THE USE OF NATURAL RENEWABLE MATERIALS IN THE SUPPORT OF SUSTAINABLE DEVELOPMENT

Isminur Aybek, Zedina Hujdur, Amar Dautović, Adnan Novalić, Sanela Klarić

Department of Architecture - International Burch University Sarajevo

ABSTRACT

Architecture design today has become far more challenging then it traditionally used to be. On top of accustomed thermal insulation thickness and heating demand, architects need to design new or renovate existing structures in compliance with the primary energy demand, CO_2 reductions, as well as ecological properties of the building materials. These properties are essential for a holistic assessment. Researches and demand for ecological building materials have been growing dramatically, particularly for insulating materials from renewable resources. Conventional design, constructions and conventional materials are still predominantly used in the world, particularly in BiH and Turkey.

The aim of this paper is to present a comparison between the use of conventional methods, constructions and materials against alternative solutions of renewable insulations materials application in the wall constructions. The conventional walls are predominantly made of cement, bricks, Styrofoam, plaster and paint. For the innovative walls, materials used for a wall 1 are: brick, wood fibre insulation, plaster, coat render, and for wall 2: timber, sheep's wool insulation, brick, OSB board and plaster. The tests results indicate the amount of primary energy and CO_2 emission which could be saved if renewable materials are used not only for insulation but for the construction as well. Findings also show great demand for a new clean technology in brick production that will save energy and CO_2 emission. Additionally, renewable materials have more ecological and fewer health damaging aspects.

Keywords: wall construction, natural insulation materials, primary energy, global warming potential, health

1. Introduction

The production of the most of today's building materials is a very high energy consuming process that includes very high CO2 emission. A lot of the wall patterns existed across the world are constructed by similar building methods or insulation materials. In BiH and Turkey, wall patterns in residential buildings are almost the same. In order to support better understanding of sustainable architecture needs and requirements for a building materials, this paper took one common wall pattern to examine and to compare with two innovative wall examples. Also, the new EU directives from 2010 have been requiring a more holistic approach to architectural design. That DIRECTIVE 2010/31/EU of the European Parliament and the European Council of 19 May, 2010 on the energy performance of buildings requires that "the energy performance certificate should also provide information about the actual impact of heating and cooling on the energy needs of the building, on its primary energy consumption and on its carbon dioxide emissions"[1]

This paper deals with necessary information and drawings for resolving important questions regarding the wall constructions as well as for their insulation materials. What makes this paper special is its analysis of one of the newest innovative insulation material (wood fibre insulation, Styrofoam, sheep's wool) that we could find on the market today. Additionally, the combination of these insulation materials with the one of the oldest brick materials as a commonly used material in all three case walls will be discussed in many aspects. Paper will achieve many tasks including the analysis of the material properties as well as their primary energy needs and environmental impact. Furthermore, it will provide methodology through historical and comparative analysis, together with an eco-balance of the materials. Results of the research could play a key role in future reduction of energy the demands of buildings as well as providing proposals for new investors considering innovative local materials in those two countries and wider.

2 Presentation of the examined wall's materials and dimensions

The location of all examined walls is the same in all three cases. Examined walls are an element of a residential building, located on the first floor, on the north side of the building, as a wall without any openings. All examined walls contain the same base construction such as brick. Wall 1 presents the most common wall pattern in BiH and Turkey. Wall 2 and Wall 3 present the innovative approach that combine brick with natural materials such as a wood and sheep's wool.

<u>Wall 1.</u>

1. Exterior wall paint 0,05 cm
2. Finishing coat with cement 0,1 cm
3. Roughcast with cement 0,5 cm
4. Horizontally perforated bricks (8,50x19,00 cm) 8,5 cm
5. Styrofoam 10 density 3 cm
6. Horizontally perforated bricks (8,50x19,00 cm) 8,5 cm
7. Gypsum plaster 0,5 cm
8. Satin gypsum plaster 0,1 cm
9. Water based silicon interior wall paint 0,05 cm

