Economic and Technical Analysis of Renewable Resources and Natural Materials Through Advanced Technologies of Energy Performance Modernization

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ABSTRACT

Buildings are the main energy consumers and implementation of renewable energy sources is a priority measure for decreasing the costs of energy and greenhouse gas emissions. The purpose of the work is to analyze renewable energy sources integration in constructions sector, for evaluating economic and technical environment, some system performance regarding decreasing energy consumes for buildings, economic benefits and greenhouse gas emissions, decreasing emissions. In this way we compared four types of buildings with different structures, from different climates. There have been used four types of technologies for analyze: a building that have integrated in the envelope a solar system for warming the air (SAHS); a building that has included a natural packet of walls formed by a layer of straws and natural innovative plasters; a building that has included a fluorescent lighting system and an incandescent one, window glazing and glass wool, roof isolation using cellulose and mounting photovoltaic systems; a building where walls are isolated with expanded polystyrene of 10 cm, windows replaced by double glazing, ventilation system installation, solar panels and photovoltaic. The techniques used consist in determination of heat loss through walls, and fossil resources dependence. The results demonstrated that using the solution packet fossil resources addiction is reduced by 15%, heat loss through walls is reduced obtaining a heat recovery bigger than 9%. Net economy, investment savings ratio, adjusted internal rate of return, global cost was determined. The whole analysis brings important contributions to the field by using in projection activity of envelope-installation renewable sources and natural materials through advanced technologies that brings significant energy savings at competitive prices.

Keywords: energy efficiency in buildings, economy analysis, innovative insulating materials, renewable resources

1. INTRODUCTION

The energy and climate changing are connected because energy production happens mainly through burning and conversion of fossil resources. Consequently, for combating climate changing, firstly changes regarding production and using of renewable energy are necessary. Because greenhouse gas emissions are released mainly by using and producing energy, energy efficiency might have an important impact over decreasing these emissions. Also, energy efficiency decreases energy imports and saves contributor’s money. Energy efficiency was described as being the fastest and less expensive solution, addressing to economical and environmental challenges and energy security. Increasing the use of energy from renewable sources it’s essential for decreasing greenhouse gas emissions and also the consumers addiction for fossil resources [1].

One of the main energy consumers around the world it’s building field, especially when are located in severe climate conditions where energy and the needs for warming and cooling are very big. Implementing renewable energy sources in the buildings for reducing them, energy consumption and eventually fossil resource it is an important measure for reducing energy invoice costs and greenhouse gas emissions [2].

Energy consumption used for warming in a building must compensate the heat losses [3], heat losses are present in heating season, which in Romania lasts over 180 days per year. Heat loss occurs on elements that separate interiors from exteriors environments, which forms building envelope [4]. The value of the annual heat loss of the building is expressed using kWh/year or, depending of the usable living area in kWh/m^2 year. Heat produced by the warming systems must compensate heat losses and it is directly proportional with their value [5]. Energy consumption and operating costs of these systems are also dependent of this heat input. Therefore, reducing the heat loss of a building leads to a drastic reduction of the costs in heating energy consumption (such as gas, liquid or solid fuel or electricity) [6]. In the same time, negative effects over the environment associated with producing or using the energy from fossil fuels are decreased, especially greenhouse gas emissions. Primary energy consumption in a building, based on surface and expressed in kWh / m^2 per year, is inversely proportional to the insulation quality of buildings [7].

Nowadays, the most buildings from Romania are not insulated or have an inefficient insulation, situation that leads to bigger costs for warming and cooling needs and also, intense pollution of the environment. The objectives regarding greenhouse gas emissions consumption are promoting and producing energy from renewable resources and increasing energy efficiency in buildings [8].

Using renewable resources means reduced emissions or almost zero. Introducing renewable energy resources might assure a long term solution for energy need that we can give to the next generations, for a less polluted and resourcefully world.

Energy sources are technologies and materials used for obtaining different energy forms necessary for developing the society. Those come direct or indirect from the sun and involve the light, the heat and the wind.

