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THE EFFICIENCY OF CELLULOSE - GREEN MATERIALS AND TECHNOLOGY USED IN THERMAL INSULATION FOR SAVING ENERGY IN NZEB BUILDINGS

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Abstract: This research presents the advantages of using cellulose - green materials in thermal insulations for saving energy for future buildings. These advantages are involved in massive reducing thermal losses in the roofs, specially for non easy accessable zones from the lofts and small height of attics. The method proposed ist o be performed the analysis of mass and heat transfer through walls with thermal insulation materials of vegetal origin like cellulose. There is analysed the condense accumulation in the outer walls under the conditions of a location in the Romanian climatic zone III for a residential building and in addition a case study for a building from the Romanian climatic zone II also a residential building. The nZEB buildings built with green materials and technology will respond to rising the efficiency of building heating/cooling energy consumptions, will have a proper diffusion capacity, so will not influence the release of moisture and will lead in raise the sustainability of these homes. The main result of this study proved that the proposed green material is an efficient high-performance thermal insulator compared to the thermal insulation used on the scale wide and prevents condensation. The conclusions of this study can be used in projecting nZEB buildings with green technologies in order to achieve the energy efficiency and internal comfort conditions performances.

Key words*: cellulose, green technology, insulation, comfort, condense accumulation*

1. INTRODUCTION

The use of green materials and technologies must be considered mandatory for our country from January 2021, in order to design nZEB type buildings. As the effect of global warming is increasingly affecting the planet, there were proposed policies for using green materials, the widespread use of innovative technologies based on the use of waste, in this case the recycling of paper waste.

According to Article 2 of EU Directive 1999/31 / EC, biodegradable waste (BMW) is defined as waste that can be subjected to anaerobic decomposition, such as paper and board. Emphasis is placed on the use of residues that reduce carbon emissions. [http://ener-supply.eu/downloads/ENER_ handbook_en.pdf]. So, the impact of natural disasters due to global warming is reduced. Moreover, the use of these materials leads to energy efficiency in residential houses, helps a healthy environment inside them and leads to a positive impact on the environment.

The improvement of the thermal efficiency in buildings by means of thermal insulation and moreover the proper mass transfer (avoiding the mold in layers) is mandatory for sustainable buildings and for achieving a healthy environment inside the residential houses. (Diakaki et al., 2008; Galvin, 2010; Lopes et al., 2005). The common insulation materials like mineral wool and polyurethane foam are energy pros and expensive (Monahan and Powell, 2010). Therefore the use of some waste materials, another requirement for a sustainable development (Mora, 2007), should offer an advantageous alternative.

The sustainable economically and energy efficient constructions are evaluated starting with the manufacturing process and materials transport, up to demolition and reuse cost.

The sustainability requirements of a building, taking into account the costs throughout the life cycle (including repair and maintenance costs) involved in the evaluation of a building can be met by such green solutions. The location of the building is also taken into account, as orientation, neighborhood and access to utilities. Given all these parameters, sustainable solutions can be chosen and the effects can be correctly predicted for a sufficiently long period to motivate the necessary investment. [1]

In this study we consider the use of cellulose, recycled newsprint, a renewable green material. There were studied the permeability to water vapor in order to reduce the condensation phenomenon, the durability of the thermal insulation properties, the construction elements resistance to water or to the polluting elements from the environment. Ease of implementation and costs were also taken into account.

All existing studies have shown that the material is economically efficient in terms of initial investment and longer-term profitability. The advantages of using fireproof cellulose have been highlighted in studies conducted to date [4].

Case study on the benefits of using fireproof cellulose

For a residential building in the climatic zone II, this solution was chosen because the costs for heating were very high in the cold season, the losses through the attic area being very high. The building has a height regime GF + A, a built area of 96 sqm (Fig. 1). In the conditions in which the external temperature had values between -5 and -1°C, at the closing of the thermal power plant, the temperature in the attic rooms reached the value of 13°C in an interval of 3 hours.

a)

b)

c)

Fig. 1 a) Residential building with height regime GF + A, climatic zone II; b), c) Thermal insulation intervention with fireproof cellulose on the attic side

a)

b)
Fig. 2 Thermofloc thermal insulation technology - www.thermofloc.com [13]

The solution for using fireproof cellulose (recycled newsprint 92%, treated with borax for protection against insects and rodents) was used precisely in order not to use invasive methods of dismantling the attic walls and not to affect the occupants.

