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Numerical thermal analysis of wall structure of a sustainable building

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Abstract. *The straw-wooden panel became an integral part of eco-building in the 21st century. Combined with wooden frame, interior and exterior protective layers, this technology allows to achieve passive house and nearly zero energy standard. This paper represents the numerical analysis of simplified fragments of straw-wooden panel in two variants: with and without accumulation layer and heating. The obtained data will be compared with the next investigations concerning the detailed structure with wooden frame and expected thermal bridges.*

Key words: straw-wooden panels, insulation, numerical analysis, housing construction, green building, sustainable development in constructions

1. Introduction

Natural conditions and local building materials had a great influence on the formation of folk architecture, the types of residential buildings, their placement. The use of local materials, such as straw, reeds, etc., has been practiced in housing construction in Ukraine since ancient times.

Each natural landscape forms its own modes of dwelling. In forests, ancient buildings have been built from wood, in the forest steppe - from clay, straw and wood, in the steppe - from clay and stone. By the nature of natural building materials, the territory of Ukraine can be divided into three lanes. The forest zone occupies the north of Ukraine to the Volodymyr-Volynsky, Lutsk, Rivne, Zhytomyr, Kyiv, Nizhyn, and Glukhiv lines. The main building material here it was wood. Clay had an auxiliary value; the cover was made of straw. The Forest-Steppe belt harbors the central part of Ukraine to the Balta, Kremenchug, Poltava, and Kharkiv lines. In the building here, there were used wood, clay, cane and straw; straw or cane cover (Fig. 1.) [1].

Along with the well-known advantages of such dwelling (ecology, economy, accessibility), the traditional constructive solutions are inherent in the shortcomings, in the first place, the failure to ensure the implementation of modern standards for energy efficiency in constructions [2].

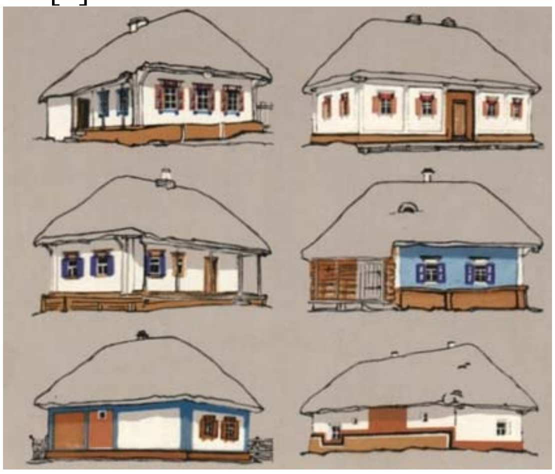

Fig. 1.Types of Ukrainian Dwelling (Poltava region, end of the XIX century) [3]

Under the conditions of the global environmental, social and economic crisis, widespread use of local materials and energy-saving technologies in the construction industry can solve a number of urgent social problems in providing the population with quality affordable housing that meets the criteria of the sustainable development policy.

For the introduction of mass ecological construction in design practice, it is necessary to adapt existing effective, unique technologies in the conditions of modern standards and norms.

For the existing material and cultural base of Ukraine, a promising construction technology is the technology of low-rise construction with the use of a wooden frame and local organic materials such as straw of cereals, hemp, reeds as insulation. Ukraine has especially considerable potential for the use of straw cereals in construction. Annually its available volume for use is about 5 million tons. [4]

Today, in the world, a wooden frame is widely used in the construction of low-rise ecological housing. The construction of the wall from local organic materials and the choice of structural details depends on the type of frame chosen - the racks are located in the center of the organic insulation, either on the outside or on the inside - and on the type of racks - simple or double ladder type or I-section (Fig. 2, Fig.3, Fig. 4). [5].

