ANALYSIS OF HEAT TRANSFER COEFFICIENT OF RAMMED EARTH WALL IN TRADITIONAL HOUSES IN VOJVODINA

by

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Traditional Vojvodina house represents an important part of the building stock of the northern Serbian province of Vojvodina. The research examines the thermal transmittance of the walls of rammed earth, which is the basic structural and façade element of traditional Vojvodina house, in two ways: by calculations in accordance with Serbian regulations and by measuring in situ. Parameters obtained from the measurements are compared with the calculated values for the three typical traditional Vojvodina rammed earth single family residential houses.

The comparison between the values of the heat transfer coefficient, obtained by the calculation, and the results determined by in situ measurements show significant differences. It indicates that the thermal characteristics are better than calculated ones according to national regulations, but at the same time that, due to the complexity of the rammed earth walls and differences in the rammed earth structures, the results differ from case to case and can not be standardized.

Keywords: *thermal characteristics, U-value, rammed earth, traditional single family house*

Introduction

Traditional rammed earth houses are an important part of the building stock of Vojvodina. According to statistical data for Vojvodina, family buildings built before 1919 represent up to 7% of the total building stock of the province and most of them are made of rammed earth or adobe. Buildings constructed in the period from 1919 to 1945 represent 26% of the total building stock of the province [1]. There are no official data how many of them are made in the same technique but, according to the experts, in this period, rammed earth and adobe were also prevailing materials used for the construction of typical single family houses. Many of these houses, although in relatively poor condition, neglected and not properly maintained, are still used for residential purposes. Homeowners nowadays prefer to demolish old buildings and build a new one instead, rather than to rehabilitate and reconstruct them, primarily due to the lack of knowledge about thermal, ecological and *green* characteristics of rammed earth buildings, which can be assessed as very high quality and are of significant importance in the context of sustainable development concept and strivings to reduce energy

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consumption. Besides, latest climatological research results indicate that warmer and drier climate in Vojvodina region can be expected in future [2]. Considering that fact, the issue of energy performance of rammed earth house thermal envelope should be treated with great care.

The goal of this research is to investigate the thermal performance of the rammed earth façade walls in traditional single-family residential buildings in this region. The main goal of this research is the analysis of the problems and constraints in the process of field testing as well as a comparison of measured results with the results obtained by calculation according to the current Serbian regulations. The results of measurements and calculations for three rammed earth characteristic buildings, according to their urban and architectural features, are presented.

Traditional single family houses in Vojvodina

Under the concept of a traditional single family house in Vojvodina, a unique architectural phenomenon is accepted: it is the house that has been created and developed in the period from the end of eighteenth, during the nineteenth, and early twentieth century in the entire province of Vojvodina, figs. 1 and 2.

Figure 1. Traditional tree-part rammed earth house with porch

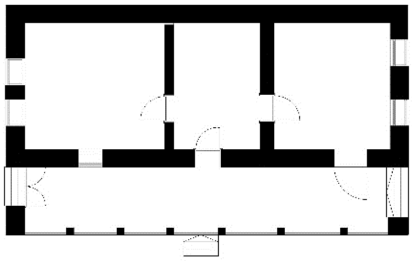

Figure 2. Ground floor plane of tree-part rammed earth house with porch

Regarding the origin of the house, theoretical expert attitudes are not harmonized, but most of them believe that this is a unique combination of German and local architectural tradition [3]. Development of the house proceeded chronologically from simpler structure to complex architectural layout shapes at the beginning of the twentieth century [4]. Building materials of structural walls are always made of earth or earth-based products as locally available. Today, there are many types and subtypes that make up the entire building stock of traditional architecture very diverse, the basic type and most common at the same time, is a three-part rammed earth house.

Up to now, many rammed earth houses are preserved but they are usually in poor condition, neglect, exposed to weather conditions, and left to decay. Many of them have suffered a number of functional transformation and intervention on the walls itself.