The thermal insulation intervention lasted approximately three hours for the surface of 112 sqm of attic and the total cost was 1000 lei at the level of 2012 (230 euros). The energy saving was 50% by counting the heating consumption before and after rehabilitation.

According to a study developed by the Natural Resources Defense Council (NRDC), one of the advantages of using this type of recyclable material is the one related to the least polluting technology, with very high energy efficiency. The fact that it takes 10 times more energy to produce fiberglass insulation than cellulose fiber insulation and the fact that cellulose fiber insulation is very easy to recycle in large quantities give particularly good qualities to cellulose fibers as a type of insulating material.The thermal conductivity is very low, the factor water vapor resistance is between 1 and 2 μ, and the degree of fire resistance is B. Cellulose is a material resistant to decomposition, hygroscopic and insulation of this type is very easy to make between rafters and other wooden connections.

From the observations made after the thermal insulation of the attic it can be concluded that this type of material balances the maximum / minimum temperatures in the summer days and protects against the cold in winter.

Following the rehabilitation of the attic walls, it was noticed that the time required for the transmission of heat through its thickness is 8-10 hours compared to the three hours in which heat was lost before rehabilitation.

Other advantages that have been observed during the 10 years since the implementation:

- Cellulose fiber insulation has not lost its energy saving capabilities over the past 10 years;
- Cellulose did not rot, no fungi or mold have appeared;
- No adverse health effects have been identified;
- As can be seen from Fig. 1 the insulation did not deteriorate (flattened) at all after 10 years from installation.

Cellulose fiber insulation has better resistance to air flow and prevents upward movement of air caused by temperature differences.

Table 1 Table comparing cellulose / expanded polystyrene properties

Name	Expanded Polystyrene	Cellulose
Origin	Synthetic	Bio
Conductivity ʎ (W/m.K)	0,029 – 0,053	0,034 – 0,069
Resistance factor to water vapor diffusion (μ)	20 - 40	1 - 2
Inflammable	Yes	Self-extinguishing
Density (kg/m^3)	15-30	35-60
Thickness (K=0,2cm)	17,50-25	20-22,50
Approximate price €/m^2	<5	<25
Presentation	Cast panels of 50x100cm	Panels and rollers, blown or cast.
Protection measures during installation	No	Dust protection. Possible risks associated with inhalation of cellulose dust during installation. It is possible to release odors and formaldehyde from the ink used for the newspaper printing.
Energy cost	75 - 125	1 - 25

Name	Expanded Polystyrene	Cellulose
Recyclable product content (0-3)	1	3
Biodegradable	No	Yes
Ecological aspects	The manufacture of raw materials involves a very high consumption of energy, ecological and health damage.	A limited amount of raw material (trees and recyclable paper). The manufacture of raw materials involves high energy consumption, ecological and health damage.
Constructive properties	A very good capacity as thermal and acoustic insulation. Used for thermal insulation of exterior walls, thermal systems frame, intermediate floors, roofs, terraces.	A good capacity as thermal insulation, especially in summer, acoustic and humidity regulation.
Use and real life time	Stable in front of moisture. Stable in shape. Long life. It can be destroyed by insects. Resistant to moisture.	It is used to insulate exterior walls, intermediate floors, trusses.

Energy consumption and CO2 emissions associated with the manufacture of panels are different, being lower in the case of cellulose and higher in other types of thermal insulation commonly used. Fig. 3 compares the energy used, emissions and the level of toxicity of cellulose to expanded polystyrene and mineral wool in the process of manufacturing them.

According to Fig. 3 cellulose is superior to other types of conventional thermal insulation both in terms of energy consumed in manufacturing, as well as CO2 emissions and the level of toxicity.

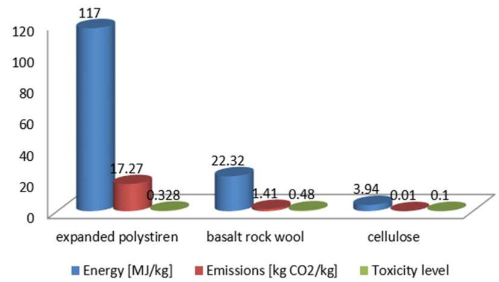

Fig. 3 Cellulose, expanded polystyrene and mineral wool - comparative analysis for manufacturing energy, CO2 emissions and toxicity level

Fireproof cellulose applications are numerous in terms of thermal insulation of the building envelope surfaces. It can be used very efficiently to increase the thermal resistance of exterior walls made of masonry or wood, for attic floors, between rafters to insulate the roof, for horizontal floors under parquet being very efficient in terms of acoustic protection. Fig. 4 shows the comparison between the thermal conductivity of cellulose and the thermal conductivity of other classic thermal insulators, but the most important thing shown is the thickness required for each of the thermal insulators to reach the passive house standard.