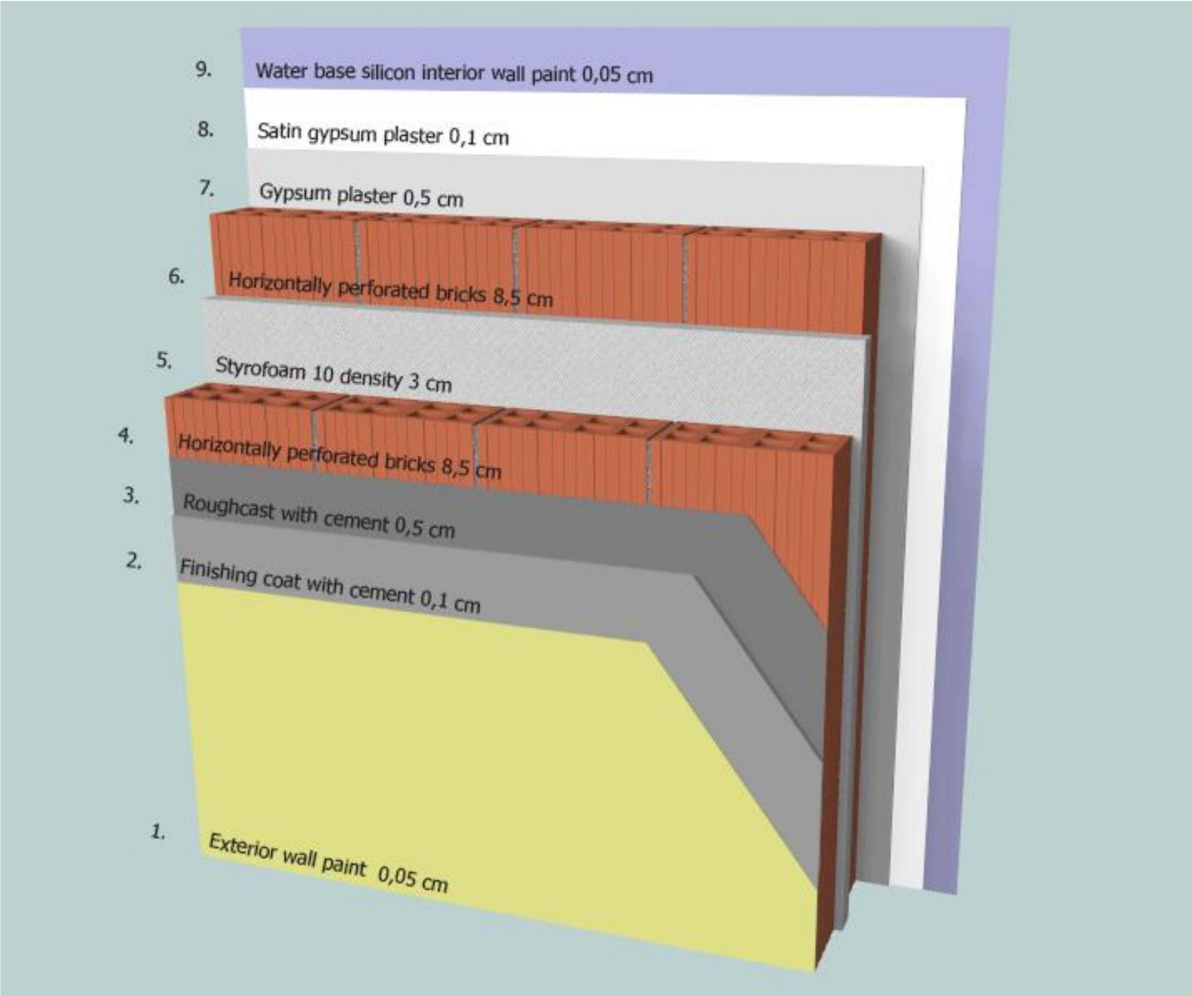

Figure 1. Wall 1 - *3D visualisation of study case external wall; Resource: Authors drawing*

<u>Wall 2.</u>

1. 15 mm plaster
2. 215 mm brickwork (0.75 W/mK)
3. 200 mm rigid wood fibre insulation(0.043 W/mK)

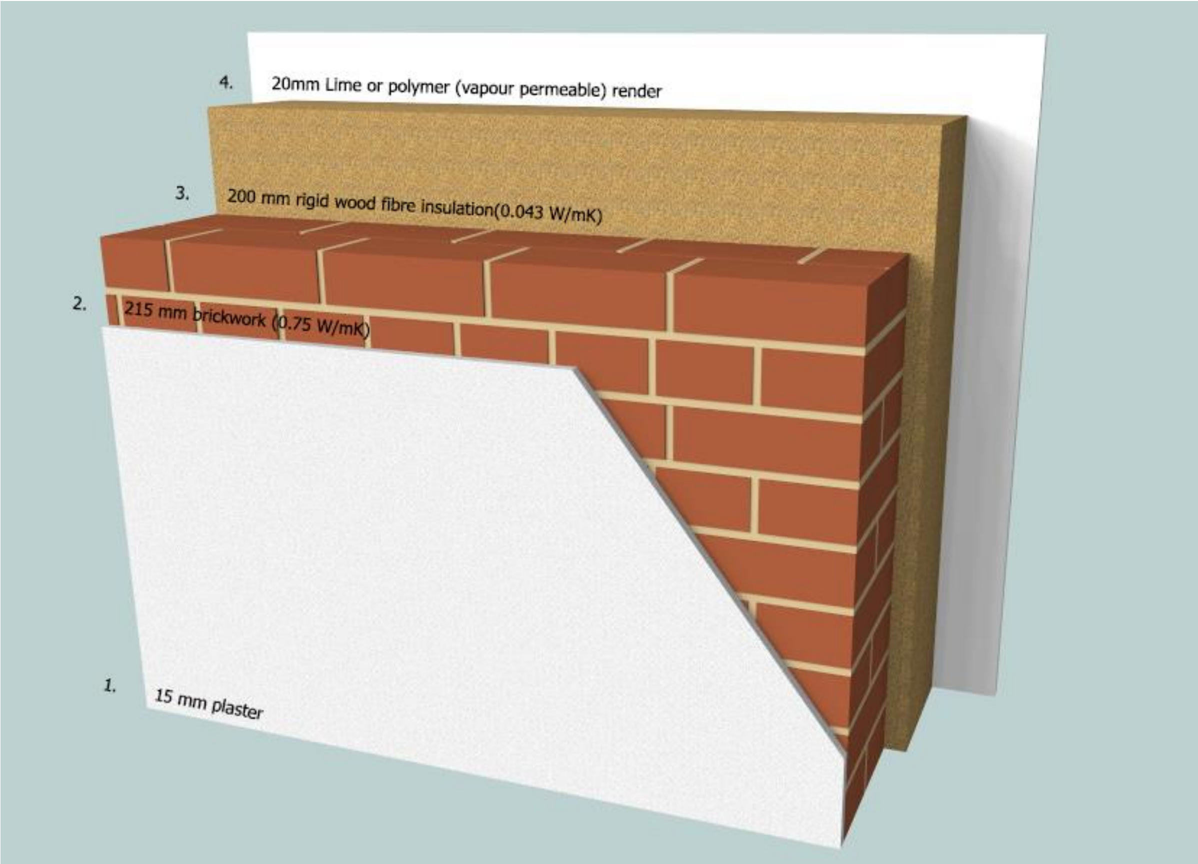

Figure 2. Wall 2 - 3D visualisation of study case external timber frame wall; Resource: Authors drawing

Wall 3.