Besides the fact that they have a positive impact over sustainable development, natural construction materials have also technical properties comparable with standard materials and important additional qualities. Natural and recycled materials have a remarkable lower impact over the environment than the materials produced in standard way [9].

Natural materials such as bale of straws and wood have substantially lower incorporated energy than processed materials, so their using in construction of building might give a valuable contribution in durability [10].

In this regard we compared four types of buildings located in different climates, with four different construction types for evaluating which of these has a more efficient energy performance.

Paraschiv in 2020 [1] analyzed a building constructed in 1975 that has no additional insulation, windows cover a significant surface and has no shadow during the day. It is a multy-family building with seven floors and 128 apartments. The building's wall that has been analyzed is oriented towards the equator, with a deviation of 20^o to west from normal direction and an available surface of 475 m^2 for installing the sun collector. Energy necessary for building its calculated for Galati climate, which its located in south-east of Romania.

Pazouki in 2021 [2] analyzed parts of an university building from Teheran. The building its P+6 floors, includes two different lightning systems, with relatively decreased efficiency. Because of the lack of insulation modernization and replacing the windows is taken to consideration. On the roof will e placed photovoltaic systems.

Fregonara in 2016 [11] analyzed a residential family building with two floors, located in Carmagnola (south Torino, north of Italy). The building, constructed in 1963 has a rectangular surface and includes two apartments, for a total surface of 204 m^2. A vertical extension has been made, obtaining a 3rd apartment on the building. Besides that, a lateral extension was made, so the apartments already existent were enlarged. Measures has been taken to insulate the exterior walls, replacing the windows with double glazing, there were installed controlled mechanical ventilation devices, solar and photovoltaic panels.

2. METHODOLOGY

2.1. Describing the study case building

In this study we analyzed a building located in the north-east side of Craiova, in the continental temperate climate perimeter. The building was built in 2021 with final destination of individual building with ground floor height regime, with concrete foundation, double joinery with a sheet of glass and a thermal insulating glass, exterior walls made of traditional materials (BCA walls having a thickness of 25 cm, polystyrene 10 cm and plasters of cement-chalk mortar) as seen in figure 1.