The technique of construction of rammed earth walls

Traditional houses of Vojvodina, in their earliest stages of development, were built entirely of rammed earth. Later, the evolution in the application of building materials was also based on the local earth (clay, loam) but with a higher degree of processing, adobe and finally brick came into the use [5]. The choice of building materials was, as a typical characteristic of traditional and vernacular architecture, based on the current situation and real needs, experience and knowledge and available means of the local population. As the result, rammed earth buildings were built for a very long period of time, from the beginning of the eighteenth century, through nineteenth century but also at the beginning of the twentieth century.

The masonry technique was relatively simple: semi-dry, crushed earth was well mixed with chopped straw (chaff) which was used as reinforcement and then the earth was rammed between the two boards, which served as planking. The earth used as a construction material was dug in a close proximity, usually in the garden of the house.

The best results could be obtained by first mixing the yellow and black loam and then mixing it with straw and chaff, but only yellow clay could be used also. The process of preparing the loam for construction is as follows: first, the earth has been well moistened and then mixed with straw and chaff. The mixture is stirred with a hoe or waded with feet, as long as the mud starts to be easily separated from the hoes [6]. The mixture is then compacted with hammers in layers of 20 cm, walls reaching the thickness of up to 60 cm [7]. As additional reinforcement for preventing cracking of the walls, chipped branches, vines or reeds, were used. The corners of the buildings were specially treated by putting branches at right angles. Rammed earth walls were later plastered with mud mortar on both sides.

Measuring of wall thermal characteristics

Results from many foreign studies, conducted on traditional buildings, have shown that due to many variations and local specifics, the most reliable way to determine the heat transfer coefficient (U-value) is by measuring thermal characteristics on the site [8]. In Serbia, up to now, the thermal characteristics of rammed earth buildings were not the subject of the research, especially when measurements *in situ* are in question. So, this research, although limited only by thermal characteristics of rammed earth walls, represents, in the most general sense, the first research of the energy performance of traditional single family houses in Vojvodina.

The process and methodology of measurements on site

The measurement was conducted in accordance with the regulations ISO 9869. The equipment used for measurement is the device ALMEMO 5690-2/Ahlborn. The device measures following parameters: external air temperature, external surface wall temperature, heat flux, internal air temperature, and internal surface temperature of the wall. The device consists of;

– flux meter plates for measuring the heat flux, rigid and soft, different sizes,
– set of sensors for surface (contact) temperature measurement,
– set of sensors for air temperature measurement, and
– the device itself with the display, commands, and memory for saving data.

The plates for measuring the heat flux are always set in the middle of the wall to avoid the zones around the windows and in the corners, where significant thermal losses due to 2-D heat transfer can occur. When measuring the thermal characteristics of the wall of rammed earth, whose surfaces are not ideally flat, soft plates for measuring heat flux must be used in order to achieve better contact with plates and wall surface. The plate is attached to the wall by special glue, and then its position is additionally fixed with adhesive tape. Sensors for contact temperature measuring on the inside of the wall are set in the same way as a sensor for measuring the heat flux on the external side. When positioning the sensors on the external wall side, the direct impact of rain, snow, and wind must be avoided as well as the direct impact of solar radiation, if possible.

Sensor for measurement of air temperature in the interior is set at half the distance between the walls and half the height between the floor and ceiling in order to avoid the influence of radiation of surrounding surfaces as much as possible. External sensors for air temperature should be positioned in the vicinity of the wall, the direct impact of rain, snow, wind, and solar radiation, as well as the radiation from the wall, must be avoided.

In this way, by the measurement of all these parameters over a longer period of time, the obtained value of thermal transmittance of the wall is determined by the real parameters of temperature changes, other climatic conditions as well as the thermal mass of the wall [9].

