Athens Journal of Technology and Engineering - Volume 9, Issue 4, December 2022 – Pages 305-320

Environmentally Friendly Building Materials with Beneficial Potential for Indoor Air Quality

By Gabriela Adela Călătan * *& Carmen Dico*±

Following the obvious increasingly interest for environmental protection and pollution reduction, worldwide, there is a strong orientation for identification and use in buildings some materials that require low power consumption and to determine a pollution low level in all stages of their production and exploitation. These energy and environmental protection criteria can be met successfully by a combination of unburned masonry bodies made of clay, mixed with various other natural materials, and sheep wool thermal insulation mattresses. These construction elements have a beneficial influence on the air quality of the interior space, ensuring, through the permeability to water vapor, the regulation of the relative humidity of the air and, through ability to store thermal energy in warm periods and release it in the cold ones, a uniform temperature distribution inside and avoiding high temperature fluctuations between seasons. Based on the experimental research results, we can identify solutions for achieving a vernacular housing (resistance walls, partition walls, floors, plasters, water protection, thermal insulation and finishing) in terms of safety, comfort and current aesthetic criteria.

Keywords: *adobe bricks, clay, hemp fibers, straw, sheep wool*

Introduction

Today, more than half of the population lives in the city and we are consuming natural resources faster than ever before. We are, without a doubt, the most "inventive" and "powerful" living thing on the planet. We are so full of "success" that we have arrested the entire planet in our interest, and the consequences are almost uncontrollable.

Fortunately, globally, the field of construction from ecological, natural, local materials is on the rise. In many countries, governments encourage their use in construction, with local authorities being among the most important beneficiaries. In Romania, natural, ecological houses have started to become more and more known and more and more specialists are interested in this type of construction (Ciurileanu and Bucur Horvath 2011).

One of the most commonly used vernacular materials is clay soil. It is suitable for making masonry bodies mixed with sand, lime, oils, natural resins, etc. The good behavior and satisfactory durability of constructions made of beaten clay and clay masonry bodies have been documented since the 19th century (Ciurileanu and Bucur Horvath 2011, Minke 2005). The clay is known as a material with adhesive

*Senior Researcher, NIRD URBAN-INCERC Cluj-Napoca Branch, Romania.
±Senior Researcher, NIRD URBAN-INCERC Cluj-Napoca Branch, Romania.

https://doi.org/10.30958/ajte.9-4-3 doi=10.30958/ajte.9-4-3

properties in the fresh state, with mechanical strength in the hardened state and even with waterproofing properties, after burned. Well-known are the old adobe houses covered with straw, the yurts of the nomadic peoples of the steppes of Central Asia heat-insulated with wool, special finishes made of bamboo, reeds or other fibers obtained from plant processing, all beautifully colored with paints obtained from fine grinding of some minerals, etc. Looking around us we easily find useful materials for each stage of the construction of a future house: structural material necessary for the construction of the foundation, walls, pillars, thermal insulation materials, waterproofing materials or noise insulation materials for pleasant-looking finishes. With a reduced financial, energy and labor effort, we can process these materials to be used to achieve a sustainable construction that meets the current needs of the user.

Another important property of clay is that it can be reused, obtaining very good results. The physical and mechanical performances of these newly manufactured bricks are not adversely affected by the use of recycled clay material. The paste obtained from the recycled clay material allows dispersed reinforcement by introducing vegetable fibers (straw or hemp fibers). These are well covered by the clay matrix, and after drying the specimens show physical-mechanical performance similar to those recorded when using freshly extracted clay.

By replacing, where possible, classical building materials with environmentally friendly materials, an important contribution is made to protecting the environment. The possibility of recycling, reuse, reintegration into nature, environmental protection and efficient management of natural resources are the basic indicators in the context of sustainable development. Thermal insulation construction materials made of unburned clay, wheat straw and sheep wool are successfully included in the category of ecological products (Minke 2005).

Another important quality of environmentally friendly materials is that they provide a healthy and pleasant climate for users. Clay-based building materials used in construction allow natural and efficient ventilation of the walls, water vapor permeability, thermal constancy and a constant humidity of the indoor environment. Also, these walls made of clay-based bricks have no toxic emissions, a factor that plays a very important role in reducing the risk of respiratory diseases, allergies and much more.