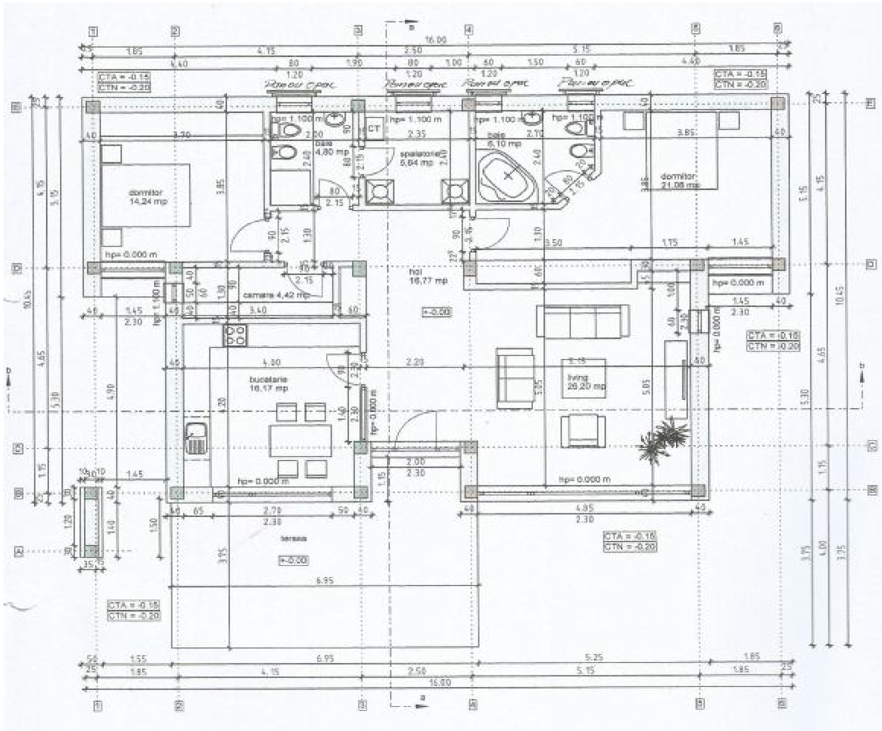


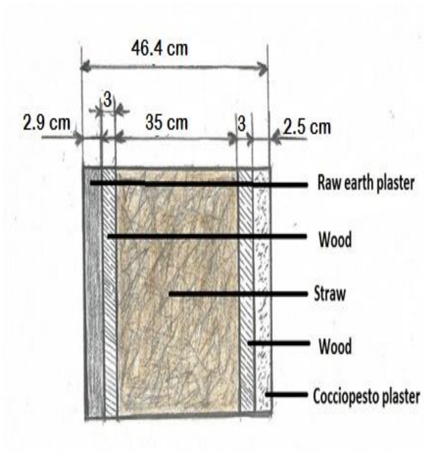
Fig.1. Ground floor plan

After an technical expertise, compared to conventional solutions, the building was investigated through Energy Performance Calculation Methodology of buildings elaborated for application of Law 372/2005. There were taken into consideration energy consumptions (warming, hot water, cooling, lightning and appliances) and data were taken from the simulation results.

For the disposal of high costs of warming/cooling and for disposal of high pollution of the environment and for improving the energy efficiency, the external traditional walls have been replaced with walls from natural materials (walls with multiple layers- straw wall –SW) formed from a layer of bale of straws and innovative natural plasters, offering a rational assessment of its using potential in sustainable construction of the building.

The potential of straw bale for wall package in energy efficiency was assessed by introducing the construction element in an already existing project of a building whose envelope was designed according to the norm regarding the thermotechnical calculation of the construction elements of the buildings, C107 / 3.

The economy potential analysis of the building provided with the new wall package was performed comparing its energy performance with the reference building. The innovative system SW was compared then with a traditional wall TW (fig.2 and fig 3) whose characteristics are shown in table 1 and table 2.



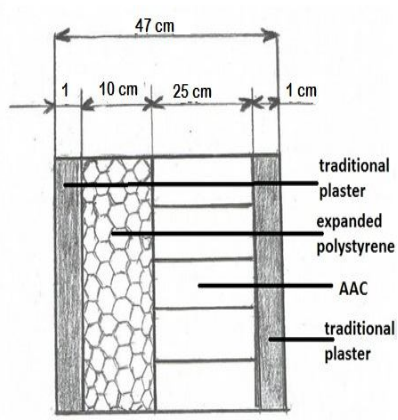


Fig.2. Straw bale walls **Fig. 3**. Traditional solution of the wall taken to consideration for comparison with the innovative system regarding environmental impact.

In table 1 and table 2 are presented the characteristics of materials used for AAC walls respectively bale straw walls.

Table 1. Traditional AAC wall characteristics

Layer (inside-outside)	Δ[m]	λ[W/mK]	R[m^{2}K/W]
Mortar chalk inside	**0.01**	**0.7**	**0.014**
AAC	**0.25**	**0.22**	**1.136**
Expanded polystyrene	**0.1**	**0.044**	**2.272**
Cement-chalk mortar	**0.01**	**0.87**	**0.011**

Table 2. Straw bales characteristics

Layer (inside-outside)	Δ[m]	λ[W/mK]	R[m^{2}K/W]
Exterior plaster brick + stone + chalk	**0.029**	**0.92**	**0.031**
Bale straw wall	**0.35**	**0.065**	**5.228**
Laminated fir wood	**0.03**	**0.089**	**0.337**
Raw soil interior plaster	**0.025**	**0.982**	**0.025**

Table 3 and 4 are a representation of primary energy and a CO_2 emissions of traditional wall and straw bales wall.