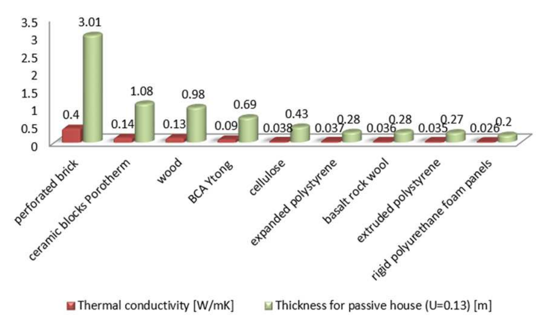

Fig. 4 The thermal conductivity of cellulose compared to other classic thermal insulators and the thickness of the layer required for the passive house (U = 0.13 W / m2K)

2. MASS TRANSFER THROUGH WALLS THERMALLY INSULATED WITH CELLULOSE. COMPARATIVE STUDY

A comparative analysis is made between the residential building from climatic zone II presented above and a residential house from climatic zone III with indoor and outdoor climatic parameters from Table 2 and the risk of condensation and water accumulation in the cold season is evaluated [5-7] .

Table 2 Indoor and outdoor climatic parameters necessary to verify the progressive accumulation of water

Indoor climatic parameters		
	Zone III	Zone II
Indoor air temperature	20 ºC	20 ºC
Relative humidity of indoor air	60 %	60%
Coefficient of thermal transfer for the inner surface	8W/m^{2}ºC	8 W/m^2 ºC
External climatic parameters		
Average annual outdoor air temperature	7.50 ºC	9.50 ºC
Relative humidity of outdoor air	80 %	80%
Heat transfer coefficient at outer surface	24.00 W/m^{2}ºC	24.00 W/m^{2}ºC

The component layers of the envelope element are presented in Table 3. It was considered a classic component, a wall of GVP (brick with vertical gaps) with a thickness of 35 cm, and the thickness of the thermal insulation is 10 cm, similar to that of a classic thermal insulation with EPS. [8-11] It is considered an indoor air temperature of 20°C, and the average annual outdoor air temperature is 7.50°C for climatic zone III and 9.5°C for climatic zone II.

Table 3 The composition and characteristics of the construction element

Code	Layers of the construction element (they must be introduced from the inside to the outside)	Layer thickness (m)	Thermal conductivity (W/mºC)	Vapor permeability resistance factor (—)
52	Mortar of lime	0.0100	0.700	5.30
202	Brick masonry with vertical holes, GVP type	0.3500	0.580	4.50
206	Cellulose	0.1000	0.038	2.00
51	Cement and lime mortar	0.0100	0.870	8.50

Outside air temperature at which condensation occurs is -9.46 ºC, at a relative humidity of 85%. The outside air temperature during condensation is -15.46 ºC for the climatic zone III and -14.46 ºC for the climatic zone II.

Table 4 Temperature and partial pressures on the surface of the layers

Indoor climatic parameters	
	Zona III/II
Indoor air temperature	20 ºC
Relative humidity of indoor air	60 %
Coefficient of thermal transfer for the inner surface	8 W/m^{2}ºC
External climatic parameters	
Outside air temperature at which condensation occurs	-9.46 ºC
Relative humidity of outdoor air	85 %
Heat transfer coefficient at outer surface	24 W/m^{2}ºC

The parameters for calculating the amount of condensed water are shown in Table 5, where it is observed that the saturation pressure in the first tangent point is 166 Pa for the climatic zone III, respectively, 181.1 Pa for the climatic zone II. The duration of the condensation process is different with 554 hours for the climatic III and 304 hours for the climatic zone II.