According to the relevant standard, the process of measurement of thermal transmittance should last continuously for a minimum of 72 hours. Nevertheless, numerous published researchers, that considered the thermal performance of walls of traditional buildings, recommend that the measuring process should last longer, depending on the structure that is investigated, and that the period of up to two months will give absolutely relevant data. The recommendation is, when thick walls and massive structures are in question, that the measurement should last two to three weeks [10]. In that way, during the first week of measurement all the measured values are stabilized. The deviation of the measured heat transfer coefficient, U, which can be up to ±10% for the measurement period of 72 hours is reduced to ±5% during the two to three weeks measuring period [9]. The value, that can be considered completely reliable, is obtained after continuous measurement lasting 27 days [8]. Such a long measurement period is also required due to external weather conditions that can change over time and if the measurement does not last long enough, the data may be inaccurate. It is recommended also, that during the measurement period, a temperature difference of at least 10 °C between the air temperatures inside and outside exists, however, the level of uncertainty increases where the temperature difference across the wall or building element is small [10]. The uncertainty of the measured U-values within the similar reasrech is estimated generally about ±10% [10].

Selection of the sample – the houses in which the measurement was carried out

For this research, three buildings in Vojvodina were selected, based on following criteria:

– as the construction material for façade load bearing walls rammed earth was used, the thickness of the walls was in average thickness range (50 to 60 cm),
– the buildings are in a rather good condition, still in use for residential purposes,
– rooms are constantly heated through the heating period, usually with night break, and
– the transformation of the buildings consisted of extensions with adding new rooms, did not have any influence on rammed earth walls that were measured.

Basic characteristics of the buildings are summarized in tab. 1.

Problems and limitations of rammed earth walls thermal transmittance measurement in traditional buildings

Measurements for this research were performed in the heating season 2014-2015 on the rammed earth single family houses still in use for residential purposes. At the first stage of planning the field investigations, according to the relevant standard, 72 hours monitoring was planned for each sample of the wall. After the first data were obtained and processed, it was concluded that such a short period of measurement (although in accordance with the standard) gives imprecise results as mentioned in other published researches. The plan of field monitoring was changed and the measurement of one wall was prolonged to a minimum of one week period.

Table 1. Basic data about buildings that were measured

Basic data about buildings	House 1	House 2	House 3
Location	Vojlovica	Vojlovica	Pancevo
Address	Petefi Shandor str.129	Svetozara Markovica str. 48	Ive Kurjackog str. 71
Year of the construction	~1930	~1930	~1810
Data about the measured wall			
Building material of the wall	Mud plaster Rammed earth Lime plaster	Mud plaster Rammed earth Lime plaster	Mud plaster Rammed earth Lime plaster
Wall thickness	60 cm	50 cm	60 cm
Orientation of the wall	South east	East, wall on the porch, protected from direct solar irradiation	South
Measurement data			
The period of measurement	17 days	9 days	7 days
The start of the measurement	November 7, 2014	November 24, 2014	December 8, 2014
The end of the measurement	November 24, 2014	December 3, 2014	December 15, 2014

During the measurement process, as a major problem and limitation, several sets of conditions occurred. One of them was the inability to provide a steady-state temperature of the air outside and inside. Major fluctuations in daily inside air temperatures were caused by the behaviour of the user (intermittent heating) and on the outside due to weather conditions as the wind, solar radiation, and other atmospheric influences. In order to get more stable conditions, when the inner air temperature is in question, the inhabitants accepted to have continuous heating during the measuring period while for the outside conditions more shaded and protected parts of the walls were chosen, but still, significant air temperature differences could not be avoided.

Another problem is the fact that the building was built of locally available building materials, earth (clay, loam) was used from the building construction site causing the different composition of the material. In the process of building, straw, chaff, vine branches, often horse and pig hair were added and today, it is impossible to determine the exact composition of the wall without laboratory analysis, fig. 3. The photograph at fig. 4 presents the lack of uniformity in the structure of a rammed earth wall. Clearly, the difference in the layers in the structure of the wall can be seen. In other words, each wall has its own peculiarities in composition and structure and thus the thermal performance may vary in a rather wide range and the overall thermal characteristic of rammed earth wall in traditional single family houses in Vojvodina can be estimated only as a mean value of measured values.