1. 103mm brick external leaf
2. 50mm unventilated cavity
3. 10mm OBS board
4. Vapour permeable membrane
5. 140mm timber frame fully filled with 140mm wool thermal
6. Vapour control layer
7. Internal finish of 12.5mm standard plasterboard

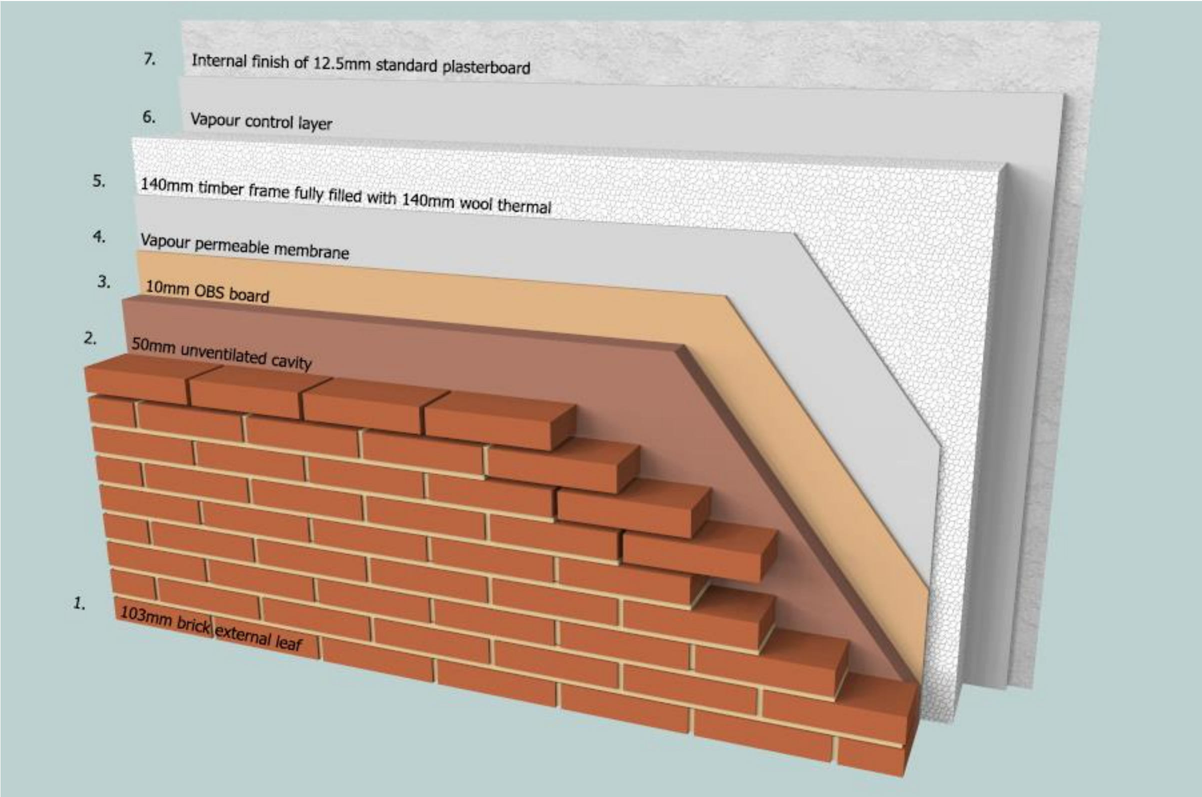

Figure 3. Wall 3 - 3D visualisation of study case external timber frame wall; Resource: Authors drawing

3 Presentation of the examined wall's construction and insulation materials

In order of better understanding of sustainable requirements of building materials, an assessment of the energy requirement and CO_2 emissions has been made for the following materials:

3.1 Fired bricks

Fired bricks were invented in 3500 BC and have become the world's most common form of masonry. They are made from the natural material, clay. Naturally drained bricks (čerpič/ kerpiç) are more sustainable but fired brick have a higher embodied energy because they are fired at temperatures of 900-1200 ºC with high level of the CO_2 emissions. In that regard, the most environmentally friendly option is to recycle (buy reclaimed bricks), although it is essential to match the type of brick to its function: facing bricks for cladding, strong engineering bricks for structural walls, and common bricks, which are durable but not attractive, for foundations and internal walls. Also there are some researches that test combinations of clay with other natural materials like hemp, straw or sheep's wool in order to find the optimal combination that could achieve similar characteristic as fired brick. Bricks come in a bewildering array of designs, shapes, textures and colours, and they can be laid in various patterns, called bonds. They can be used for cladding, framework, foundations and features such as chimneys. Roughly, 17 % of a brick wall is made up of mortar. Portland cement is the most common mortar material, but traditional lime mortar is increasingly being revived, as it is made from a natural non-toxic material and allows walls to breathe.

The advantages of those materials are as follows: they are made from natural material; most clay pits are carefully managed, and refilled and replanted after use, idly durable and low-maintenance, combination with lime mortar, high thermal mass, they can be reused or recycled or are able to be used as a construction aggregate.

Also this material has disadvantages such as: high embodied energy, most often laid with Portland cement, which is also a high-energy product, often used as exterior cladding on lightweight buildings which negates their thermal-mass properties, since any radiant heat escapes outwards into the atmosphere. [2]

3.2 Styrofoam

Styrofoam, which also called EPS, is not a natural material. It is most common material that we could see on building construction site today. It is also one of the cheapest insulation material on the market. But the question about the embodied energy of this material is a part of the debate and discussion. “Debate on the choice of insulation materials tends to be related to environmental considerations, durability and build ability. If we first consider the environmental aspects (and keep in mind that it can be misleading to talk about an element out of context, i.e. insulation without considering the entire, say, wall construction) a principal concern for plastic insulations is ensuring that ozone-depleting chemicals are not used in their manufacture. The situation is in flux and so, individual manufacturers must be contacted on their products. [3] Because of these reasons, architects need to be cautious when they are choosing insulation materials taking into consideration their influence on nature.

