal properties of the materials and the thermal transmittances are constant over the range of temperature fluctuations occurring during the test, and if the change of amount of heat stored in the element is negligible when compared to the amount of heat going through the element. This method is widely used but may lead to long periods of measurement and may give erroneous results in certain cases;
- Using a dynamic theory to take into account the fluctuations of the heat flow rate and temperatures in the analysis of the recorded data.

According to the new adopted Macedonian Rulebook on the energy performances of buildings, there is a limitation of the U-value. The maximum allowed U- values are prescribed, depending on the considered building in the structure, [8]. The façade walls analysed in this paper belong to the first category, and the maximal U-value equals to 0.35 W/m^{2}K.

Analytical calculation of the U-value. The analytical software calculation of the thermal transmittance is performed with the simple software "Ucalc", with an approximate thickness of the external layer of the insulating material, due to the improper geometrical form of the layer of extruded polystyrene. The obtained value of such a simplified calculation is U= 0.22 W/m^{2}K. This value, according to the standards is used as a point of reference for comparison of the final measured results on a real building.

4. Measurement of the heat flux of the wall

4.1 Description of the measurement instrument TRSYS01 – HFM

TRSYS01 – HFM (Heat flow meter) is a measurement system for analysis of thermal resistance and thermal transmittance of building elements by in situ measurement, [9]. It can be used for measurements according to ISO 9869, [9], and ASTM C1155 and C1046 standards, [10]. In its usual

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standard configuration, the system is equipped with two heat flux sensors, as well as with two pairs of matched thermocouples for differential temperature measurements, Fig. 2.

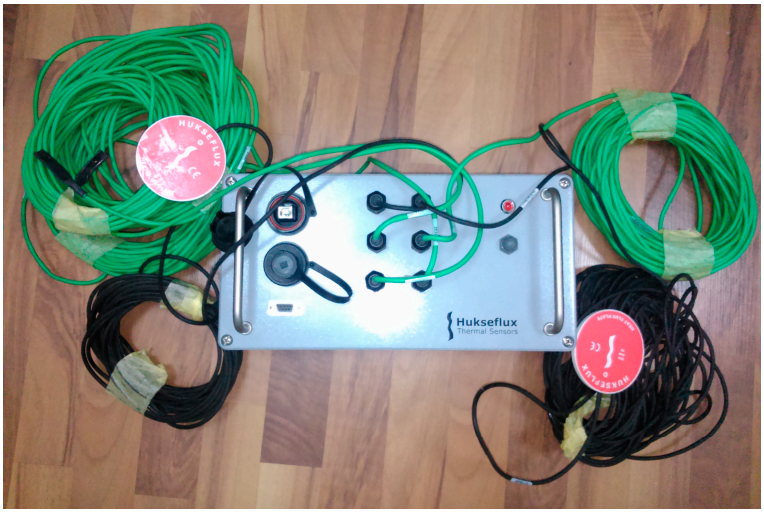

Figure 2. Measurement instrument TRSYS01 – HFM

Temperature sensors, presented in Fig. 3, are transducers giving an electrical signal which is a monotonic function of its temperature. A minimum of two temperature sensors are used, one on each side of the tested structural element.

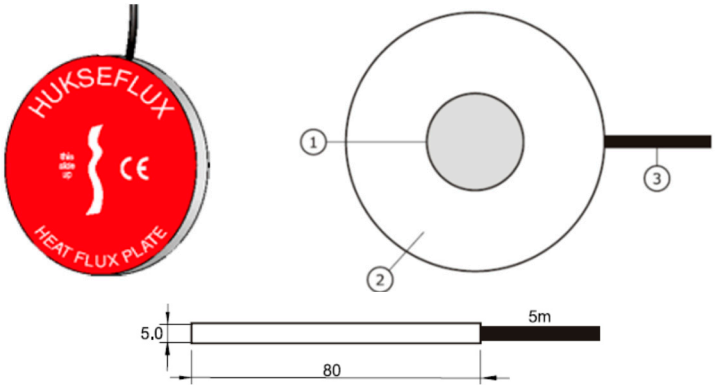

Figure 3. Sensor for measurement of the heat flux, HFP01, [9]

During the measurements, few recommendations should be followed:

- location with exposure to direct solar radiation should be avoided as much as possible;
- the more heat flux, the better; strongly cooled or strongly heated rooms are ideal measurement locations;
- the location of installation preferably should be a large wall section which is relatively homogeneous;
- areas with local thermal bridges should be avoided, etc.