An additional problem, which occurred during the measurements on site, was established the fact that over the time, many of those residential houses underwent numerous transformations. Traditionally built of rammed earth, walls as structural façade walls were plastered on both sides with mud mortar. Unfortunately, they were usually renewed by adding new mortar, cement on the outer and lime-cement on the inside while the mud mortar was not used any more. Most of the owners do not know who and when made the interventions nor they can explain the range and content of the intervention. When the walls are in good condition, it is very difficult to define the inner structure of the wall just by observation. So the assumption was adopted based on the used mortar that all the walls still plastered with mud mortar have traditional structure of the rammed earth.

Figure 3. Rammed earth wall with a large quantity of added straw (chaff) plastered with mud mortar, a house in Vojlovica

Figure 4. Cross-section of the rammed earth wall, abandoned house in Ivanovo

All the data collected during the measurements on site for three buildings are presented in tables and graphics. The parameters were recorded automatically by the ALMEMO 5690-2 / Ahlborn device at intervals of five minutes.

The methodology of analysis and processing of the measured parameters

For each measurement, the relevant period taken into account was defined by the time interval with the most stable measured temperatures. The determination of the wall heat transmittance resistance was calculated based on the measured parameters in a defined time range;

– the inside and outside surface wall temperature, $T1$ and $T2$, and
– heat flux, Q.

The following expression was used for the calculation of the wall heat transmittance resistance R_{gk} [$\mathrm{m^2KW^{-1}}$]:

$$R_{gk} = \frac{\Delta T}{Q} \tag{1}$$

where ΔT [K] is the temperature difference between the inner and the outer surface of the wall ($T1 - T2$) and Q [$\mathrm{Wm^{-2}}$] is heat transfer (wall transmittance) through the wall.

This practically means, that based on the measured parameters of the heat flux and temperature differences, heat transmittance resistance, R_{gk}, of the wall can be determined. If the following relation between the coefficient of heat transfer and overall thermal resistance R_u is used, it is possible to determine the heat transfer coefficient U:

$$U = \frac{1}{R_u} = \frac{1}{R_{si} + R_{gk} + R_{se}} \tag{2}$$

where the total thermal transmittance, R_u, represents the sum of thermal resistance (from indoor air to the wall, through the wall and from the exterior surface of the wall to the surrounding air). The values are taken from the regulations on energy efficiency in buildings amounts $R_{si} + R_{se} = 0.17$ m^{2}K/W and conduction heat resistance of the wall structures R_{gk} is taken from eq. (1).

Within the defined time interval, ALMEMO 5690-2 /Ahlborn device measured data at intervals of five minutes, so there are a large number of measured values that enable the calculation of the average value of thermal characteristics of the traditional Vojvodina house rammed earth walls.

Determination of thermal characteristics based on measurements of the rammed earth walls

According to the methodology previously described, the coefficient of heat transfer of rammed earth wall was determined based on certain parameters measured in situ. The principle of data processing for one of the three measured walls of the traditional houses in Vojvodina where the measurement is presented. Other data measured in the field will be presented in tables.

Measuring of the rammed earth wall thermal transmittance

The measurement is carried out in accordance with the standard ISO 9869 and according to the previously described methodology. The process will be presented for the house No. 1 where the measurement period lasted 17 days, which is significantly above the minimum required time of 72 hours. The walls were measured for the longer period of time to allow for the impact of thermal mass and for fluctuations in temperature to be stabilized. In the measured period of time the most stable interval (in terms of temperature swings) has been chosen, assuming that the differences in measured U-values would be in acceptable range.

In fig. 5, the measured values of temperature for the entire period of measurement are presented. It can be concluded that during the most of the measurement period weather conditions were inadequate: temperature fluctuations were very high and the adequate temperature difference of min 10 ºC in the air temperature (internal-external), defined by the standard, was achieved only at the end of the measurement period, fig. 5(a1).