This insulation material could be used on or below sub-floor slabs, between timber joints, partial or full fill wallboards or flat or pitched roofs.

Advantages of those material are: moisture resistance (low water vapour transmission, no capillary action, high resistance to moisture absorption), resistance to diluted acids and alkalis, cheap, variation of dimensions, recyclable.

This material has also disadvantages such as: not being resistant to organic solvents, melts and shrinks away from small heat sources, ignites with severe flames and smokes heavily when exposed to a large heat source, has a high embodied energy and is expensive to recycle.

3.3 Wood fibre

Wood fibre is a new insulation material which was introduced twenty years ago. It arises from inventing new ways of transforming timber waste from thinning and factories into insulation boarding. It is also a recyclable and reusable material that absorbs CO_2 from the environment in a very sustainable way. Its significance lies in its range of functions including rigid insulation, sheathing and sharking for timber frames, roofs and flooring as well as flexible insulation for studs and rafters.

The advantages of those material are: breathability which helps the regulation of moisture, material density (necessary for adding a degree of decrement delay that will be useful for hotter summer days), heating capacity (twice more than mineral wool), the capacity to both absorb and release moisture making it a breathable structure, manufactured from a renewable resource, reusable if it is in a suitable condition, recyclable, compostable or can be used in energy recovery, sequesters CO_2 during tree growth, hygroscopic – provides a degree of humidity control and decrement delay

Also this material has some disadvantages such as: high embodied energy, if imported from another country that could increase the embodied energy, rigid boards can be fragile and difficult to use on site.

3.4 Sheep's wool

Sheep wool is an easily renewable, easily recyclable and environmentally friendly source of raw material, which consists on average of 60 % animal protein fibres, 15 % moisture, 10 % fat, 10 % sheep sweat and 5 % impurities. [4] Sheep's wool is a hygroscopic fibre which meanıng that ıt absorbs, stores and releases moisture much faster than other materials. Wool can absorb over 35% of its own weight in moisture without having any significant changes to its thermal performance. Sheep's wool insulation is well suited to timber frame structures making natural synergy with wood. Drawing out the moisture by sheep's wool fibres does the conditioning of the wood and as like that it protects the fabric of the whole building. Indoor air quality and maximal thermal efficiency are improved by natural insulation because it allows the structure to breath and at the same time to keep the thermal resistance.
The benefits of sheep's wool include the durability and longevity. The importance of sheep's wool insulation lays also in the fact that sheep wool ensures the product durability throughout the life of the building. The compression tests proved that sheep wool insulation has an great recovery rate within the first 24 hours of its installation. Sheep wool insulation is resistant to compaction, unlike some alternatives that will compact over time and compromise thermal conductivity. This longevity of sheep's wool ensures that the insulation will continue to act by high standards throughout the whole building's lifespan.

This natural material ensures indoor air quality because sheep's wool insulation has a unique ability to absorb noxious gases that are emitted from building products e.g. formaldehyde; a carcinogenic gas emitted from different man-made building materials. Wool deals with these gases by locking them up which helps protecting the residents from health risks. A lack of 'breathability' in buildings can cause different problems, including health issues as a result of mould and damp.

Also this material reaches high fire standards. The wool has to be washed and treated in a specific way so it becomes fire safe. The sheep's wool is a comfortable material and easy to handle with. There is no risk to human health. Handling the sheep's wool can be done without any protective clothes.

This natural material is easy to recycle and eco-friendly, it is biodegradable which means it can be composted into the ground to participate in Erath's natural cycle. Moreover sheep's wool insulation can be recycled in a way to produce extra energy.

4. U-value calculations for three wall cases

U-value - The heat transfer coefficient is about the flow of the heat U [W/m² K], through the single material or multiple materials in the construction. U-value is the essential characteristic of the outer structural element and plays a major role in the analysis of the total heat losses (kWh/m^2), and thus the energy consumption for heating. When the heat transfer coefficient is decreased, the thermal insulation of buildings becomes better.

4.1 Comparison of U-values for all three case walls (Wall1, Wall2, and Wall3)

Below is presented the method of calculation of the U-value for the three types of wall presented with all of the materials that have been chosen. All walls are tested to reach passive house standards which are 0, 15 Wm²k. For that reason, all walls has been calculated with more insulation materials in order to reach those standards. The method of the calculation has been adopted by the TUW (Technical University in Vienna) as the official U value calculation method.

This method will use following information for the materials: dimension, density, CO_2 emission, water vapour permeability coefficient and basic dimensions.

Wall 1.

Table 1. Final result of U-value calculation (data resource: Baubook Richtwerte und Produkte, IBO, Gramitech, Naporo)

Exterior wall reconstruction with 25 mm EPS

Sandwich Brick Wall	d	l	m	Rsi+Rse	r	Potencial Global Warming (CO2-Äq.)	Equivalent CO2	Acid manner (SO2-Äq.)	SO2-Ekvivalent	KEA	KEA	Primary Energy
	[m]	[W/mK]	[1]	[m2K/W]	[kg/m3]	[1]	[kg C02]	[1]	[kg S02]	[MJ/m3]	[MJ/m2]	[MJ/m3]
Air				0.17								
Satin Gypsum plaster	0.01	0.3	50		30	0.246	0.0738	0.00147		9,180	91.8	
Gypsum plaster	0.05	0.3	50		30	0.246	0.369	0.00147		9,180	459	
Horizontally Perforated Bricks	0.085	0.55	7		1700	0.176	25.432	0.000553		4,233	359.805	
Styrofoam 25 density	0.25	0.042	60		25	4.169	26.05625	0.0149		3,288	822	
Horizontally Perforated Bricks	0.085	0.55	7		1700	0.176	25.432	0.000553		4,233	359.805	
Roughcast with cement	0.005	0.7	50		1000	0.246	1.23	0.00147		9,180	45.9	
Finishing Coat with cement	0.001	0.7	50		1000	0.246	0.246	0.00147		9,180	9.18	
U-Wert	0.15	W/m²K										

During the calculation of the U-value of Wall 1, results of the calculation showed that U-value for the common pattern (insulation only 30-80 mm of Styrofoam) is 0.71W/m²K, that is too high, and the only way to make the results better for an energy efficient wall was to decrease U- value, and that is done by increasing thickness of the Styrofoam insulation from 30 mm to 250 mm. With this move, the U-value is satisfying 0.15 Wm²k which enables good thermal performance of the building envelope.