For thousands of years, sheep have been able to adapt to even the harshest of environments, as their wool protects them through hot, cold, damp and dry seasons. In this time, man has also used wool for this very protective property and for the many other benefits offered by the material. Because of their crimped nature, when wool fibres are packed together, they form millions of tiny air pockets which trap air, and in turn serves to keep warmth in during winter and out in the summer.[1]

Wool's unique advantage is its breathability. That is it's ability to absorb and release moisture from the surrounding air, without compromising it's thermal efficiency. When wool fibres absorbs moisture, they generate tiny amounts of heat. This warmth acts to prevent condensation in construction cavities by maintaining the temperature above the dew-point in damp conditions. This property creates a

[1]http://www.sheepwoolinsulation.ie/why_wool/default.asp.

natural buffering effect, stabilising heat changes that occur with relative humidity. Practically, this reduces the need to keep adjusting heating or cooling levels as wool insulation will keep a buildings cooler during the day and warmer during the night.[2]

Crimped wool fibres also gives the manufactured product particularly good resilience. This means that insulation made from wool will retain its thickness, one of the main contributors to insulation efficiency. As wool contains moisture, it is fire resistant, extinguishing itself when the source of flame is removed. It is also a very effective airborne and structureborne acoustic insulation, significantly reducing noises that can be heard throughout a building.

Being made from a naturally produced fibre, Sheep Wool Insulation requires less than 15% of the energy required to produce than glass fibre insulation. It can absorb and break down indoor air pollutants, such as formaldehyde, nitrogen dioxide and sulphur dioxide. Wool is a sustainable and renewable resource, that has zero ozone depletion potential and at the end of it's useful life can be remanufactured or biodegraded. Sheep wool insulation is safe and easy to handle and no protective clothing or special breathing apparatus is required to install it.[3]

Literature Review

Studies are presented in the literature that demonstrate the durability of constructions made with local materials and local techniques in different geographical and climatic conditions (Minke 2005).[4]

A major drawback of clay is that there is a high risk of cracking during drying due to significant axial shrinkage. The ideal clay soil, in order to be used in construction, must contain at least 15-16% clay, because it has the right plasticity and workability to obtain a quality finished product (Minke 2005, Bui, 2008, Kumar and Pushplata 2013, Ciurileanu and Bucur Horvath 2012). Thus, a linear contraction between 3 and 12% is accepted for bricks from soft mixtures or between 0.4 and 2% for drier mixtures (Moquin 1994). In order to obtain a good thermal insulation, the specialized literature indicates an apparent density of the material between 1,600 – 2,000 kg/m^3 (Bui, 2008, Kumar and Pushplata 2013, Ciurileanu and Bucur Horvath 2012, Moquin 1994).

In terms of mechanical strength, ASTM Code D1 633-00 New Mexico indicates a minimum compressive strength of the material required to make clay walls, of 2.07 N/mm^2. Zimbabwe's Code regarding the Clay Walls, requires for 400 mm thick and a single-level houses, a minimum compressive strength, of 1.5 N/mm^2 and of 2.0 N/mm^2 for two levels houses. The Australian standard indicates a compressive strength of at least 1.15 N/mm^2, and ASTM International E2392 /

[2]http://www.sheepwoolinsulation.ie/why_wool/default.asp.

[3]http://www.sheepwoolinsulation.ie/why_wool/default.asp.

[4]JournalSeek, getCITED, Google Scholar, Ideas-RePEc, IndexCopernicusTM, Intute, Israel Institute of Technology - Technion, Lupton Library, Munich Personal RePEc Archive, National Library of Australia, OPACPlus, Open J-Gate, ProQuest/Illustrata, ResearchGATE, Structurae, TIB/UB Hannover, UlrichswebTM, Universia, VUBIS, WorldCat®, WorldWideScience.org.

E2392M-10e1-2010 [6,7] indicates a value of 2,068 N/mm^2. ACI Material Journal Committee indicates values of compressive strength depending on the composition of the soil, as follows: 2.76 - 6.89 N/mm^2 for sandy soil, and 1.72 - 4.14 N/mm^2 for clay soil.

Currently there are some thermal insulation materials considered "classic" due to the high frequency of use. They are inorganic in nature (fiberglass wool or mineral wool) or organic in nature (expanded or extruded polystyrene, polyurethane foam) and account for about 87% of the market. "Alternative" thermal insulation materials represent only 13% of the market and include straw bales, hemp products, sheep wool, cotton wool, "smart" materials whose thermal insulation properties change dynamically depending on temperature (Bui et al. 2009, Kiroff and Roedel 2010).

Straw is an agricultural product. Compared to ordinary building materials, often used, neither their production, nor their use as a building material nor after demolition does not harm the environment or our health (Suciu and Suciu 2007).

