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NUMERICAL THERMAL ANALYSIS OF WALL STRUCTURE FOR SUSTAINABLE BUILDINGS

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ABSTRACT

Actuality. The last years the development of pre-urban areas around big European cities has intensified. The strict energy efficiency requirements force the developers to apply measures to ensure the high level of thermal protection in low-rise building. But in the same time business interest of the minimizing the initial costs of such buildings initiates the wide implementation of synthetic, non-recyclable or difficulty recyclable building materials for insulation, such as polystyrene insulation widely used, what is not sustainable taking into the consideration all life cycle of the building**.** **The purpose.** The main objective of the presented research is to define the eco-structures of recyclable organic based materials as the efficient industrial alternative to the modern insulation of low-rise buildings. **Methodology.** Engineering design has been applied to develop the structure solution and laboratory study has been realized to analyze the main physical and thermo-physical properties of the proposed structure. **Finding.** 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 has been developed. Experiment of the thermo-technical properties study of the proposed structure element has been released in the big climate chamber TiR32 in the laboratory of building physics of Civil Engineering Faculty (STU in Bratislava). During the tests the following parameters have been evaluated: the temperatures in the external and internal surface of the test element in several points including on the joints (wood frame elements), where the thermal bridges were expected; overall thermal image of the external and internal wall in the extreme negative temperatures; thermal flow to the interior (during the first stage) – to define the coefficient of thermal conductibility of straw-wooden panel itself as well as the required long of heating periods and energy consumption to ensure temperature stability within thermic barrier integrated in the wall element. **Scientific novelty and practical value.** The received parameters are to implement for design of sustainable low-raised buildings structures of natural origin materials. The implementation of the proposed structure solution will facilitate balanced development of lo-raise building in EU.

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INTRODUCTION

According to the UNEP, building sector consumes about 40% of global energy, 25% of water and creates 1/3 of greenhouse gas (GHG) emissions. At the same time, buildings offer the greatest potential for achieving significant GHG emission reduction. The European Parliament and the Council reasonably accepted Energy Performance Buildings Directive (EPBD) [1], which shall ensure that by the end of 2020 all new buildings must be Nearly Zero-Energy Buildings (NZEB). However, a progress is slower than expected because of lack affordable solutions in innovative building design, especially taking into account different initial conditions, social and economic situation in EU countries.

The realized research focuses on a maximizing the integration of renewable materials in design of modern sustainable buildings taking into account the energy efficiency requires together with ecological and social aspects in the context of adaptation and availability od the proposed solutions.

The action plan for the Circular Economy has been accepted by EC in 2015 [2]. The circular economy refers to an industrial economy that is restorative by purpose, where components are kept in the economy at their highest utility and value in the long-term run. In particular, the construction sector of the industry primarily needs to provide these principles in wide application.

There are several gaps not permitting to wider implementation of the sustainable policies in building sector area have been defined: complex technical solutions requiring the informatic support, expensive materials and equipment providing energy-efficiency, lack of understanding and familiarity with green products, systems, and the development process

The key feature of the upcoming research is a focus on environmentally pure and renewable local materials such as straw, flax, reed, hemp, soil-concrete and others. The core idea of this research work is to develop the most efficient industrial "easy-do" low cost combined solutions of sustainable low-rise building. This approach is based on combination elements with different functions to the autonomous unite. The cost minimization is considered in line coordinated with economical, ecological and comfort quality, e.g. building sustainability what could theoretically ensure its popularity and overall success.

The important "easy-do" principle of the considered conception requires finding the balance between complicated but effective "high-tech" and affordable but non-industrialized "low-tech" for design of multifunctional (housing and industrial purposes) buildings for rural area.

CONSTRUCTION DESIGN

It is proposed an industrial wall structure for a sustainable building containing a wooden frame, **a thermal insulation layer** from materials of vegetable origin, **an internal massive heat accumulation layer** and **an outer protective layer** - which is characterized by the formation of an energy-efficient environmental wall structure, where the bearing wooden elements are executed with metal detachable mounting elements, and work in a complex with insulation, protective and accumulating layers; Internal accumulation layer from soil concrete blocks, assembled dry and has **installation constructive holes for communications**, protective outer layer of lime-limestone compositions of carbonization hardening, heat insulation layer from a light heat-insulating material based on raw materials of vegetable origin (Fig.1).