Wall 2.

Table 2. Final result of U-value calculation (data resource: Baubook Richtwerte und Produkte, IBO, Gramitech, Naporo)

Exterior wall reconstruction with 30 mm of wood fibre isolation

Brickwork wall with rigid wood fibre insulation	d	l	m	Rsi+Rse	r	Potential global warming (CO2-Äq.)	EkvivalentCO2	Versaue-rungspoten-tial (SO2-Äq.)	SO2-Ekvivalent	KEA	KEA	Primarna energija
	[m]	[W/mK]	[1]	[m2K/W]	[kg/m3]	[1]	[kg C02]	[1]	[kg S02]	[MJ/m3]	[MJ/m2]	[MJ/m3]
Air (i und e)				0.17								
Lime mortar	0.02	0.2	10		1800	0.168	6.048	0.00049		3,222	64.44	
Brick	0.215	0.55	7		1700	0.176	64.328	0.000553		4,233	910.095	
Plaster	0.015	0.2	10		1300	0.128	2.496	0.00045		3,328	49.92	
Rigid wood fibre insulation	0.3	0.048	5		2300	0.128	88.32	0.00045		3,328	998.4	
U-value	0.14	W/m²K										

During the calculation of the U-value of Wall 2, results of the calculation showed that the U-value is 0.20 Wm²k, which is also too high. In order to decrease U- value, the thickness of the wood fibre insulation has been increased from 200mm to 300mm. With this move, the U-value is satisfying 0.14 Wm²k which enables good thermal performance of the building envelope.

Wall 3.

Table 3. Final result of U-value calculation (data resource: Baubook Richtwerte und Produkte, IBO, Gramitech, Naporo)

Exterior wall reconstruction with 20 cm of sheep wool

Exterior timber frame wall with 20 cm of sheep wool insulation	d	l	m	Rsi+Rse	r	Potential global warming (CO2-Äq.)	EquivalentCO2	Acid manner(SO2-Äq.)	SO2-Equvalent	KEA	KEA	Primary energy
	[m]	[W/mK]	[1]	[m2K/W]	[kg/m3]	[1]	[kg C02]	[1]	[kg S02]	[MJ/m3]	[MJ/m2]	[MJ/m3]
Air				0.17								
Lime mortar	0.01	0.2	10		1800	0.168	3.024	0.00049		3,222	32.22	
Brick	0.25	0.55	7		1700	0.176	74.8	0.000553		4,233	1058.25	
OSB Board	0.012	0.13	200		610	-1	-7.32	0.00603		5,685	68.22	
Vapour membrane	0.01	0.23	100000		980	2.55	24.99	0.0253		91,532	915.32	
Timber frame	0.2	0.12	50		450	-1.26	-11.34	0.0341		3,618	72.36	
Sheep wool	0.2	0.04	1		30	1.6	9.6	0.0103		3,495	699	
Vapour membrane 1	0.01	0.23	100000		980	2.55	24.99	0.0253		91,532	915.32	
U-Wert	0.13	W/m²K										

During the calculation of the U-value of Wall 3, with dimensions of sheep's wool and timber frame (140 mm) it showed that U-value is not allowable and is problematic, so to resolve this problem, the dimensions of the timber frame and wool were increased from 14 mm to 20 mm and the final U-value is 0.13 Wm²k, which is very satisfying.

In each of three wall constructions it is possible to reach passive house standards by increasing the thickness of insulation materials.

5. Natural material alternative resource and local existing materials Bosnia and Herzegovina (BiH)

Considering material resources, it can be stated that most of them can be easily found locally. Production of brick can be found in the settlement of Rakovica which is near Sarajevo. The company "TOS" gives great opportunities for people who are willing to have their construction completed with brick material, offering them a wide range of choices of brick types. Alternatively, there is also a company in Visoko called "IGM" which deals with the production of brick. All production in BiH is fired brick.

However, wood fibre production cannot be found in BiH, even though the wood industry is well-develop in BiH. Since this insulation material is new in the construction world, it is imported from the European companies such as "Agepan" from Germany and "Pro:Holz" from Austria. It is important to mention that this statement has led to the conclusion that there should be more investment in the wood products throughout BiH. This move would increase knowledge about the construction and usage of wooden materials as well as economic benefits to BiH.

In BiH the availability of raw sheep's wool is widely available with the country producing more than 1,5 million kg per year. There is currently one manufacturer of sheep's wool insulation material in BiH. Unfortunately, the cleaning of the wool is still done by more traditional methods, so there is lot of space for reconstruction and improvement. Also the production company is under developed and the final product currently does not have any certification nor any accreditation by laboratory testing. This material is not yet widely seen on the local market. This industry provides a great economic development opportunity in BiH.

Production of Styrofoam is readily available both locally or imported, and considering its wide production, it can be said that there is no problem in finding this material on the market in BiH.