Hemp is one of the first plants to be processed and used by humans over 12,000 years ago. Hemp is a variety of cannabis that is grown especially for fiber and seeds. It is one of the fastest growing plants in the world, with about 20 tons of dry produce per hectare each year. In addition, hemp is completely organic. Hemp has the highest industrialization capacity of all technical plants: nothing is thrown away, everything is capitalized. The hemp stalk from which the fibers are extracted is straight and has branches at the bottom. Its length is between 1 and 3 m, and the thickness varies from 4 to 8 mm. The anatomical tissues of the shell are more complex compared to flax. Among the many characteristics of hemp fiber are its superior hardness and durability and the amazing resistance to rot. In the composite form hemp is 2 times stronger than wood (Vural et al. 2007).

There are few references in the literature that show experimental results regarding the use of sheep wool as thermal insulation material. A synthesis of the studies carried out highlights the following characteristics and advantages: it is a natural insulating material, it has good thermal and sound-absorbing characteristics, even in the wet state, the most used fiber of animal origin; has the ability to store energy at high temperatures and transfer it to low temperatures; easily renewable, recyclable, with a low impact on the environment; beneficial to the health of the population by contributing to the preservation of the optimal indoor environment; retains its shape and volume due to the genetic structure of the threads which tend to always return to their original shape; it is a hygroscopic material (in conditions of normal humidity it absorbs water vapor up to 18%, and in conditions of high humidity until saturation, its humidity can reach up to 40%); it is a material that absorbs formaldehyde and other pollutants from the air (the products of wool's reaction with these substances are very stable products that are no longer released into the air); has a very good fire behavior, does not maintain combustion; does not contain toxic substances and has no radioactive emissions (Karim et al. 2011).

Over time, a number of criteria have been established to evaluate the quality of one thermal insulation material compared to another. In addition to thermal insulation performance, aspects of the impact on human health, from production to end of life, dust or fiber emissions, biopersistence, operational safety, environmental impact, fire behavior are currently being analyzed. , toxicity in case of fire and affordability in terms of price and method of purchase, installation and use.

Materials and Methods

The used raw materials, to make the experimental mixtures, were: clay, that was extracted from Valea Draganului, Cluj Napoca, Romania, wheat straw, hemp fibers and sheep flax.

The used sandy clay was characterized by particle size distribution (Figure 1) and oxide composition (Tables 1 and 2) (Asdrubali 2015).

Figure 1. *Sandy Clay Granulometry*

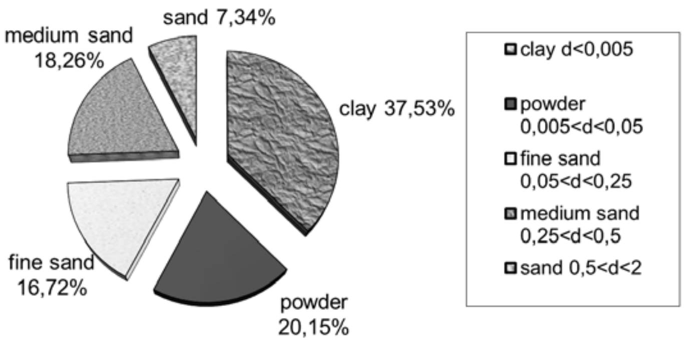


Table 1. *Clay Oxide Composition, Determined According to STAS 9163*

Oxides	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	PC
The content [%]	74.17	12.74	4.38	0.7	1.0	1.43	0.73	0.05	4.78

Table 2. *Oxidic Composition of Sandy Clay Used*

Identified oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	PC
Concentration [%]	74.17	12.74	4.38	0.7	1.0	1.43	0.73	0.05	4.78

The sand used for the experimental research was characterized by an apparent density of 1,500 kg/m^3 and the granulometric distribution (Table 3).

Table 3. *Particle Size Distribution of the Sand Used*

Granulometric sieve size [mm]	0.063	0.125	0.25	0.5	1	2	4
Past [%]	0.5	1.6	8.8	28.5	59.6	82.4	98

The straws, having a high water absorption, were used after being previously immersed in water for one hour, in order to avoid the phenomenon of water absorption from the clay matrix.

Hemp fibers were purchased commercially and they were used as such.The hemp fibers was obtained from trade.