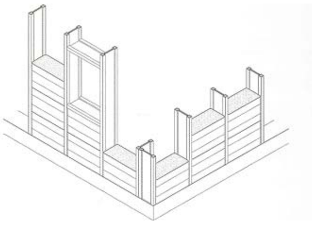

Fig. 2. I-section rack

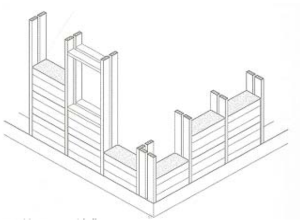

Fig. 3. Rack made of solid wood

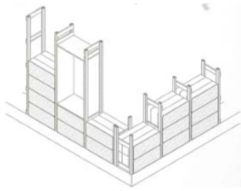

Fig.4 "Ladder" type rack

2. Case study and general assumptions

The most versatile of these technologies, suitable for any type of organic insulation (both in straw pressed blocs and in bulk packed) - is a "ladder" type frame. The main elements of external enclosing structures of this type used in the design of low-rise buildings from ecological local materials are shown in Fig. 5. [6]

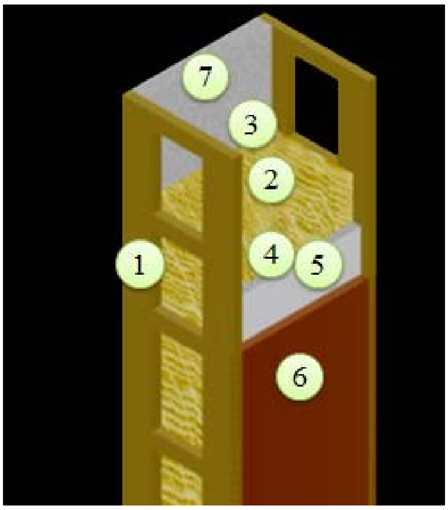

Fig.5. The main elements of external enclosing structures used in the design of low-rise buildings from environmental local materials
1 - "ladder" type rack; 2 - insulation from ecological local materials (straw cereals, light or traditional adobe, hemp or cane), 400 mm; 3 - vapor barrier; 4 - wind protection; 5 – grid; 6 - outer layer of clay plaster, 50 mm; 7 - moisture resistant gypsum board, 12.5 mm

As the insulation material it can be used any ecological plant origin local material. Meanwhile, the theoretic calculation of the presented model on energy-efficiency in the different architectural-planning context application according to the existing Ukrainian standards showed, that the most effective local ecological material from the point of view of energy saving is the pressed straw of cereal crops, although a lightweight concrete of hemp and lightweight adobe make it possible to reach the level that corresponds to the highest energy conservation class A. [7]

For the research, we have chosen the wall structure for a sustainable building containing a wooden frame, a thermal insulation layer from materials of straw origin, an internal massive heat accumulation layer and an outer protective layer.The considered element is the fragment of pre-fabricate straw-wooden panel of 250 mm of width and the overall dimensions - 1000x1000 mm (thermal insulation layer); info red heating film (heating layer) and brick accumulation layer of width of 120 mm. Characteristics of materials are summarized in the Table 1.

The analysis is carried out in two general stages:

1. First stage – test of prefabricated straw-wooden panel without accumulation layer and heating under the conditions precise in the Table 2 (temperature in external camera).
2. Second stage – test of composed wall with insulation, heating and accumulation layers under the conditions precise in the Table 2 (temperature in external camera).

Table 1

Characteristics of materials

Material	Thickness, m	Thermal conductivity λ ,W/m·K	Thermal capacity, J/(kg·K)	Density, kg/m^3
1.External clay plaster layer	0,02	0,15	880	1600
2. Straw panel	0,25	0,062	600	220
3.Heat-reflecting material (eg Izolon, Penofol, etc.)	0,005	0,037	1950	33
4.Electric heating film	0,00034	0,42	1800	1000
5.Masonry of ceramic brick	0,120	0,17	2070000	1800

3. Numerical thermal analysis of the specimens using ANSYS workbench

This paper represents the numerical analysis of simplified fragments without elements of wooden frame in order to examine the main field of the structure. The obtained data will be compared with the next investigations concerning the detailed structure with wooden frame and expected thermal bridges; and also with results of described samples testing under mentioned conditions in climate chamber. Experiment of the thermo-technical properties study of the proposed structure element is planned to realize in the big climate chamber TiR32 in the laboratory of building physics of Civil Engineering Faculty (Slovak University of Technology in Bratislava). The disposition and numbers of measurement points are represented on the Fig. 6 and 7.