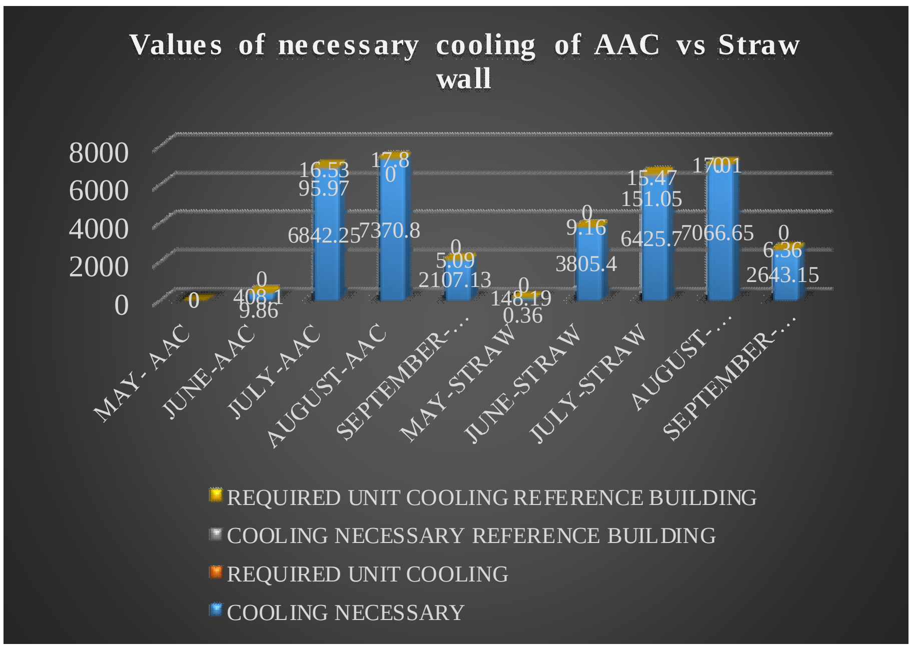
Table.3 Primary energy calculation and CO_2 emissions for AAC building

Utilities	Primary energy [KWh/m^{2}year]	Primary energy reference building [KWh/m^2 year]	CO_2 [Kg/m^2 year]	CO_2 Reference building[Kg/m^2 year]
Warming	**162.76**	**141.14**	**33.37**	**28.93**
Domestic hot water	**51.95**	**43.46**	**10.65**	**8.91**
Conditioning	**36.89**	**0.62**	**11.03**	**0.19**
Lighting	**31.7**	**31.7**	**9.48**	**9.48**

Table 4. Calculation of primary energy and CO_2 emissions in straw bales wall building

Utilities	Primary energy [KWh/m^2 year]	Primary energy reference building [KWh/m^2 year]	CO_2 Kg/m^2 year	CO_2Reference building [kg/m^2 year]
Warming	**129.96**	**108.04**	**26.5**	**22.22**
Domestic hot water	**51.77**	**43.31**	**10.61**	**8.88**
Conditioning	**36.15**	**0.16**	**10.81**	**0.05**
Lighting	**31.7**	**31.7**	**9.48**	**9.48**

The values of the necessary cooling of the traditional wall from AAC and of the wall from straw bales are represented in tables 5 and 6 and in graphic 1.



Graphic 1. Monthly delivered energy for heating and cooling, calculated per type of material

Table 5. Values of necessary cooling of AAC building

Month	Cooling necessary [KWh]	Required unit cooling [KWh/m^2]	Cooling necessary reference building [KWh]	Required unit cooling reference building [KWh/m^2]
MAY	**0**	**0**	**0**	**0**
JUNE	**408.1**	**9.86**	**0**	**0**
JULY	**6842.25**	**16.53**	**95.97**	**0**
AUGUST	**7370.8**	**17.8**	**0**	**0**
SEPTEMBER	**2107.13**	**5.09**	**0**	**0**

Table 6. Values of necessary cooling of straw bales wall building

Month	Cooling necessary [KWh]	Required unit cooling [KWh/m^2]	Cooling necessary reference building [KWh]	Required unit cooling reference building [KWh/m^2]
MAY	**148.19**	**0.36**	**0**	**0**
JUNE	**3805.4**	**9.16**	**0**	**0**
JULY	**6425.7**	**15.47**	**151.05**	**0**
AUGUST	**7066.65**	**17.01**	**0**	**0**
SEPTEMBER	**2643.15**	**6.36**	**0**	**0**