5.1 Transport

Transport accounts for nearly one-quarter of global energy-related CO_2 emissions. To achieve the necessary extensive cuts in greenhouse gas emissions by 2050, transport must play a significant role. However, without strong global action, car ownership worldwide is set to triple to over two billion by 2050. Trucking activity will double and air travel could increase four-fold. These trends will lead to a doubling of transport energy use, with an even higher growth rate in CO_2 emissions as the planet shifts toward high-CO_2 synthetic fuels. How can we enable mobility without accelerating climate change.[5]

"Transportation is one of the often forgotten factors affecting embodied energy. The further a material has to travel, the greater the energy that is used in its transport. The weight of a material will also affect the energy needed to move it." [6] However, most of materials in these walls can be easily found in BiH. Furthermore, wood fibre, which is imported from Europe, does not represent a big impact to the energy that is used in its transport. Considering that the durability of materials makes a great impact on construction world, this is something which should be taken into account. That is why, on grounds of durability, an imported natural material may be more preferable than a local artificial one (e.g. polyester) and this is why importing natural material can have great benefits in the construction industry. On the other hand, they offer advantages in breathability, temperature regulation, water absorption, antimicrobial properties, etc. This leads to the conclusion that even material which is local, should be replaced by an imported one if it provides a more pleasant and healthy lifestyle until this material is a part of production in BiH.

6. Primary energy consumption and embodied energy for three walls cases

'Primary energy consumption (PEC) refers to the direct use at the source, or supply to users without transformation of crude energy, that is, energy which has not been subjected to any conversion or transformation process.' [7] The primary energy used varies from product to product, but it is generally much lower for wood than other materials. However, there are exceptions that include wood-fibre which requires high processing temperatures. [8]

Embodied energy gives us information about the entire life time of materials. According to definitions "it is also called life cycle assessment (LCA) and a useful tool for evaluating the relative environmental impact of various building materials because it takes production, transportation and disposal into account, all things that can have a pronounced environmental impact but are not necessarily reflected in the price."[9]

Thanks to embodied energy, people who has any interest can decide on which materials will be used in a structure. Considering long life materials and environmental impact low embodied energy is the best for energy efficiency. In this study there are three materials and their embodied energies;

- EPS : 1126 kWh/m^3
- Wood Fibre : 133 kWh/m^3
- Sheep's Wool : 31 kWh/m^3

Potential global warming demonstrates the actual potential of materials for global warming. For all three walls, the potential global warming comparison for all materials has been made as well as a comparison between all materials from all three walls. That information will, once again, confirm advantages and benefits of natural materials as friendly products that have the ability to make a negative impact on the nature.

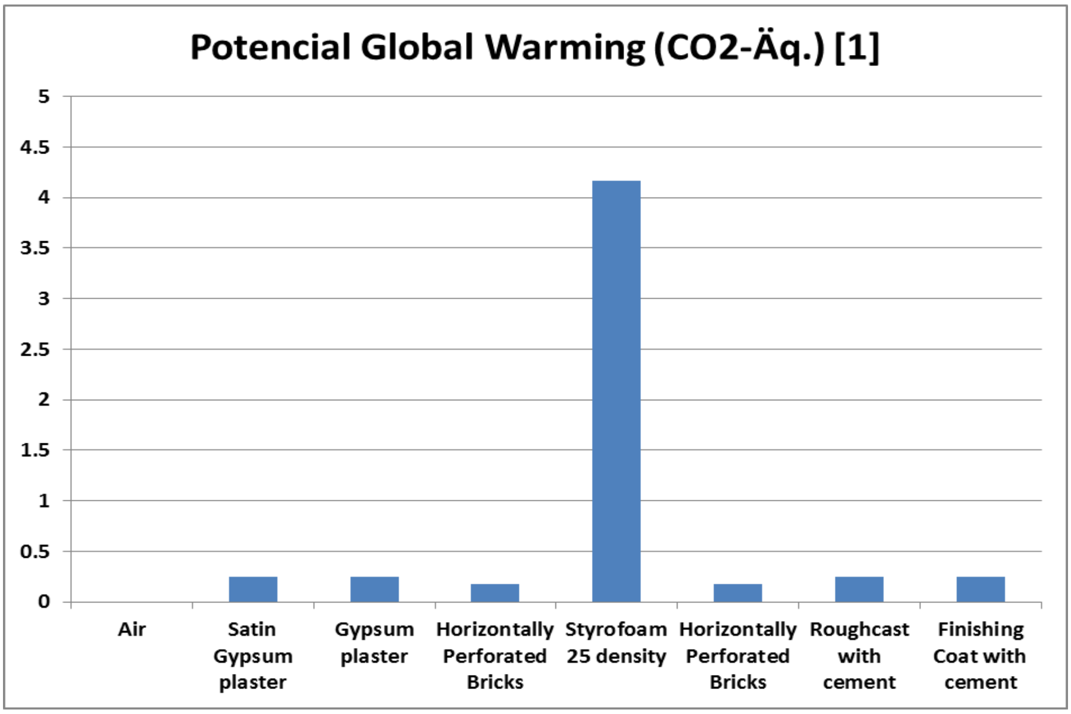

Figure 4; potential global warming of wall materials for wall 1

According to figure 4, it can be stated that Styrofoam has the highest level of potential global worming (4,169 CO2 Eq), followed by satin gypsum plaster, gypsum plaster, roughcast with cement and finishing coat with cement containing the same amount (0,246 CO2 Eq) then horizontally perforated bricks (0.176 CO2 Eq).