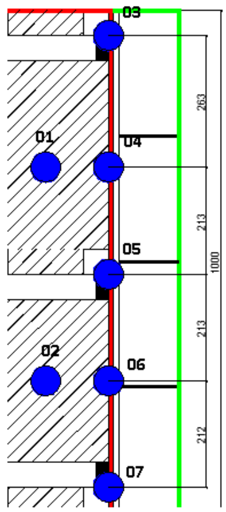

Fig.6. Disposition of measurement elements for the first stage of experiment

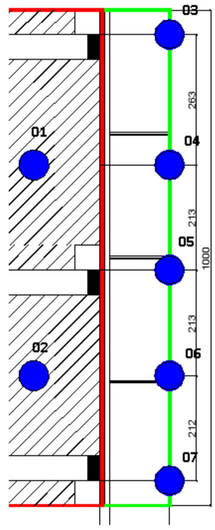

Fig.7. Disposition of measurement elements for the second stage of experiment

The numerical analysis was carried out by ANSYS workbench, a program to calculate the three-dimensional steady-state temperature distribution and heat transfer. The numerical approach permitted also to verify required dimensions of the samples in order to avoid distortion of the temperature field caused by edge effects during the experiment. The thermal conductivities of the materials are summarized in Table 1. Heat transfer coefficient of the interior surface is αint=8,7 W/m^2·K and for exterior surface αint=23 W/m^2·K. The calculations were done by choosing an appropriate grid [7] resulting in 5853 nodes for the first stage of experiment and 11055 nodes for the second stage. The power capacity of the electric heating film is 10 W/m^2.

The exterior temperature is varying from -15 to +10°C. The figure 8 represents prefabricated straw panel without accumulation layer and heating. The figure 9 represents composed wall with insulation of straw, heating and accumulation layers. For the illustrated example for the both variants we imposed -15 °C on the cold side and 20 °C on the hot side with the purpose to obtain a maximal temperature difference of 45 °C.

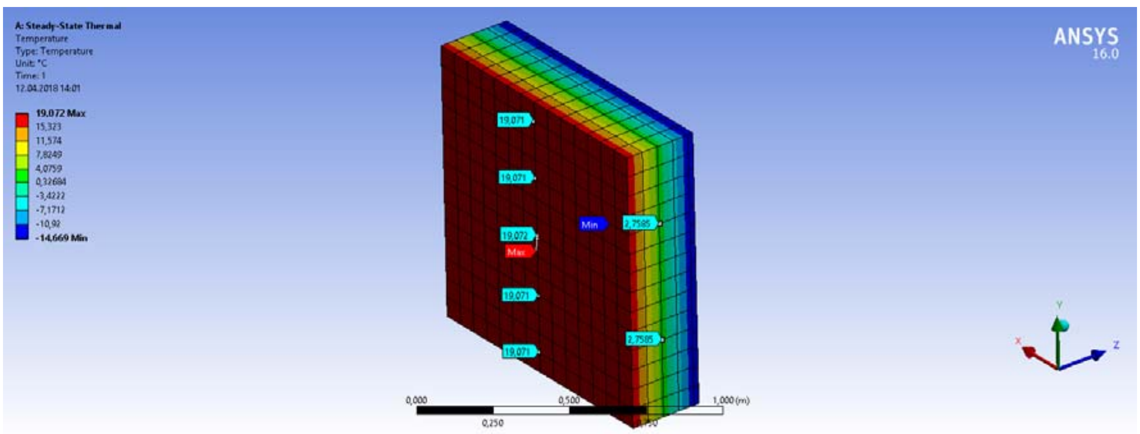

Fig. 8. Prefabricated straw panel without accumulation layer and heating.