4.2 Data acquisition

The electrical data from the Heat flow meter (HFM) and the temperature sensors have been recorded continuously or at fixed intervals over a period of complete days. The maximum time period between two records and the minimum test duration depends on: the nature of the element (heavy, light, inside or outside insulation); indoor and outdoor temperatures (average and fluctuations, before and during the measurement); the method used for analysis. Due to the standards recommendations, the minimum test duration is 72 h (3 days) if the temperature is stable around the HFM. Otherwise, this duration may be more than 7 days.

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4.3 Analysis of the data

Two methods may be used for analysis of the data in accordance with this International Standard ISO 9869: the so-called average method, which is simple, or the dynamic method, which is more sophisticated, but which gives quality criteria of the measurement and may shorten the test duration for medium to heavy elements submitted to variable indoor and outdoor temperatures, [10]. The average method assumes that the conductance or transmittance can be obtained by dividing the mean density of the heat flow rate by the mean temperature difference, the average being taken over a sufficiently long period of time.

For "j" individual measurements, the resistance of the heat flow can be obtained by the following expression:

$$R = \frac{\sum_{j=0}^{n}(T_{sij} - T_{sej})}{\sum_{j=0}^{n} q_j} \tag{1}$$

where:
T_{si} – internal surface temperature, measured in [°C],
T_{se} – external surface temperature of the wall, measured in [°C],
q – heat flux density, i.e. heat flux on unit area, measured in [W/m²].

The conductance Λ is presented by the expression:

$$\Lambda = \frac{\sum_{j=1}^{n} q_j}{\sum_{j=1}^{n}(T_{ij} - T_{sej})} \tag{2}$$

The thermal transmittance (U-value) is calculated according the following relation:

$$U = \frac{\sum_{j=1}^{n} q_j}{\sum_{j=1}^{n}(T_{ij} - T_{ej})} \tag{3}$$

where T_i is internal ambient temperature, while T_e is external ambient temperature.

After the calculation of the abovementioned values after each measurement, the convergence of the results to an asymptote value should be analysed.

Finally, U-value of the measured wall must include r_{int} and r_{ext} - the standard values for the external and internal surface resistance on the wall, respectively:

$$U_t = \frac{1}{\frac{\sum_{i=1}^{t} Tsi_i - \sum_{i=1}^{t} Tse_i}{\sum_{i=1}^{t} Q_i)} + r_{\text{int}} + r_{ext}} \quad (4)$$

Their values are r_{int} = 0.13 [m²K/W] and r_{ext} =0.04 [m²K/W].

The output data of the measurement can be obtained and read with corresponding software LoggerNet 4.1 and they can be used as datasheet for further analysis. The expected accuracy of the obtained results is ± 5%.

5. Analysis of the results

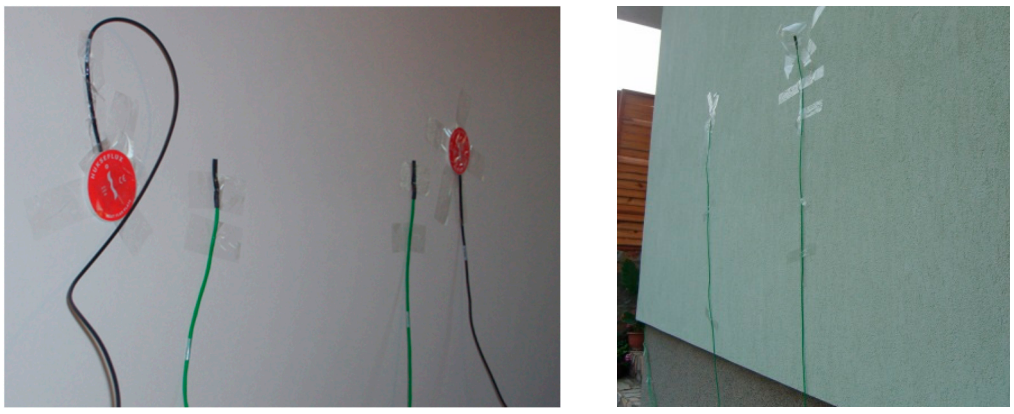
The measurements for this research were performed using the equipment for measuring the thermal transmittance. The measurements were performed on three different buildings walls, built of the façade system Fragmat NZ-1. The heat flux meter has to be placed in a direct contact with the wall surface. Greater deviations in the temperature field should be avoided, and therefore the connection on the smooth and flat part of the wall is recommended. Any incorrect placement of the sensors can deliver changes in the heat flow, which is one of the key factors for precise analysis. The temperature sensors should be mounted near the placed flux meters, in order to register the contact temperature.