Table 5 The amount of water accumulated by condensation in the cold season

External climatic parameters					
				Zone III	Zone II
Outdoor air temperature during condensation				-15.46 ºC	-14.46 ºC
No	Layer surfaces	Partial pressure (Pa)	Saturation pressure (Pa)	Temperature (ºC)	Temperature (ºC)
Indoor air		1402.2	2337.0	20.00	20.00
0	Interior surface	1402.2	2156.3	18.71	18.74
1	Boundary between layers 1 / 2	1367.0	2136.5	18.56	18.60

2	Boundary between layers 2 / 3	323.0	1431.3	12.32	12.53
3	Boundary between layers 3 / 4	190.5	166.0	-14.91	-13.93
20	Outer surface	134.1	164.2	-15.03	-14.04
	Outdoor air	134.1	157.8	-15.46	-14.46
Parameters for calculating the amount of condensed water					
			Zone III		Zone II
Saturation pressure at the first tangent point			166.0	Pa	181.8
Saturation pressure at the second tangent point			166.0	Pa	181.8
Vapor permeability resistance $R'_v / 10^8$			98.7	m/s	98.7
Vapor permeability resistance $R''_v / 10^8$			4.6	m/s	4.6
Duration of the condensation process			554.0	ore	304.0
The amount of water accumulated by condensation			0.111	kg/m^2	0.0526

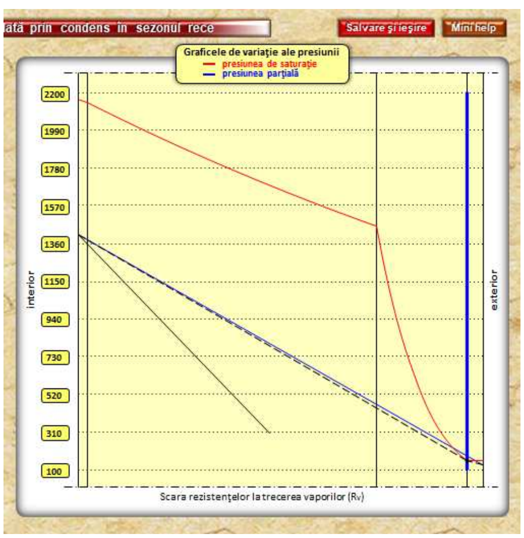

Fig. 5 Condensation layer for both climatic zones

The thickness of the resulting condensation layer is negative for both climatic zones. Therefore no condensation occurs in layers. Thus, fireproof cellulose, due to its quality related to the water vapor permeability factor, leads to the certainty that condensation does not appear in layers for a classic building envelope element.

3. RESULTS AND DISCUSSIONS

In Figure 6 it is presented the consumption curve for heating for the residential uilding in climatic zone II, before and after rehabilitation, in 2012, but also the comparison with the previous year 2011. The readings at the gas meter were made daily, during January 1, 2012 – February 28, 2012. No large temperature differences were identified (extreme temperatures-deviation -5.6°C from the average interval) during this period.

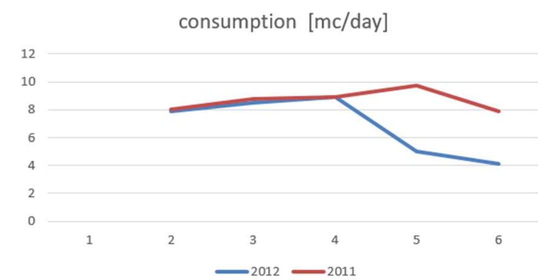

Fig. 6 LPG consumption curve for heating before and after rehabilitation, in 2012; comparison with the previous year 2011

The thermal insulation was made on February 1, 2012. The building was further monitored, the following winter a new layer of expanded polystyrene thermal insulation was implemented on the outside (existing 5 cm, added another 10 cm). In Fig. 7 there are presented comparatively the consumption curves between 2012 and 2013.

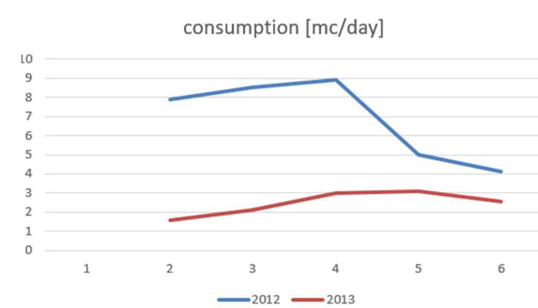

Fig. 7 LPG consumption curve for heating before and after the rehabilitation of the attic / attic floor, in 2012; comparison with 2013- after the rehabilitation of exterior walls

According to the recorded results, it is observed that the reduction of energy consumption used to heat the building before and after the rehabilitation of the floor to the attic / attic was 42-49%. According to the presented thermal calculation, there are no unwanted effects of condensation in layers. As an important result, we can also note the rehabilitation of the exterior walls - the comparison between winter 2012 and winter 2013 - where the energy consumption for heating was reduced by about 31-34%.