Plant materials were introduced into the clay matrix, expressed as a percentage by volume relative to the clay mixture (34% sand, 64% clay, 2% lime homogenized with 1.25% bone glue solution). Thus, 10% by volume of hemp fiber and 40% by volume of straw were introduced, respectively. The straw and fibers were cut to a length of about 7 cm. The bone glue was dissolved in warm water. From each mixture thus made, a set of 3 prismatic specimens, 40x40x160 mm, to determine the apparent density, axial shrinkage and mechanical strength and a set of 3 specimens of 300x300x40 mm, to determine the thermal conductivity were made. The specimens were kept in laboratory conditions until the equilibrium humidity was reached. The workability of the mixture during the preparation and manufacture of the test pieces was monitored (Călătan et al. 2016).

The thermal insulation material in sheep's wool comes from the Minet company, which managed to obtain a much more efficient thermal and acoustic, ecological insulation product made of natural wool fibers.

Sheep wool goes through certain stages of processing to the stage where it can be used as thermal insulation for homes. The wool is washed, mechanically combed and pressed into small layers. It is a non-woven product made by carding technology - folding from a mixture of recycled PET (polyethylene terephthalate), waste fibers PES (polyester) recycled, waste fibers, natural sheep wool fibers and vegetable fibers, cellulose and siliconized fibers, TENCEL®. In the final phase, after processing, the wool is brought in the form of thick and fluffy mattresses, condensed and with a shape similar to the basalt wool, used for insulation (Călătan et al. 2015, Abdou and Budaiwi 2013).

Figure 2.
a) Clay with Straw *b) Hemp Fiber Clay* *c) Sheep Wool Mattress*

Figure 3. *Wool-Based Composite Product*

The characteristics of the wool-based composite product were determined according to the standards for thermal insulation, by assimilation. The following tests were performed for 40mm thick wool mattress: bulk density, tensile strength perpendicular to the faces, short-term water absorption by partial immersion, long-term water absorption by total / partial immersion, tensile strength on longitudinal and transversal direction of the fabric, thermal conductivity, compressive strength.

In Figure 2, there are pictures of the clay mixture with straw (a), the clay mixture with hemp fibers (b) and the mattress made of sheep's wool.

Finally, a mixture was made for mortar, clay, sand, lime and bone glue (45.5% clay, 45.5% sand sort 0-2 mm, 9% hydraulic lime mixed with 3% bone glue solution) for plastering the wool mattress, Figure 3, and the appearance of cracks, adhesion resistance and water absorption on the plaster treated with linseed oil were followed (Adams 2017).

Results and Discussion

The tests were performed when the equilibrium humidity was reached, which was considered to be obtained after 40 days of storage of the specimens in laboratory conditions.

The clay biggest disadvantage is that it has a high shrinkage on drying, which causes cracks to appear on the surface of the products. When clay-based bricks are produced, they shrink when dried by reducing their size, so the brick obtained on drying will be smaller than the wet brick, but the finished product no longer has cracks, so it can be used as such, without the need for the addition of sand, that lowers the mechanical strengths.

When we want to get a plaster or clay masonry mortar, the contractions that produce cracks during drying are very important and and the aim is to reduce them (axial contractions). Drying cracking can be reduced by the addition of sand, which reduces shrinkage. The addition of sand will reduce the mechanical strength, but for a mortar this is not a problem. The most important properties of a masonry or plaster mortar are adhesion, in addition to water vapor permeability. For the plaster mortar applied to the outside, it is also necessary to improve the water resistance. Lime and/or dextrin are recommended to reduce the shrinkage of drying of a mortar and also to improve the resistance to erosion. Taking into account these recommendations resulting from previous studies, the clay-based mortar recipe, presented in the chapter Materials and methods, has been developed.

Also, for the significant improvement of the water resistance, the surface of the clay plaster was treated with linseed oil.

Analyzing the appearance of the clay specimens produced in accordance with the studied recept, at 40 days, it can be noticed the lack of surface cracks, which is a very important aspect for clay-based mixtures (Figure 4).

Figure 4. *Appearance of the Hardened Specimen Surface*

Table 4 shows the recipes made of clay, and Table 5 shows the results of the tests on the test pieces made on the basis of respective recipes.

Table 4. *The Made Recipes*

Recipe	A1	A2
Components added in mass percentages	34% sand, 64 % clay, 2 % homogenized lime with 1.25% bone glue solution	
Volume percentage	10% hemp fiber, 7 cm	40% straw, 7 cm

Table 5. *The Results Obtained*

Characteristic	A1	A2
Axial contractions [%]	6.1	3.4
Compressive strength [N/mm^2]	4.00	1.02
Bending strength [N/mm^2]	2.95	2.50
Density [kg/m^3]	1680	1383
Thermal conductivity [WmK]	0.38	0.17
Water vapor permeability μ	1.51	1.48

The results obtained on the nonwoven product made from a mixture of recycled PET (polyethylene terephthalate) waste fibers, recycled PES (polyester) waste fibers, natural sheep wool fibers and vegetable fibers, cellulose, siliconized, TENCEL® 40 mm thick, are shown in Table 6. The tests were performed in accordance with the European standards for thermal insulation.