5.1 The first building

The building is a reinforced-concrete skeleton system, consisting of ground floor and first floor, with façade walls of system Fragmat –NZ1, and inbuilt appropriate insulation in the floor and the roof structures. The measurements for the first building were performed during 8 days, on a façade wall in the ground floor, with a north-east disposition. The sixth day was characterized with rainy and windy weather.

Temperatures during the measurement period do not develop significant oscillations, excluding the night-day temperature difference, typical for the summer period in Macedonia. The figures 4(a) and 4(b) represents photographs of the sensors placed on the internal and external part of the wall during the measurement.

According to the significant changes of the external temperature during a day-night time, the calculation of the U-value was restricted to time intervals with a heat flux in one direction. The most reliable measurements were after 15 h, period when no direct solar radiation on the façade wall was experienced. Opportunity that beneficially affects the preciseness of the results is the stabile internal temperature, which does not vary more than 1°C in the analysed time period of few hours.



(a) **(b)**

Figure 4. Installed sensors on the first building: (a) internal side, (b) external side

The contact external and internal temperatures on the measured location are represented in Fig. 5.

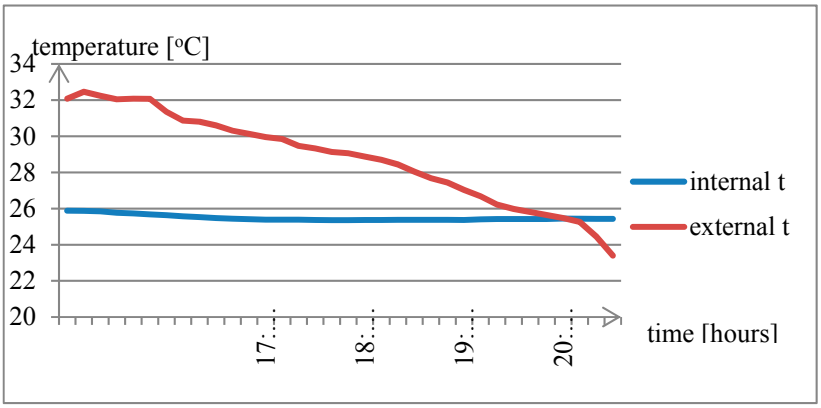


Figure 5. Contact temperatures, the first day, time interval 15:00 to 20:20

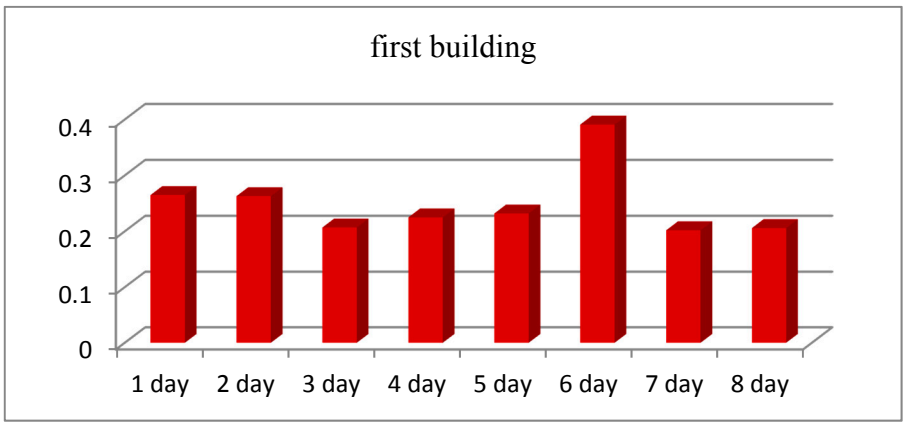


Figure 6. U-values for the first building during the measurements, given by day

The average value of the U-coefficient, calculated according to the measured values from all the days is 0,227 [W/m²K]. The result obtained on the sixth day is excluded from the calculation, because of the rainy weather and the increased humidity, which initiate unreal increase in the U-value (U = 0.391 W/m²K).