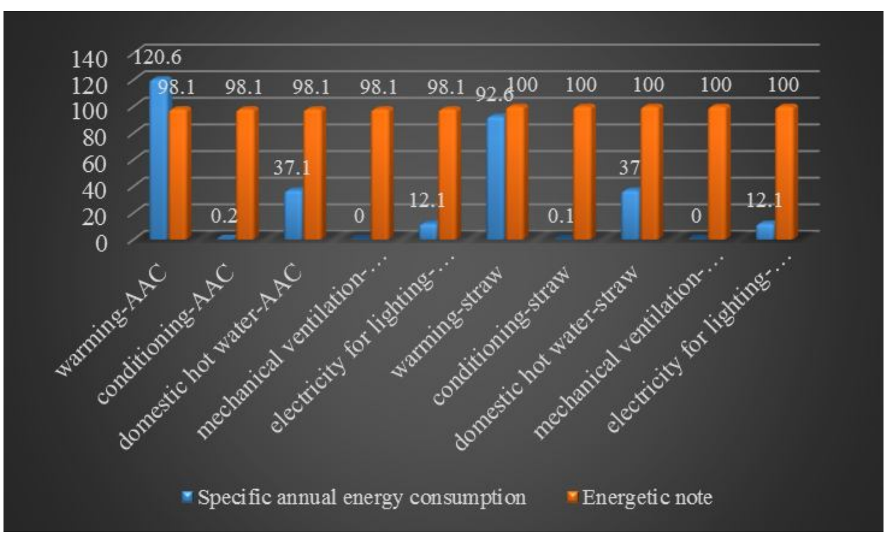
The values assigned annual consumption of energy can be seen in table 7 and 8 and graphic 2.

Table 7. Total energy consumption at the AAC walled building

Specific annual energy consumption [KWh/m^2 year] for		Energetic note
Warming	**120.6**	**98.1**
Conditioning	**0.2**	
Domestic hot water	**37.1**	
Mechanical ventilation	**-**	
Electricity for lighting	**12.1**	

Table 8. Total energy consumption at straw bales wall building

Specific annual energy consumption [KWh/m^2 year] for		Energetic note
Warming	**92.6**	**100**
Conditioning	**0.1**	
Domestic hot water	**37**	
Mechanical ventilation	**-**	
Electricity for lighting	**12.1**	



Graphic 2. Annual energy consumption and energetic note calculated per type of material

3. RESULT

Regarding the economic analysis, initial costs of traditional materials for the reference building were evaluated and the costs of the natural materials used for reduction of the initial cost for the investment or replacing costs, energy costs and maintenance costs.

For the execution of the traditional walls the data for construction materials are taken directly from the warehouse:

- AAC walls 0.25[m]=28.94[mc]=11457.06 RON;
- Mortar cement sand 0.02[m] = 444.518 RON;
- Expanded polystyrene 0.1[m]=115.77[mp]= 2766.903 RON;
- Mortar cement chalk 0.02[m] = 1904.58 RON (inside and outside plaster);
- Road transport of construction materials on a distance of 10[km]= 216.55 RON.

Total expenses: 168880.578 RON.

For the execution of the straw bales wall the data for construction materials are taken directly from the warehouse:

- Different dimensions of Straw bales, standard dimension being 458x900x350;
- A bale weights between 15-20 kilos, and the price its between 2 and 6 RON including transportation;
- Masonry from straw bales 0.35[m] = 771.81 RON;
- Raw soil interior plaster 0.025[m] =0 RON it is a natural source already existing near the building – prepared locally (water and soil);
- Outside plaster from chalk, sand and chopped straws 0.029[m] = 751.5 RON;
- Laminated fir wood 0.03[m]=6[mc]= 5.7885 RON;
- Road transport of construction materials on a medium distance of 10[km] = 40.205 RON

Total expenses: 6942.275 RON.