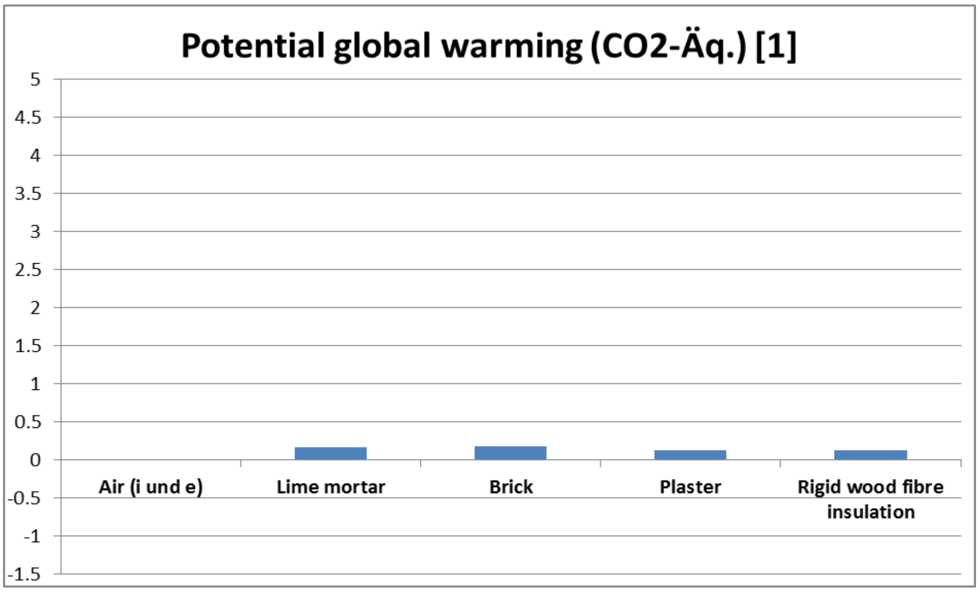

Figure 5; Potential global warming of wall materials for wall 2

Potential global warming demonstrates the actual potential of materials for global warming. According to figure 5, brick has the highest level (0.176 CO2 Eq) followed by lime mortar (0.16 CO2 Eq). After these two materials is plaster with 0.12 CO2 Eq. The rigid wood fibre insulation has an amount of -0.8 CO2 Eq which represents that there is no potential for global warming considering the absorption of CO2.

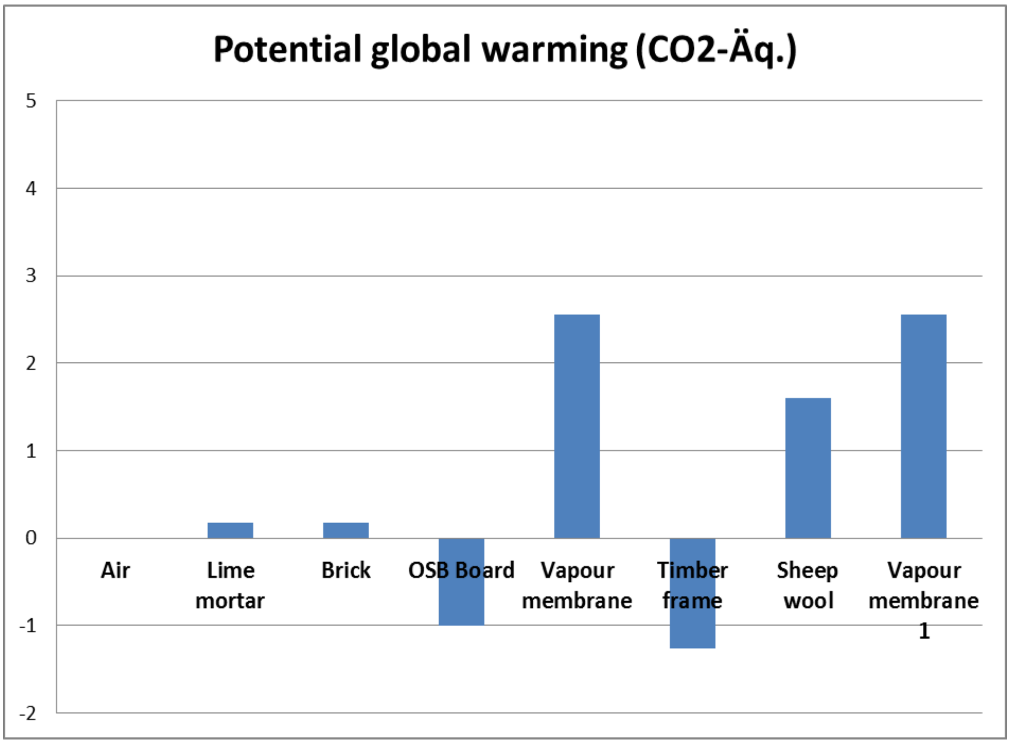

Figure 6; Potential global warming of wall materials for wall 3

According to figure 6, vapour membrane has the highest level (2,55 CO2 Eq) which is followed by sheep's wool (1,6 CO2 Eq). After these two materials, the next is brick with (0,176 CO2 Eq) then lime mortar (0,168 CO2 Eq). Finally, OSB board (-1 CO2 Eq) and timber frame (-1,26 CO2 Eq) represents that there is no potential for global warming considering the absorption of C02.

Comparison of insulation materials in accordance to Potential global warming, Equivalent CO2 and Embodied energy