For the determination of the average value of thermal transmittance for house No.1, as a relevant measurement time period, the specified period with the most stable weather conditions has been adopted. It lasted for 12 hours, from November 23, 2014 at 21.00 to 09.00 at November 24, 2014, and is characterized with a total of 145 sets of measured data (every five minutes), fig. 5(b1) with following characteristics;

– the external air temperature was in the interval from 1.3 °C to 4.4 °C,

– external surface wall temperature follows the fluctuation of air temperature, is measured in the interval of ±1.2 °C from a minimum of 2.5 °C to a maximum of 4.9 °C,

– the internal air temperature was in the range from 15.7 °C to 19.4 °C,
– internal surface wall temperature is measured in the interval of ±0.65 °C, from a minimum 15.3 °C to a maximum of 16.6 °C, and
– the average measured value of heat flux was 9.15 W/m^2.

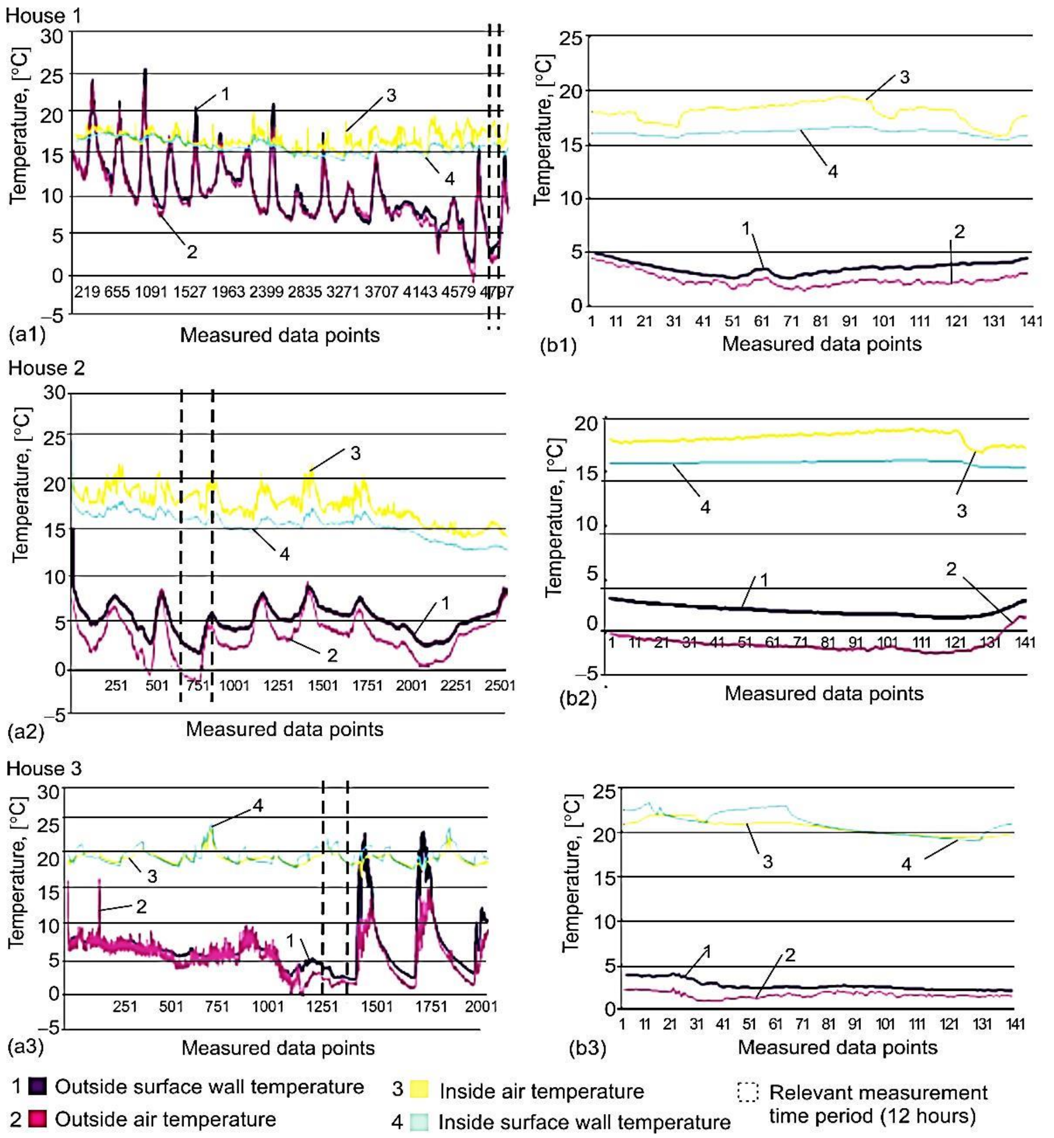

Figure 5. The inside and outside air and surface wall temperature measured in situ; (a) the measured values of temperature for the entire period of measurement and (b) the measured vales of temperature for a relevant measurement time period (12 hours)

According to the previously described methodology and based on these 145 sets of measured parameters, the values of heat transfer coefficient, *U*, for a rammed-earth wall was calculated giving the average value of the No. 1 house of U = 0.65 W/m^{2}K. The same procedure was repeated for the remaining two houses. The overview of field measurements and average *U*-values are presented in tab. 2.

Table 2. Overview of parameters measured no site and obtained results for three buildings in Vojvodina

Building	House 1		House 2		House 3	
Relevant measurement period						
Date/time of the beginning of measurement	November 23, 2014 21 hours		November 26, 2014 22 hours		December 12, 2014 20 hours	
Date/time of the end of measurement	November 24, 2014 09 hours		November 27, 2014 10 hours		December 13, 2014 08 hours	
Duration of measurement	12 hours		12 hours		12 hours	
Number of measured data sets	145		145		145	
Measured parameters						
Surface temperature of the wall	range	average	range	average	range	average