4. ANALYSIS

- It can be observed that energy efficiency of the implementation of the solar system installed on the Galati building's wall depends totally of weather conditions, maximum efficiency being 24,68% and minimum of 15,53%. The collected heat and provided by solar system does not cover the heat demand for whole building, therefore this energy difference must be covered by main warming system;
- The results of the study from Teheran show that external supports and the financial incentives affect significantly the profitability of the project, uncertainty of the data, that have been less taken into consideration regarding energy modernization studies, and has notable effects over choosing the decisions and investment strategy. The best strategy does not requires necessarily a huge investment, remarkable energy consumption improvements might be done with half of the maximum budget, which is also the optimum value most of the times.
- The interventions over Torino building lead to an energy performance class A and the investment has been huge from two reasons:
    - Using more technologies;
    - The costs have a negative impact regarding economic indicators.

Natural materials win more and more space as a construction materials thanks to their thermal characteristics and durability.

In this area, straw bale wall and natural plasters has been characterized by its thermal behavior and the impact over the environment. In the winter the straw bales have the capacity of heat accumulation and during the summer they keep a cool temperature comparative with AAC wall, as can be seen in the table 5 and 6.

Following the simulation realized with Methodology for calculating the Energy Performance of buildings developed according to Law 372/2005 applied to the new wall SW and to the traditional wall TW it has been shown the primary energy consumption of 162,76 for the AAC wall and for the bale straw a primary energy consumption of 129,26 [KWH/m^2] and a CO_2 emissions of 64.529 [kg/m^2an] for AAC wall and 57,42[kg/m^2an] for straw bale wall. The straw bales wall has a better performance than traditional wall. The energy delivered by cooling for straw bale wall it is bigger than the traditional wall. It can be seen in table 5 and 6 the bigger insulating performance for straw in relation to polyestyrene.

5. CONCLUSIONS

In this article it is suggested a general view over the decision making regarding modernization of the energy of the building by adding new efficient facilities or replacing the not efficient ones with better ones available on the market.

Modernization of a house was addressed through an analyze based on energy efficiency and related costs.

A building made of traditional materials (expanded polystyrene, AAC, cement-chalk mortar) and replacing these with natural materials (such as straw bales, mortar, brick stone chalk, solid ground plasters, laminated fir wood)

All the interventions let to an A energy performance class , and economic analyze that was made presented a different cost for each solution as following:

- For traditional walls- total expenses: 168880.578 RON;
- For straw bales walls – total expenses: 6942.275 RON.

The results demonstrated that using the solution package the fossil fuels addiction is reduced by over 15%, the heat loss of the building through walls is reduced, obtaining a heat recovery bigger than 9%.

Besides economic benefits, the paperwork highlights also the benefits for the environment, meaning reduction of CO_2 emission.

Classification of the building in the A, B or C energy class shows that it is well insulated, has low loss of energy for warming, cooling, ventilation, domestic hot water preparation and lightning. In our case, the straw bale walls it is more energy efficient than the one with AAC walls.

Besides the fact that have a positive impact over durable development, natural construction materials have also technical properties similar with standard materials and important additional qualities.

In this way, a new straw bale wall and natural plasters has been characterized through evaluating its thermal behavior and its impact over the environment.

The straw bale wall was used as a construction material on this study case and the simulation showed a better energy performance than the defined reference building.

After the economical analysis had been made, between the straw bale wall building and the AAC wall building a difference of 9938.303 RON resulted.

The innovative wall seems promising for being used in construction both in terms of energy savings and also for the impact over the environment.

Concluding, it is worth to highlight the fact that the purpose of the article its not to find an exemplary project but to delimit an instrument for sustaining the design activities. Innovative scenarios and natural materials that were presented allow testing a working approach useful for the interventions on the built good and especially over the buildings. Moreover, it is important to highlight that the real estate building is deeply influenced by energy performance and the exploitation costs of the assets; meanwhile, the environment problems influenced the technologies and consequently production over the construction field.

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