The most important property of clay products is the permeability to water vapor. Water vapor permeability is a characteristic of porous materials that under the effect of molecular forces and of the imbalance between the external humidity of the environment and the humidity of the material allows diffusion through the material until an equilibrium is established. The diffusion rate through porous materials defines the vapor permeability coefficient. These products are vapor permeable which gives to the walls the property to breathe. The wall made with such products maintain a healthy and pleasant indoor environment.

Table 6. *The Obtained Results on the Sheep Mattress*

Characteristic		Value	Measurement Units
Apparent density		29.33	kg/m^3
Tensile strength perpendicular to the faces		1.3	kPa
Compressive strength	compaction at 0.12 kPa	7.2	%
	compaction at 0.25 kPa	16.7	
Tensile strength on the fabric longitudinal direction		0.05	N/mm^2
Elongation at tensile strength on the fabric longitudinal direction		23.48	%
Tensile strength on the fabric transverse direction		0.06	N/mm^2
Elongation at tensile strength on the fabric transverse direction		37.98	%
Short-term water absorption by partial immersion,Wp		0.191	kg/m^2
Long-term water absorption by partial immersion,Wlp		0.51	kg/m^2
Long-term water absorption by total immersion,Wh		12.91	%
Thermal conductivity coefficient		0.0358	W/mK
Water vapor permeability	W	11.30	m/m^{2}hPa
	μ	1.26	-

Following the results obtained, it can be stated that the thermal insulation product composite mattress based on sheep wool, is the best insulating material, with the lowest value of thermal conductivity. Straw clay has a good conductivity, but about 80% higher than sheep's wool. The advantage of clay materials over sheep linen is that they can be used as masonry bodies to make the walls, instead, the sheepskin mattress needs to be applied to an already built wall. Wool is also very sensitive to the action of mold and degradation in contact with the ground, it is not water resistant. A possible protection of the wool from mold and degradation could be the plaster, applied on its surface. For this purpose, a plaster based on clay, sand and lime was made. (45.5% clay, 45.5% sand sort 0-2 mm, 9% hydraulic lime mixed with 3% bone glue solution). The clay is also sensitive to water, but after applying 2 layers of linseed oil, it becomes waterproof (Suciu ανδ Suciu 2007). The first observation is that no cracks appear on the surface of the plaster, when drying, therefore, the tests were performed, the results of which are presented in Table 7.

Table 7. *The Test Results on the Test Specimen Made of Wool Plastered with a Clay Mixture and Treated with Linseed Oil*

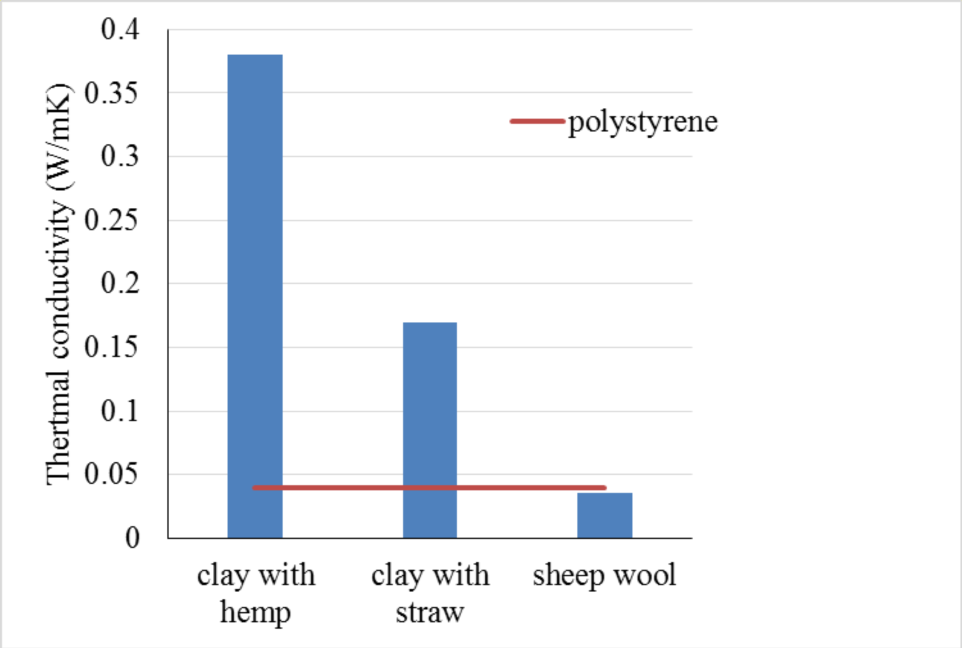
Characteristic	Value	Measurement Units
Adhesion strength	1.30	kPa
Short-term water absorption by partial immersion,Wp	0.00	kg/m^2
Long-term water absorption by partial immersion,Wlp	0.01	kg/m^2