The use of cellulose in the thermal insulation of the attic/attic floor- is particularly important to be taken into account due to the fact that such minimally invasive solutions may be chosen, without demolishing the existing closing elements, useful solution for interstices where it is difficult to reach and to obtain uniformly formed layers using introducing under pressure). Reducing energy consumption by over 40% is all the more important as recyclable material is used. Reducing energy consumption by over 40% is even more important as using recyclable material.

4. CONCLUSIONS

The paper aims to demonstrate that for both buildings in climatic zone II and climatic zone III, the use of cellulose to thermally insulate the closing elements of the building envelope is more than very efficient. Thus, cellulose flakes are energy efficient and advantageous thermal insulators compared to widely used thermosystems such as expanded polystyrene. The presented study shows that cellulose flakes help prevent condensation in the layers for buildings located in climatic zones with low temperatures in the winter season (-15°C for climatic zone II and -18°C for climatic zone III). This type of thermal system has diffusion capacity, i.e. it does not influence the yield of humidity. As for this type of insulator, very good sound insulation capacities are also highlighted, it can be concluded that it can be recommended as an ecological (green) product excellent for thermo-hygro-phono insulation of residential buildings.

Its remarkable hygroscopic properties and low cost of installation recommend it for research and innovation in the field of insulating materials for buildings. Cellulose can be used as an insulator for all elements of the building envelope, moreover it leads to the successful provision of the fundamental requirements applicable to constructions related to health, hygiene and the environment. At the same time, it helps in considerable proportion to ensure the fundamental requirement regarding energy saving and thermal insulation.

According to the recorded results, it is observed that the reduction of energy consumption used to heat the building before and after the rehabilitation of the floor to the attic / attic was about 48.45% given that there are no unwanted effects of condensation in layers. As an important result, we can also note the rehabilitation of the exterior walls - the comparison between winter 2012 and winter 2013 - where the energy consumption for heating was reduced to an average of 33%.

Designers / architects can use this study to use cellulose efficiently – a recyclable material to make up the building anvelope fasteners. The thermal calculation and the calculation regarding the diffusion of water vapor may be also used by the manufacturers of construction materials that must indicate in the Product Declarations of Performance, the characteristics regarding the thermal conductivity / thermal resistance and the permeability to water vapor. The use of building envelope elements with a composition containing green materials that have a favorable behavior in the diffusion of water vapor satisfies the durability requirement of constructions which is an essential component of the fundamental requirement for the sustainable use of natural resources.

All the conclusions of this research can be used in projecting nZEB and passive houses in order to achieve all the performances requested to these type of future buildings.

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Eficiența celulozei - material ecologic și a tehnologiei utilizate în izolația termică pentru economisirea energiei în clădirile NZEB

Rezumat: Lucrarea prezintă avantajele utilizării materialelor verzi – celuloza la izolarea termica pentru economisirea energiei pentru clădiri. Acestea se refera la reducerea masivă a pierderilor termice din acoperișuri, în special pentru zonele care nu pot fi accesate ușor de la mansarde in special la mansarde de inaltime mica. Metoda propusă consta in analiza transferului de masă și căldură prin pereți izolati cu materiale termoizolante de celuloza. Se analizează acumularea de condens în pereții exteriori în condițiile unei cladiri din zona climatică III pentru o clădire rezidențială și un studiu de caz pentru o clădire din zona climatică II. Clădirile nZEB construite cu materiale și tehnologii ecologice vor asigura creșterea eficienței consumului de energie pentru încălzirea / răcirea clădirilor, vor avea o capacitate adecvată de difuzie la vaporia de apa, vor duce la creșterea durabilității acestor case. Rezultatul principal al acestui studiu a dovedit că materialul verde propus este un izolator termic efficient, de înaltă performanță în comparație cu izolația termică utilizată pe scară largă și previne condensul. Concluziile acestui studiu pot fi utilizate în proiectarea clădirilor nZEB cu tehnologii ecologice pentru a obține performanțe de eficiență energetică și condiții de confort intern.

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