$T1$ [°C] internal	15.3-16.6	16.04	15.3-16.6	15.76	19-23.4	21.04
$T2$ [°C] external	2.5-4.9	3.45	1.5-3.3	2.15	2-4	2.58
Thermal flux						
Q [W/m2]	9.15		11.21		20.71	
Air temperature						
$T1$ [°C] internal	15.7-19.4	17.89	16.7-18.9	18.08	19.4-22	20.56
$T2$ [°C] external	1.3-4.4	2.36	–1.8-1.6	–0.96	0.8-2.3	1.50
Calculated result						
U [$Wm^{-2}K^{-1}$]	0.65		0.71		0.94	

The calculated heat transmittance (*U*-value) for the rammed-earth façade wall of traditional Vojvodina single family house, based on the measured values of heat flux and internal and external wall surface temperatures, ranged from 0.65 to 0.94 W/m^2K. These results correspond to the results of several published international researches were the *U*-value for similar rammed-earth walls without additional insulation where in the range from 0.7 to 1.5 W/m^2K depending on the composition and thickness of the wall [9].

Calculated *U*-values

Heat transfer coefficient of building wall, *U*, is calculated in the general case for the construction element of simple heterogeneity, for the rammed-earth wall with two layers of mud mortar, in accordance with standard EN ISO 6946 and Serbian regulation, as follows [11] , eq. (3):

$$U = \frac{1}{R_{si} + \sum \frac{dm}{\lambda m} + R_{se}} \tag{3}$$

where R_{si} [m^2KW^{-1}] is the value of surface resistance of the internal wall side 0.13, R_{se} [m^2KW^{-1}] – the surface resistance of external wall side 0.04, d [m] – the thickness of the m^{th}

element layer, and λm [$Wm^{-1}K^{-1}$] – the value of thermal conductivity for compacted earth and for mud mortar (lime plaster).

It should be noted that the current Serbian Regulation provides very limited information for a very limited number of traditional construction materials, while some common traditional materials are not even mentioned. The earth as a construction material is mentioned only as loose earth (wet), with thermal conductivity λ = 2.1 W/mK, while compacted dry earth, rammed earth or mud mortar is not mentioned. The adopted values of thermal conductivity are therefore taken from different Serbian and international standards: thermal conductivity for compacted earth λ = 1.2 W/mK [12] and thermal conductivity for mud mortar (lime plaster): λ = 0.8 W/mK [13].