The wooden frame 1 is formed by connecting the vertical wooden racks to the two-girder column by connecting the horizontal bar 2 and the diagonal slits on the removable mounting elements 3 to ensure geometric unchanging. The step of the columns of the step is determined by calculation depending on the chosen architectural decision. The insulating layer 4 is provided by filling the spaces between the columns with a light insulation material based on raw materials of straw origin (straw of cereal crops, flax, hemp, etc.). The thickness of the thermal insulation layer is determined by the design of the energy efficiency class of the building. The protection of wooden constructions and insulation of organic origin is carried out by a moisture-resistant parboiler 5, separating the main structure from the internal accumulation layer. The internal accumulated thermal energy of the massive layer is formed by the concrete concrete blocks 6, which are formed dry without a solution and have technological openings 7 for the arrangement of communications. Painting layer 8 provides the tightness of the accumulation ball and the structure as a whole. From the outside of the wall, the frame elements and insulation isolate the wind barrier 9. The outer protective layer 10 consists of solid blocks of limy-limestone carbonization hardening compositions.

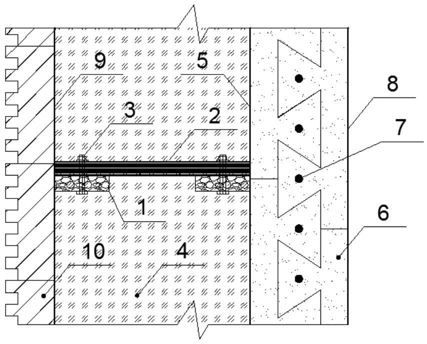


Figure1. Detailed model of the proposed straw wall element.

LABORATORY STUDY METHODOLOGY

Laboratory study has been proceeded on the simplified model of the proposed straw wall element. The heating layer has been ensured by info-red heating film and the accumulated one by the standard silicate brick. Experiment of the thermo-technical properties study of the proposed structure element has been released in the big climate chamber TiR32 in the laboratory of building physics of Civil Engineering Faculty (Slovak University of Technology in Bratislava). The test 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 electric heating film, infro film Eco Term of width 1 m (thickness 0,34 mm) 140W/m2б 1x1 m (heating layer) [4] and brick accumulation layer of width of 120 mm. (Fig. 2)

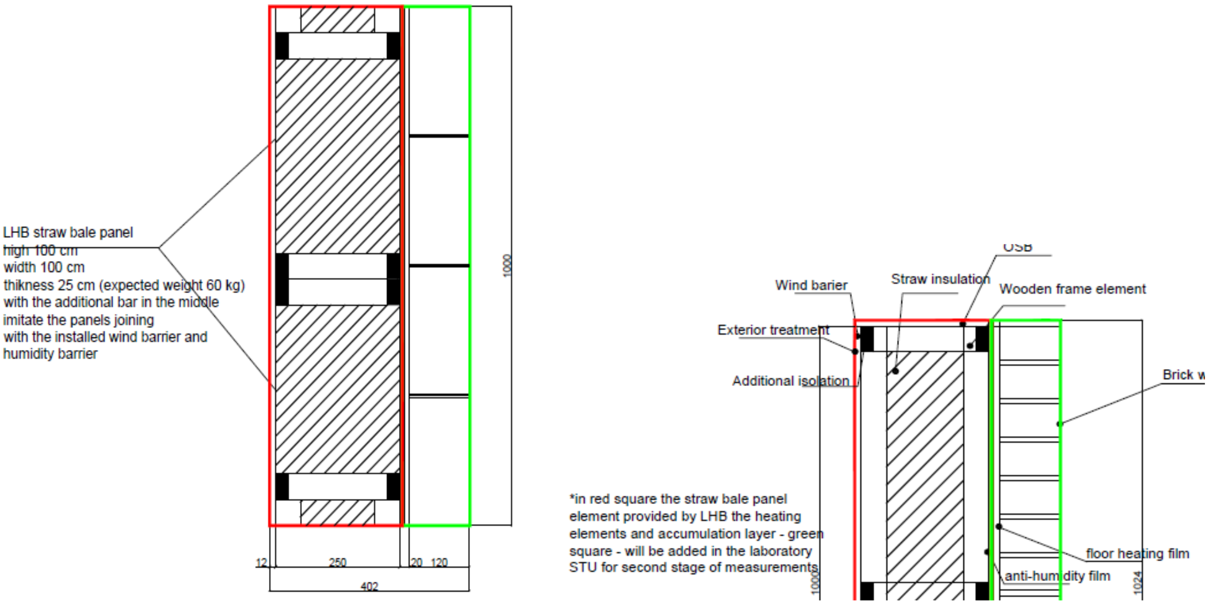


Figure 2. The composition and parameters of the test sample.