5.2 The second building

The second building is a reinforced-concrete skeleton system, consisting of ground floor and three floors, with façade walls of system Fragmat –NZ1. The measurements for the second building were performed during 4 days. Mounting of the sensors on the external side of the wall was very difficult due to the high ground floor and the garage under it. Therefore, they were mounted on the parapet under the windows as a unique solution. Locations of the installed sensors are presented in the Fig. 7.

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(a) **(b)**

Figure 7. Installed sensors on the second building: (a) internal side, (b) external side

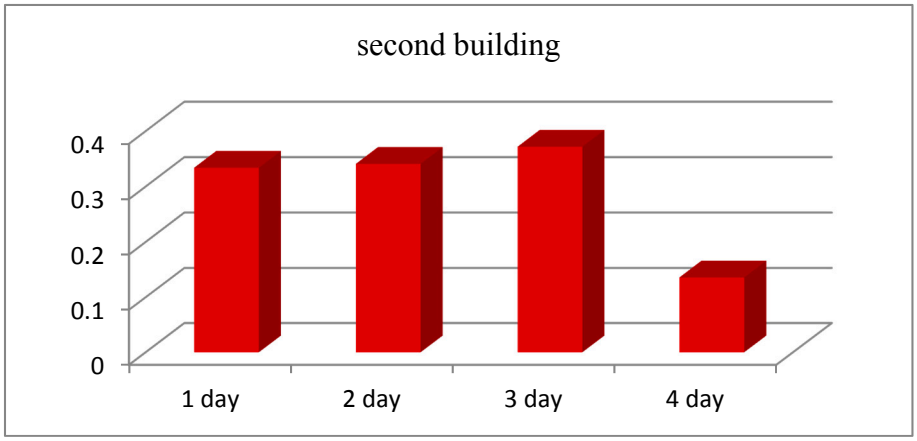
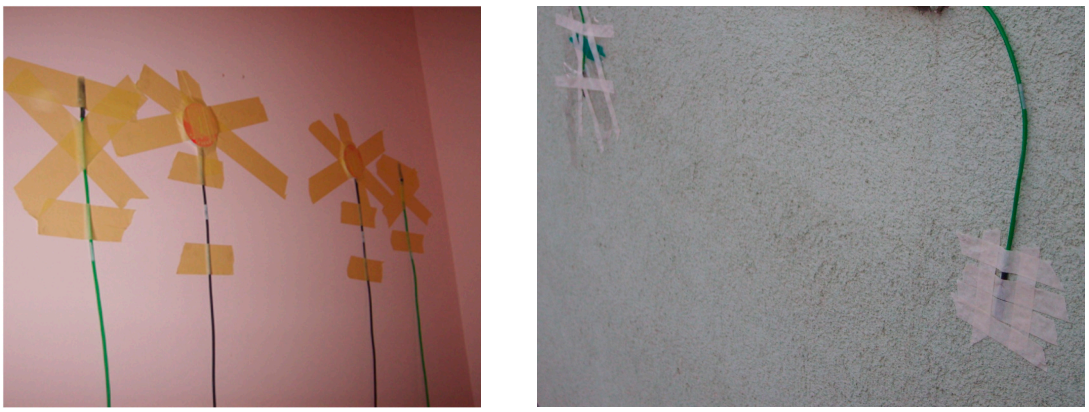


Figure 8. U-values for the second building during the measurements, given by day

The obtained average value of the thermal transmittance is U = 0.349 [W/m²K]. This result significantly withdraws from the expected value, calculated analytically and obtained during the measurement of the first building. The unfavourable position of the instrument on the wall could be the cause of this result. As it is presented in Fig. 6, due to the limited space and impossibility to mount the sensors on the external façade, they were located at the only approachable location, the parapet under the windows on the north-east façade of the building. The window is close to the measurement location; therefore the possibility of a thermal bridge existence is very huge, which influenced the higher U-value. Another possible factor is the unknown position of the instrument from the point of view of the cross section's geometry of the wall. If the thickness of the polystyrene is smaller than the one of the concrete layer, than the obtained higher conductivity is due to the inferior insulating characteristics of the concrete.

5.3 The third building

The measurements for the third building were performed during 4 days. Due to the south-west orientation of the measured façade wall, the data registered during the night period between 21.00-03.00h are considered as optimal ones, in order to avoid the direct solar radiation during the afternoon hours.