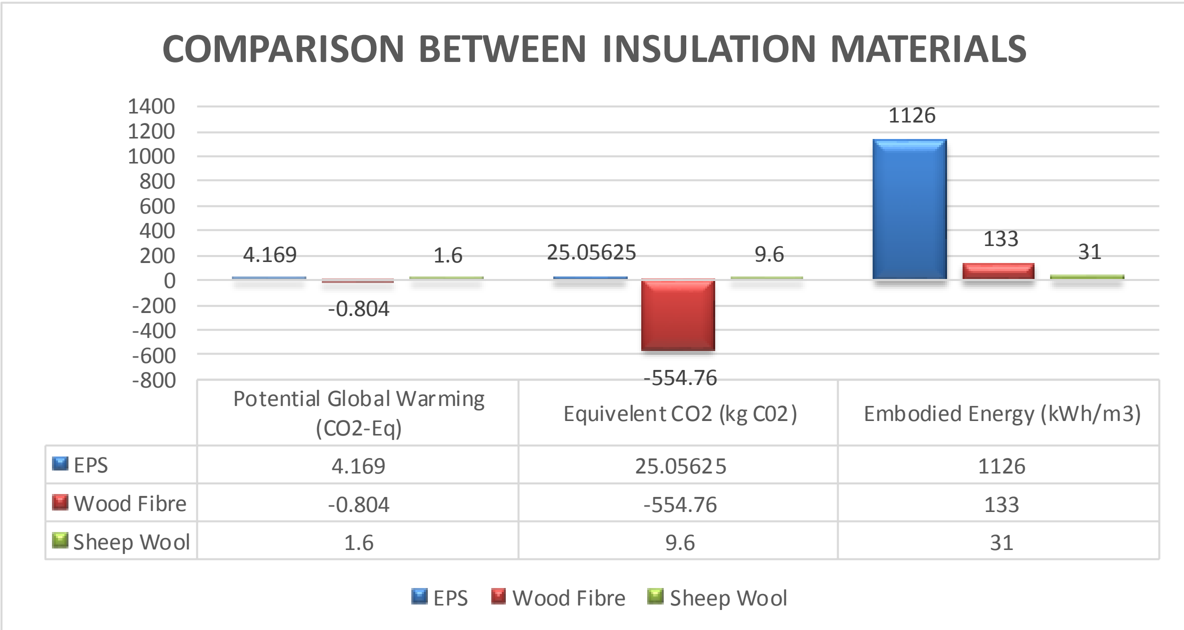

Figure 7; Potential global warming of wall materials for all three walls

Equivalency of CO2 demonstrates how many kg of CO2 is produced per 1kg of materials shown in figure 7. According to the graph of equivalency of CO2, it can be seen that the wood fibre has conceivably the lowest level (-554,76) followed by sheep's (9,6). the EPS (Styrofoam) contains the highest level of CO2. These statistics show that the CO2 of wood fibre has the best effect, which is absorbed and does not stay in the atmosphere which represents a perfect state when taking into consideration potential global warming.

7. Conclusions and Recommendations

Today, when materials have been making an immense impact on the environment, all characteristics of the materials should be taken into account during the design of the residential buildings. A comparison between values and impacts of natural and synthetic materials is shown through the analyses of wall designs. The most important thing is to recognise the advantages of all materials and to maximise the use of those with a minimal impact on the environment.

Styrofoam, a material that is not natural, is the most common in construction due to its durability, build ability and price. However, Styrofoam's embodied energy, together with its inflammable characteristics and instability presents a great threat to the environment. Alternatively, modern natural wood fibre has a high embodied energy as well, but unlike Styrofoam, it provides a healthier life with benefits to the residents including breathability, heating capacity, material density, etc. Another natural material, sheep's wool, is comfortable and easy to handle without potential risk to human health. Also, this material does not have a high embodied energy and could be sourced locally. Brick, the common material in all three cases, is made from clay, having a high thermal mass. Moreover, its enormous embodied energy is affecting the health of the environment, a disadvantage which should be a key point when thinking about selecting this material.

The main advantage for the environment is having a unique ability to absorb noxious gases emitted from some building products and achieving a fire performance rating of Euro Class E which ensures that the material is flame retardant. The natural materials, sheep's wool and wood fibre, show very good fire resistance performances compared with Styrofoam, which has different negative performance in flames.

Concerning U-value, in all three wall constructions it is possible to reach passive house standards by increasing the insulation thickness. However, potential global warming is the true indicator which shows the true value of natural materials. During its analysis, it has been shown that Styrofoam clearly has the highest potential for global warming. Another important factor is the equivalency of CO2 in which wood fibre has shown the best value with a negative impact on environment. In BiH Styrofoam is very inexpensive, which is a great motivation for most investors when it comes to choosing insulation materials. In addition, wood fibre production cannot be found in this country. This could indicate that there is a great opportunity for investment in the wood products in Bosnia and Herzegovina. There is also great potential for local economic development and export for Sheep's wool insulation materials productions which could be achieved by applications of EU standards and procedures.

The analysis of the materials described above are the best supporters for natural materials and their value. The investors as well as architects should be careful when choosing material for construction, since it is becoming a part of our sustainable life approach. Most importantly, the health of the planet is something that people should keep in mind, and by all means implement ways to help keep the planet healthy. One way surely is through the use of natural materials, which will fulfil all requirements, for individuals and planet.

8. Acknowledgements

Thanks to the Head of Department of Architecture Assist. Prof. Dr. Nermina Mujezinović for her support in designing of the curriculum for the master topic Energy Efficient Architecture.

The authors would like to thank to Professors Thomas Bednar and Professor Azra Korjenić from the Technical University of Vienna for their technical support and advises. Also we would like to thanks to the colleagues Yaşar, Serdar and Ahmet Sencer, who provided some valuable data from Turkey for this research.

10. References

[1] DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings, Official Journal of the European Union.
[2] Strongman C. (2008) 'The Sustainable Home', Merrell, London, New York
[3] Environmental design, an introduction for architects and engineers, Edited by Randall Thomas, Max Fordham LLP
[4] A. Korjenic, T. Bednar, Developing a model for fibrous building materials, Energy and Buildings 43 (2011) 3189–3199.
[5] International Energy Agency (IEA) 2014), http://www.iea.org/topics/transport
[6] Roaf S., Fuentes m., Thomas s. (2001). "Ecohouse": A design guide; Architectural Press, Oxford
[7] https://stats.oecd.org/glossary/detail.asp?ID=2112
[8] Berge B. (2001). "Ecology of building materials", Architectural Press, Oxford
[9] https://stats.oecd.org/glossary/detail.asp?ID=2112

[10] http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=Notes