Discussion

Following the results obtained, it was found that the addition of straw to clay mixture, decreases the drying shrinkage, so the appearance of cracks, increases the resistance to bending, decreases the thermal conductivity, instead decreases the resistance to compression. When adding hemp fibers, the mechanical strengths are higher than with the straw-added test tube, however, the thermal conductivity is higher.

Based on the experimental results presented, regarding the sheep wool mattress can be said to have good performance in terms of thermal insulation capacity, has low mechanical strength, has good capabilities in terms of influence on indoor air quality - very good water vapor permeability, is sensitive to the action of water.

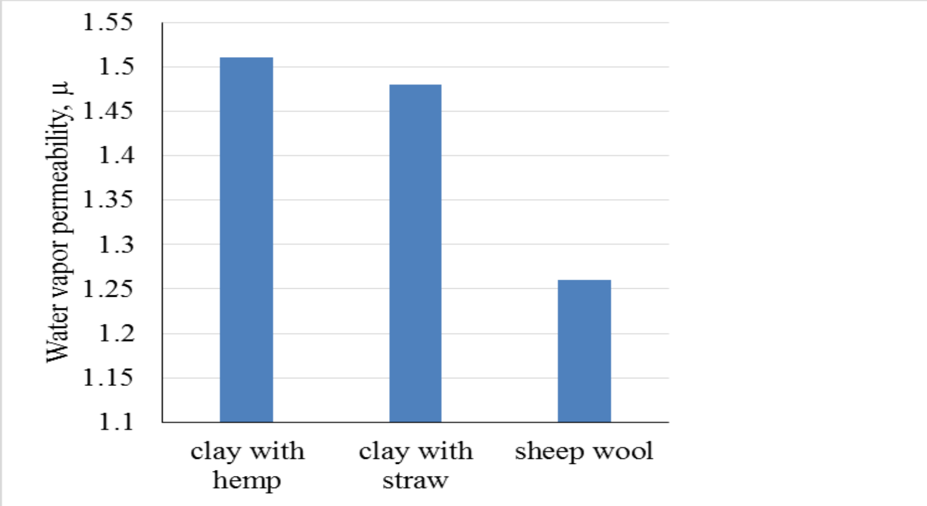
Figure 5. *The Thermal Conductivity Values of the Studied Materials Compared to Those of Polystyrene*



As shown in the graph in Figure 5, the composite mattress made of sheep wool is characterized by a lower coefficient of thermal conductivity than a polystyrene EPS 100.

The products obtained from clay have a higher thermal conductivity than polystyrene which has a higher thermal conductivit than the sheep's wool, so it can be concluded that the sheep's wool mattress is the best thermal insulation material, but it must be applied on a wall, already built.

Figure 6. *The Water Vapor Permeability Values of the Studied Materials*

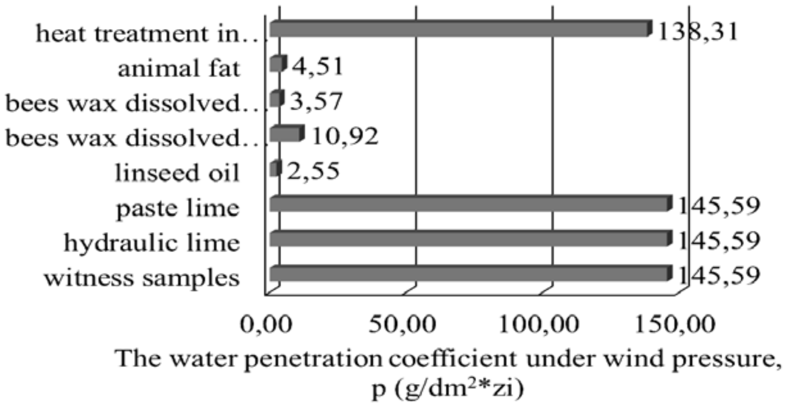


The graph in Figure 6 shows the values of the water vapor permeability coefficient of the product from hemp clay, straw clay and mixture of recycled PET (polyethylene terephthalate), waste fibers PES (polyester) recycled, waste fibers, natural sheep wool fibers and vegetable fibers, cellulose and siliconized fibers, TENCEL®. The higher is the permeability coefficient, the more waterproof the product is. Polystyrene EPS 100, has a vapor permeability coefficient of about 150. According to the graph, the studied products have a water vapor permeability coefficient in the range of 1.26-1.51, so it can be said that they are permeable to water vapor, which gives the wall, made of such materials, the property of breathing, while maintaining a constant humidity in the interior.