Comparison of the results obtained for the heat transfer coefficient

Comparative analysis of the results shows that the average values of thermal transmittance for the rammed earth walls obtained by field measuring are considerably lower than the values obtained by calculation in accordance with the existing Serbian regulations. This significant difference is in the variation from 33% to 55%. The proof that the obtained results are valid is that other similar researchers found that this variation can be from 30 to 50% [10]. Summary of the results are shown in tab. 3.

Table 3. Heat transfer coefficient for rammed earth walls

Building	House 1	House 2	House 3
Coefficient of thermal transmittance, U [$Wm^{-2}K^{-1}$]			
Measured on site	0.65	0.71	0.94
Calculated	1.40	1.59	1.40

The obtained results can be interpreted as the result of several factors causing it. The heat transfer coefficient is caused by a large wall thickness d = 50-60 cm which also has a high thermal mass influencing the slow flow of heat through the wall [14].

Published research on traditional rammed-earth walls show, that in this type of walls steady-state thermal resistance is low but for the wall thicker than 45 cm, as is the case in the most traditional house of Vojvodina, cyclic state thermal resistance is high and increase exponentially [14]. This practically means that, during measurement process of the rammed-earth walls, heat transfer coefficient of building elements, U, is caused by cyclic state thermal resistance. On the other hand, the current regulation and all codes of practice are based on the steady-state conditions where the difference in temperature across the material is kept steady, which is a practically impossible situation in real terms when measuring in situ. This statement can explain lower U-values measured in situ, and on the other hand, high computational heat transfer coefficient when traditional Vojvodina house rammed-earth walls are in question. In addition, the statement indicates unreliable data in the calculations of U-value for this type of construction [15].

Another factor influencing the relatively low value of wall heat transmittance measured in situ is the structure of the wall that consists of packed earth mixed with horsehair and a large amount of straw, which certainly improves the insulating properties of the wall. In addition, the inside of the wall is plastered with the mud mortar with a large amount of added husks, fig. 3. Values obtained by measuring in situ are influenced by these peculiarities in the walls, while the calculation uses a single value for thermal conductivity and thus the specificity of the walls are practically irrelevant.

Conclusions

By the conducted research the wall heat transmittance (U-value) of the traditional Vojvodina rammed earth façade wall was investigated. The research was conducted in two separate steps. The first step was calculating the U-value according to the methodology and thermal conductivity values defined in Serbian and international regulation (as already noted the current Serbian Regulation provides data for the very limited number of traditional construction materials). The second step was defining it by field measurements of wall thermal conductivity. The comparison of the results showed that there are significant differences in values obtained by those two methodologies pointing to the complex issue of thermal performance of rammed-earth walls.

Research has shown that the heat transfer coefficient for the specific rammed-earth walls obtained on the basis of the parameters measured in situ, shows far better results than the calculated values obtained in accordance with the regulations. However, obtained values with range from U = 0.65 W/m^{2}K to U = 0.94 W/m^{2}K nider meet the current maximum allowed heat transfer coefficient for new construction ($U_{\max}$ = 0.3 W/m^{2}K), nor the values defined for the rehabilitated walls of existing buildings ($U_{\max}$ = 0.4 W/m^{2}K)

Due to big differences, it can be concluded that calculation of the heat transmittance according to the regulations of Republic of Serbia showed the evident shortcomings when it comes to the treatment of traditional building materials and can not be considered relevant in the case of Vojvodina's traditional home of rammed earth.

It may be concluded that the issue of energy performances of traditional rammed-earth buildings is a complex issue which needs special attention. The research indicates a rather good thermal properties of the walls of rammed earth. Further research is necessary to consider the possibility of improvement of existing facilities to meet current standards in terms of energy efficiency.

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