The test was realized 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 1.
2. **Second stage** – test of composed wall with insulation, heating and accumulation layers under the conditions precise in the Table 1.

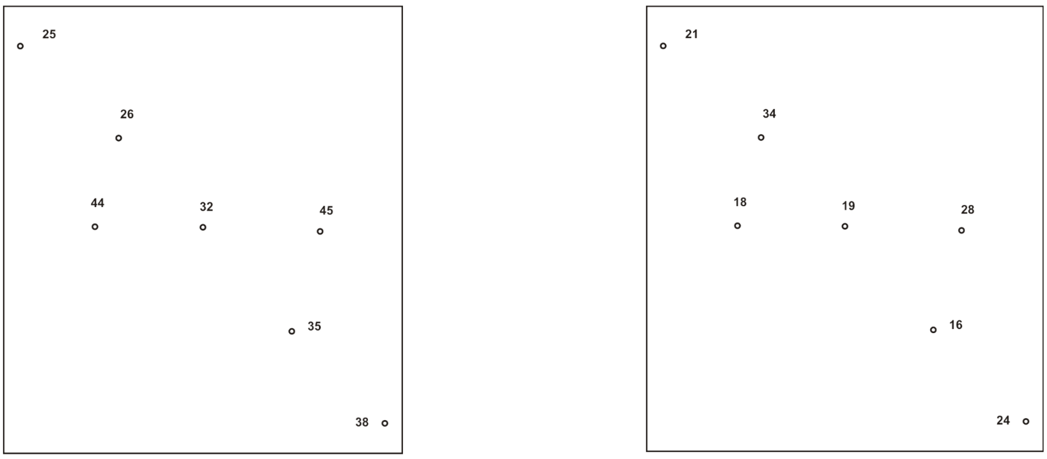
The parameters of the test are presented in the Table 1.

Table 1. The parameters of the stages of the experiment.

Stage (type of sample)	Temperature in external camera*, t_{ex}, °C	Temperature in internal camera, t_{in}, °C	Level of heating, temperature of heating film, t_h, °C	Relative humidity in external camera, W_{ex}, %	Relative humidity in internal camera, W_{in}, %
First stage prefabricated straw-wooden panel	-15	20	0	50	50
	-5		0	50	50
	+5		0	50	50
Second stage composed eco wall with insulation, heating and accumulation layers	-15	20	28	50	50
	-5		28	50	50
	+5		28	50	50

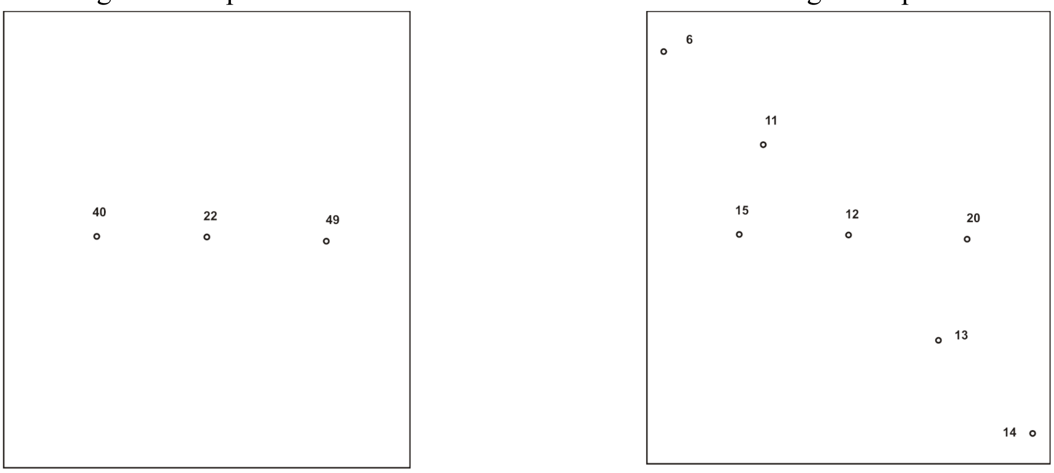
*Temperature-humidity regime has been supported certain period of time at least 24 hours

The disposition of measurement elements for the both stages of the experiment are shown on the Fig. 3 and Fig. 4.