Following the results obtained on wool, it is observed that it is a thermal insulation material that has a lower coefficient of thermal conductivity than that of polystyrene, which means that it is a better thermal insulator than polystyrene. In addition, sheep's wool is also permeable to water vapor, and this means that water vapor diffuses through the linen layer. The problem with the linen mattress is that it must be applied to a wall that has already been made, due to poor mechanical strength of the mattress. In order for the wall to be completely breathable, it must be made of bricks made of materials with water vapor permeability such as clay, for example. Therefore, a solution would be for the wall, to be made of clay bricks, and for better insulation, to apply the linen mattress mixture of recycled PET (polyethylene terephthalate), waste fibers PES (polyester) recycled, waste fibers, natural sheep wool fibers and vegetable fibers, cellulose and siliconized fibers, TENCEL® and then, to continue to be plastered with a vapor-permeable clay-based mortar. To find out the compatibility between the linen mattress and the clay materials, it was treated with a clay-based plaster mortar, the recipe of which was indicated above. Following the results, it can be concluded that the adhesion of this plaster to wool is very good, also the water resistance is much improved, so it can be considered as an adequate method to protect the wool thermal insulation material. It is also an ecological and natural method, possible with local materials.

In conclusion, to obtain a wall, made of natural materials that have a good coefficient of permeability to water vapor, i.e., to be able to breathe, to have a low coefficient of thermal conductivity, i.e., to be a good thermal insulator and to have a good water resistance, materials based on clay, sheep's wool and linseed oil surface treatment can be used. The bricks from which the wall is made can be made of clay according to the studied recipes, then a layer of recycled PET (polyethylene terephthalate), waste fibers PES (polyester) recycled, waste fibers, natural sheep wool fibers and vegetable fibers, cellulose and siliconized fibers, TENCEL®. This mattress can be applied to the wall with the help of a studied clay-based mortar, and then plastered with clay mortar in 2 or 3 layers. For a good resistance to the action of climatic factors, the surface of the clay plaster on the outside is treated with 2 layers of linseed oil. The water resistance of flaxseed oil plaster has been previously studied and very good results have been obtained (Călătan et al. 2017). Figure 7 shows the results of water penetration tests under wind pressure, performed on various surface treatments in order to improve water resistance (Călătan et al. 2017). From the graph, it can be seen that the flaxseed oil treatment has the lowest water penetration coefficient under wind pressure, therefore it is the most effective treatment for improving the resistance to the action of climatic factors.

Figure 7. *Influence of the Surface Treatment on Water Penetration Coefficient under Wind Pressure (Călătan et al. 2017)*



Conclusions

Following the study, the following conclusions can be drawn:

- Mixtures made of clay have a good workability, which allows a necessary homogenization.
- The value of the axial contractions is within the limit specified by the specialized literature, so that no clay mixture shows cracks when drying.

- The value of the density in hardened state of the clay mixture with the addition of hemp fibers is in the range 1,600 – 2,000 kg/m^3. According to the literature, this range is satisfactory in terms of thermal efficiency, which indicates a property of the wall made with such material, to keep a certain constant of the temperature of the indoor environment. The apparent density of the clay mixture with the addition of straw is below the lower limit of this range indicated by the literature, which means that this material, compared to the clay mixture with hemp fibers, has a lower capacity to store heat, on which, it can then give way when the temperature drops, instead it is a good thermal insulator.
- The products obtained from the two clay mixtures with the addition of hemp and straw, respectively, can be used to build a wall, due to the mechanical strength they have.
- Wool insulation material - has very good performance in terms of thermal insulation capacity, but has low mechanical strength, is sensitive to the action of water, is very sensitive to the action of mold and degradation in contact with the ground.
- Wool protection can be achieved by plastering its surface with a suitable plaster mortar, based on clay.
- Due to the fact that the clay material is also sensitive to the action of water, the surface of the clay plaster must be treated with a waterproofing solution, and previous studies show that the best solution for protection of clay plaster is the treatment with natural linseed oil.
- A combination of the two materials, the clay mixture and sheep's wool presents a suitable solution for creating an ecological, natural wall that gives a pleasant and healthy indoor climate.