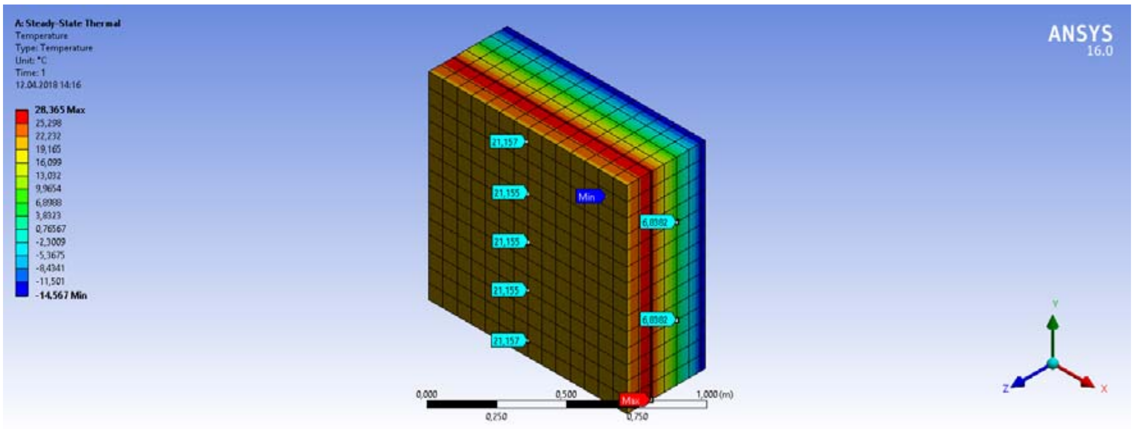

Fig. 9. Composed wall with insulation of straw, heating and accumulation layers.

The results of modelling for all variants of temperature conditions are represented in the Table 2.

Table 2

Results of numerical thermal analysis

Stage (type of sample)	Temperature in external camera*, t_{ex}, °C	Temperature values, °C						
		01	02	03	04	05	06	07
First stage prefabricated straw-wooden panel	-15	2,769	2,76	19,071	19,071	19,072	19,071	19,071
	-10	5,222	5,22	19,204	19,204	19,205	19,204	19,204
	-5	7,685	7,68	19,336	19,336	19,337	19,336	19,336
	0	10,148	10,148	19,469	19,469	19,467	19,469	19,469
	+5	12,611	12,611	19,602	19,602	19,602	19,602	19,602
	+10	15,074	15,074	19,735	19,735	19,735	19,735	19,735
Second stage composed eco wall with insulation, heating and accumulation layers	-15	6,8382	6,8382	21,157	21,155	21,155	21,155	21,157
	-10	9,7151	9,7151	21,268	21,266	21,266	21,266	21,268
	-5	12,593	12,593	21,379	21,377	21,377	21,377	21,379
	0	15,47	15,47	21,49	21,489	21,489	21,489	21,49
	+5	18,347	18,347	21,602	21,6	21,6	21,6	21,602
	+10	21,224	21,224	21,713	21,711	21,711	21,711	21,713

The temperature difference between values for the first and for the second stage of point № 05 (under -15°C in external camera) located in the middle of the straw insulation layer reaches 2,083 °C. In other words the presence of heating film and an accumulation layer assure higher temperature on the hot side of the wall and protect it additional heat losses. Those results will be compared with experimental data from climate chamber.

6. Conclusion

The paper was dedicated to the study of two variants of the wall structure for a sustainable building containing: for the first stage - a wooden frame, a thermal insulation layer from materials of straw origin and an outer protective layer; for the second stage – mentioned components plus a heat-reflecting material, an electric heating film and a masonry of ceramic brick as an accumulating layer. This paper represents the numerical analysis of simplified fragments without elements of wooden frame in order to examine the main thermal field of the structure. The presence of heating film and an accumulation layer assure higher temperature on the hot side of the wall and protect it from additional heat losses. The obtained data will be compared with the next investigations concerning the detailed structure with wooden frame and expected thermal bridges. And also the obtained data will be compared with results of described samples testing under mentioned conditions in climate chamber.

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