(a) (b)

Figure 9. Installed sensors on the third building: (a) internal side, (b) external side

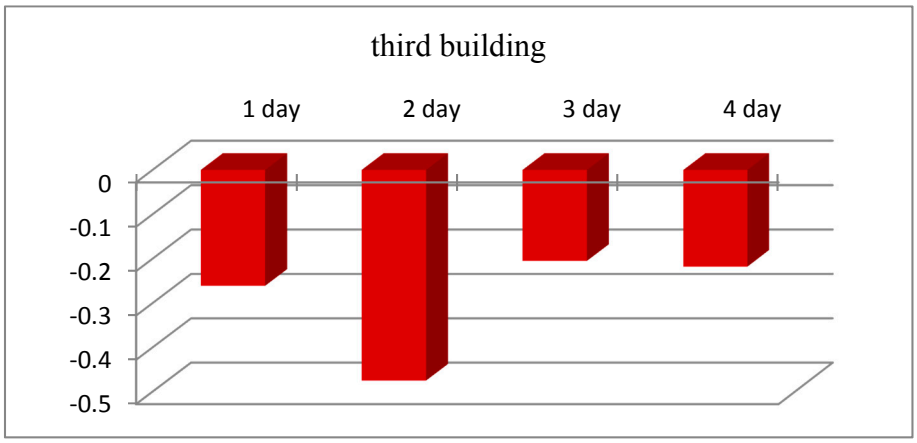


Figure 10. U-values for the third building during the measurements, given by day

The obtained average value for the thermal transmittance is U = -0.228 [W/m²K]. In this case, the result of the measurement on the second day is not taken into account, due to the rather high external temperature and the insufficient difference between the internal and external temperature.

The final conclusion of the measurement of the three different buildings is that the analytically calculated thermal transmittance is approximately the same with the regular measurements, and for this façade system is U = 0.22 [W/m²K].

6. Discussion

The testing of the thermal transmittance is applicable for: determination of the real insulated condition of a building, an analysis of the repaired condition, determination of the heat transfer of the walls with unknown composition, as well as for determination of the heat transfer of new building systems.

The results of the analysis show that the in situ measuring is a useful tool in the validation of the accuracy of the analytically calculated values, since it was difficult to gain precise results from the analytical calculations only, especially when the wall layers are with non-uniform thickness.

This paper deals with analysis of the new façade walls of the system Fragmat – NZ, in terms of defining their thermal transmittance, as well as with finding an adequate method for its calculation, due to the specific geometry. The direct in-situ measurement is recommended for a precise result.

The final result of determination of the U-coefficient is influenced by many factors. Primarily, the type of the analysed wall should be determined: massive or lightweight construction. That precondition defines the duration of the measurement, necessary for obtaining accurate results. In

this case, the structure does not require a long time interval; therefore the testing time is reduced to the minimal according to the standards. Due to the significant day-night temperature variations, the heat flux registers high oscillations. For that reason, the representative data for this measurement are day-light periods when the heat flux stabilises, even though that for walls with a great ability of thermal accumulation, this kind of results will not be accurate.

A small variation in the internal temperature has a significant influence on the result. In this case, this condition was satisfied, because the rooms chosen for measurement were with small (or without) people frequency. Therefore, changes in the internal temperature caused by an exterior factor were not detected.

The variation in the air humidity has also an unfavourable influence on the final result and it should not be taken into consideration. The rain on the sixth day of the measurements of the first building was rainy and humid and caused increase of the thermal transmittance of the wall, which was unreal compared to the other values.

The choice of an adequate location for installation of the sensors has a key role in the obtaining of relevant results. Therefore, the sensors should be installed on a wall without a direct solar radiation; the contact surface should be as smooth as it can; location with a variation of the thermal conductivity should be avoided, as well as location with potential thermal bridges. This condition was not fulfilled for the measurement of the second building due to the space limiting and impossibility of installation of the external sensors. The results are not reliable. Nevertheless, this is a proof that the adequate installation and location of the sensors has a huge role.

For further investigations of the thermal transmittance of these façade walls, they should be measured in laboratory conditions. This will avoid the effects of the environment, and will enable determination of the influence of the sensor's location.

In general, for this type of measurement, a standardization of the measurement procedure for the Macedonian local climate conditions which are affected by huge temperature differences during daytime is recommended. Furthermore, an improvement of the U – value calculating software performances is recommended, in a manner that it would be able to compute more complicated elements, due to the fact that most of the software programmes works with homogenous layers with uniform thickness and uniform λ - coefficient.

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Conflicts of Interest: The authors declare no conflict of interest.

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