The bricks made according to the recipes made of clay material studied can be used successfully to make the walls of buildings, and the insulation can be done with wool mattresses plastered and then with a clay-based mortar, and finally the surface is treated with linseed oil. A wall made in this way has good capacities in terms of influence on indoor air quality, very good permeability to water vapor, ability to absorb/desorb moisture from and into the environment, environmentally friendly, energy efficient and conferring a pleasant and healthy climate for inhabitants. At the same time, the basic principles of traditional vernacular architecture, which are modeled in accordance with current technological progress, are preserved.

Acknowledgments

This paper was financially supported by the Project "Entrepreneurial competences and excellence research in doctoral and postdoctoral programs - "ANTREDOC", project co-funded by the European Social Fund financing agreement no. 56437/ 24.07.2019."

Partial support was received from The Ministry of Research, Innovation and Digitalization (MCID) through the project PN 19 33 03 01, "Researches to achieve the acoustic and thermal comfort inside the buildings, using an innovative tool for choosing the optimum structures of construction elements, from classical versus modern materials".

References

Abdou A, Budaiwi I (2013) The variation of thermal conductivity of fibrous insulationmaterials under different levels of moisture content. *Construction and Building Materials* 43(Jun): 533–544.

Adams T (2017) *Sound material – A compendium of sound absorbing materials for architecture and design*. Tyler Adams.

Asdrubali F, D'Alessandro F, Schiavoni S (2015) A review of unconventional sustainable building insulation materials. *Sustainable Materials and Technologies* 4(Jul): 1–17.

Bui Q (2008) Durability of rammed earth walls exposed for 20 years to natural weathering. *Building and Enviroment* 44(5): 9–12.

Bui Q, Morel JC, Hans S, Meunier S (2009) Compression behaviour of non-industrial materials in civil engineering by three scale experiments: the case of rammed earth. *Materials and Structures* 42(8): 1101–1116.

Călătan G, Hegyi A, Dico C, Mircea C (2015) Additives influence on the earth characteristics used in vernacular construction. *Ecoterra - Journal of Environmental Research and Protection* 12(1): 7–20.

Călătan G, Hegyi A, Dico C (2016) Adobe bricks constructions. past experience, the base of the contemporary buildings. In *Proceedings of the 16th International Multidisciplinary Scientific GeoConference & EXPO – SGEM 2016, Section Green Buildings Technologies and Materials*. 28 iunie - 7 iulie 2016, Albena, Bulgaria.

Călătan G, Hegyi A, Dico C, Mircea C (2017) Experimental research on the recyclability of the clay material used in the fabrication of adobe bricks type masonry units. *Procedia Engineering* 181: 363–369.

Ciurileanu GT, Bucur Horvath I (2011) *The new vernacular based architecture*. JAES, Section Civil Engineering and Installations.

Ciurileanu GT, Bucur Horvath I (2012) Modular building using rammed earth. *Acta Technica Napocensis: Civil Engineering & Architecture* 55(2): 173–181.

Karim MdR, Zain Muhammad FM, Jamil M, Lai Fook C, Islam MdN (2011) Use of wastes in construction industries as an energy saving approach. *Energy Procedia* 12: 915–919.

Kiroff L, Roedel H (2010) Sustainable construction technologies: earth buildings in New Zealand. In *Proceeding of Second Internatiol Conference of Sustenable Constructions Materials and Technologies*. Ancona, Italy.

Kumar A, Pushplata (2013) Vernacular practices: as a basis for formulating building regulations for hilly areas. *International Journal of Sustainable Built Environment* 2(2): 183-192.

Minke G (2005) *Building with earth. Design and technology of a sustainable architecture, Birkhäuser*. Publishers for Architecture Basel Berlin Boston.

Moquin M (1994) *Ancient solutions for future sustainability: building with adobe, rammed earth, and mud*.Tampa, Florida, USA.

Suciu MC, Suciu N (2007) Dezvoltarea sustenabila - Problema cheie a secolului XXI. (Sustainable development - The key issue of the 21st century). *Buletinul AGIR* 1: 124–125.

Vural N, Vural S, Engin N, Sumerkan MR (2007) Eastern Black Sea region. A sample of modular design in the vernacular architecture. *Building and Environment* 42(7): 2746–2761.