Exterior room Interior room

Figure 3. Disposition of measurement elements for the first stage of experiment.



Exterior room Interior room

Figure 4. Disposition of measurement elements for the second stage of experiment.

The expected test parameters for evaluation in the frame of the presented laboratory study are: the temperatures in the external and internal surface of the test element in several points including on the joints (wood frame elements), where the thermal bridges are expected; overall thermal image of the external and internal wall in the extreme negative temperatures; thermal flow to the interior (during the first stage) – to define the coefficient of thermal conductibility of straw-wooden panel itself; heating periods and energy consumption to ensure temperature stability within thermic barrier integrated in the wall element.

RESULTS OF THE STRAW WALL STUDY

The temperature measurements results are shown in Tables 2–3. The received results describe the differences of temperatures on the surfaces in interior and external rooms of climate chamber. According to the received differences transmission of heat through a building wall has been calculated.

Table 2. First stage of measurements.

Position	ex	in	ex	in	ex	in	ex	in	ex	in	ex	in	ex	in
Meas. point	25	21	26	34	44	18	32	19	45	28	35	16	38	24
-15	-14.5	16.6	-12.2	18.1	-13.4	16.5	-14.2	17.13	-14.4	17.9	-14.8	15.7	-14.8	13.9
-5	-4.7	17.5	-3.4	19.1	-4.1	18.1	-4.8	18.01	-4.7	18.7	-4.9	17.7	-4.8	16.1
+5	5.1	18.4	5.7	19.6	5.3	19.1	5.4	18.77	5.1	19.3	5.1	19.0	5.2	18.2

Table 3. Second stage of measurements.

Position	ex	in(brick)	ex	in(brick)	ex	mid	in(brick)	ex	mid	in(brick)	ex	mid	in(brick)	ex	in(brick)	ex	in(brick)
Meas. point	25	6	26	11	44	40	15	32	22	12	45	49	20	35	13	38	14
-15	-14.5	19.9	-13.2	20.3	-14.4	15.8	19.4	-14.4	17.1	20.0	-14.7	17.4	19.9	-14.9	19.1	-14.9	17.86
-5	-4.8	19.7	-4.0	20.2	-4.6	17.5	19.7	-4.5	18.1	20.0	-4.8	18.3	19.9	-4.9	19.5	-4.9	18.67
+5	5.1	19.8	5.4	20.2	5.2	19.3	20.1	5.37	19.6	20.2	5.1	19.6	20.1	5.1	19.9	5.2	19.42

Table 4. Coefficient of thermal conductibility of straw wall under different thermal conditions.

Temperature regime, °C	U, W/m2K	Coefficient of thermos-transmission in different temperature regimes, W/m*K
-15	0.38	0.095
-5	0.32	0.08
+5	0.27	0.068

The analyze of the regime of work of heating layer to ensure the required interior regime is presented in the diagrams on the Fig. 5 – Fig.6.

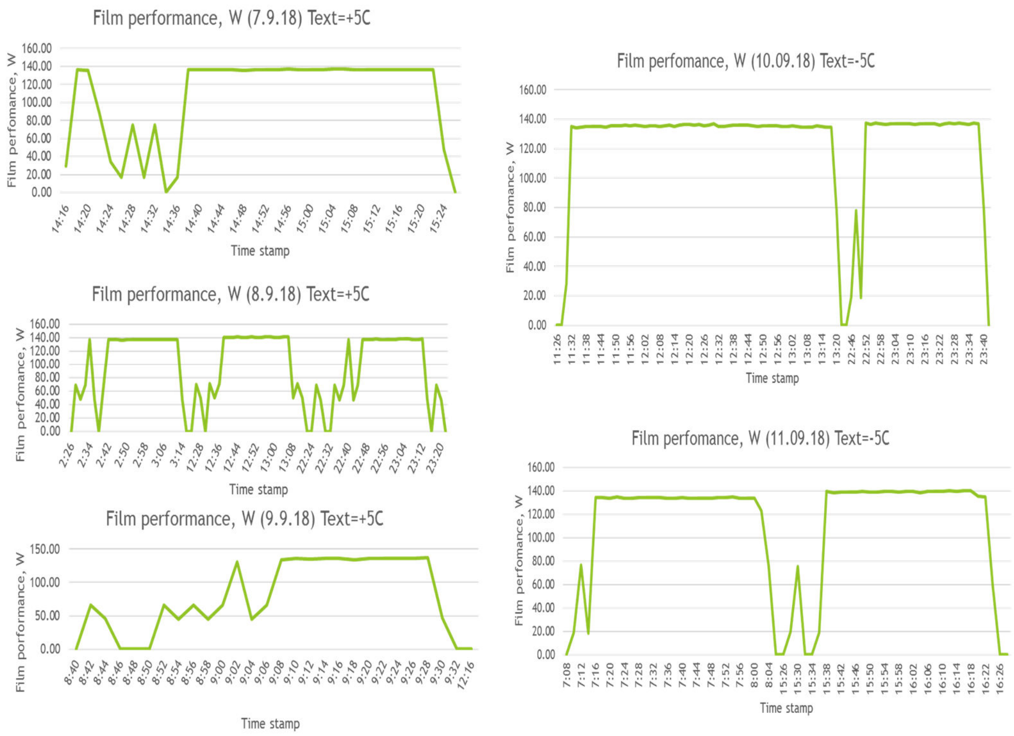


Figure 5. Heating periods under the external temperature regime +5°C and -5°C.

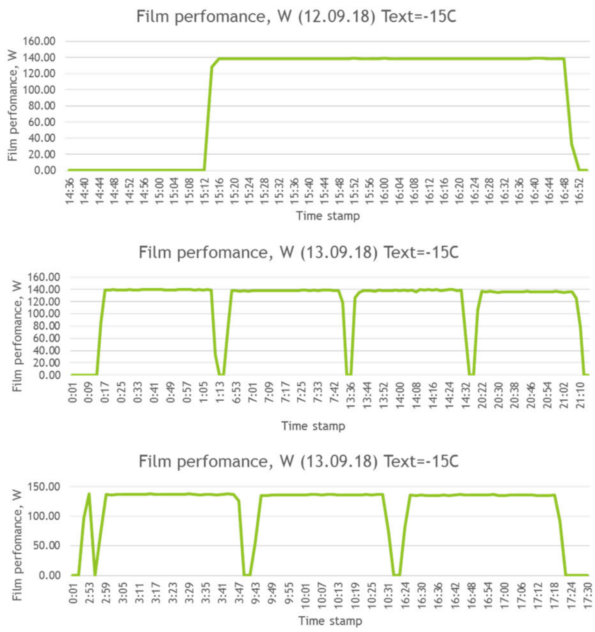


Figure 6. Heating periods under the external temperature regime -15°C.

CONCLUSIONS

1. The composite structure solution of straw wall for sustainable buildings has been developed. The structure is containing a wooden frame, a thermal insulation layer from materials of vegetable origin, an internal massive heat accumulation layer and an outer protective layer.

2. The complex study of thermal properties of the proposed structure has been proceeded in big climate chamber TiR32 in the laboratory of building physics of Civil Engineering Faculty (Slovak University of Technology in Bratislava). Coefficient of thermos-transmission in different temperature regimes for the studied wall structure varies 0.095 - 0.068 W/m*K according to the external temperature conditions.

3. The enfro-red heating film performance has been analyzed according to the supporting the temperature regime in interior room ($\geq +20°C$) and provide required temperature barrier. In average to support the required interior temperature regime during 10 hours under the external temperature +5 °C, the heating layer should work on the maximum regime (140 W) for 1 hour; to support the required interior temperature regime during 7-10 hours under the external temperature - 5 °C, the heating layer should work on the maximum regime (140 W) for 1-2 hours; to support the required interior temperature regime during 4-6 hours under the external temperature - 15 °C, the heating layer should work on the maximum regime (140 W) for 1 hour.

ACKNOWLEDGEMENT

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