COMPARISON OF WOODEN AND CONVENTIONAL HOUSES SUSTAINABILITY: INCREASING APPLICATION OF MODIFIED WOOD IN R. OF MACEDONIA

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The residential sector in Republic of Macedonia, situated in South-East Europe, is responsible for the consumption of significant amounts of resources and for the production of large amount of emissions and waste. The increased application of wood products can substantially improve these conditions and contribute towards increasing the sustainability in the construction industry and the creation of sustainable homes. The contribution of this paper is the simulation of four different alternatives of residential buildings in the Republic of Macedonia, evaluated in terms of energy performance and Life-Cycle Assessment (LCA) for the "cradle to gate" phase. The results of this study revealed that by replacing conventional concrete and masonry constructions with wooden constructions in low-rise family houses, the carbon emissions can be reduced up to 145%. The contribution of this paper is the simulation and analysis of the energy performance by using Building Performance Simulation (BPS) tools and Life-Cycle Assessment of a residential building and its optimization through several models. The results give significant insight on the influence that the different construction materials have on the environment and buildings performance. Also, the research enables stimulation of the construction industry in utilizing wooden structures and delivering legislation that could increase their use. These actions would provide means for the development of sustainable buildings, neighborhoods and sustainable development of the Republic of Macedonia.

Key words*: sustainability, Life-Cycle Assessment, energy performance, building simulation performance, residential buildings,* CO_2 *emissions.*

1. Introduction

The construction industry as a resource intensive industry is one of the main contributors to the climate changes, participating with 50% of resources depletion, 40% of the energy consumption etc. [1]. Most of the existing buildings are planned and constructed in an unsustainable manner and are held responsible for nearly 40% of the global energy consumption and approximately 36% of the total carbon dioxide emissions [2]. The carbon emissions occur during the buildings' life cycle, starting from the production of building materials, building construction, use and demolition. Therefore, the materials used in construction is of utmost importance, as they represent more than 50% of the embodied energy in buildings [3].

The use of wood in building construction has been a characteristic for the vernacular architecture in R. of Macedonia [4], and suppressed by the advent of the concrete structures as well as the city-fires which have occurred in the last centuries [5]. However, in the recent decades there is a significant scientific research and policy promulgation regarding implementation of the concept of sustainability in buildings and improving their performance. Hence, the use of wood and wooden products regain their importance and increased application, due to their large potential for improving the overall sustainability of the buildings and their environmental friendly characteristics. Also, the wood has a significant role in mitigation of the greenhouse effect [6]. Accompanied with the advancement of the wood modification technologies, the wooden products offer new possibilities for improvement of the buildings and the effects from such application need to be assessed.

In the common construction practice in R. of Macedonia, reinforced concrete (RC) structures and masonry walls are generally used. The residential stock hold in the country is the largest consumer of energy and they account for 36% of the total electrical energy consumption from which 71% of the total amount is used for heating and cooling [7]. In order to mitigate this situation and to improve the buildings sustainability the government puts its efforts for reduction of their energy demands by 20% until 2020 [8].

In order to tackle these conditions in the construction, the concept of sustainability is introduced, which means reducing the adverse impact onto the environment by control of the exploitation of resources, considering the human wellbeing and health, the economic and the social circumstances as well. With the Energy Performance of Buildings Directive (EPBD) (2010/31/EU) it is defined that by the end of 2020 (2018 for public buildings) all new constructions should be “nearly Zero Energy Buildings” (n-ZEBs) [9]. For achieving this aim, two strategies are proposed in general, such as: to reduce the energy demand within the building and to provide the energy demand by means of on-site renewable energy sources [10]. Therefore, the construction of sustainable buildings is of great importance for future sustainable development of humanity which inquires meeting the basic needs of all people and extending the opportunities for environmental, economic and social advancement. Authors stress the need for holistic design of the building elements and structure of the building thus taking into consideration multitude of sustainable aspects, such as: energy performance, LCA, Life-Cycle Costs, comfort, visual aspects, ambient values etc. [11], as well as the necessity of managing the design process in a sustainable manner in order to produce more sustainable building design [12].

The aim of this research is to compare wooden structures versus conventional masonry and concrete elements, regarding their influence onto buildings' energy performance and life cycle emissions. For that reason several software models of a single-family house are developed, made of different types of masonry, concrete, wooden and modified-wood products and tested in terms of energy performance and Life-Cycle Analysis (LCA). The research is focused on the residential sector as it has the largest share in consumption of material and energy resources. In the models, the different materials are applied to the buildings’ envelope as one of the main contributors to the buildings’ energy consumption and environmental impact, as well as to the load-bearing elements of the building.

2. Review of modified-wood and modification technologies and their use in Macedonia

The application potential of wooden products and modified wood elements in different building typologies as well as buildings elements is made by several authors. Authors have investigated wood in terms of refurbishing historic buildings and improving the buildings performance [13]. The wood has been extensively used as a primary construction material in the vernacular architecture in Macedonia until the middle of the 20th century.

However, in the modern construction practice in the country, the wood and its sustainable properties, has been neglected on the account of masonry and concrete construction. One of the reasons is that, since the expansion of the residential sector in R. of Macedonia, after the disastrous earthquake of 1963, there was an urgent need of fast production of residential units. A lot of new neighborhoods were planned which are comprised of different building typologies. Certain neighborhoods that were planned with low-rise buildings, have been constructed from prefabricated wooden elements or from lightweight panels of porous concrete. The majority of the new city areas were planned with mid-rise and high-rise buildings and due to the high seismic activity of the country were designed in reinforced concrete. This trend of construction is kept until today.

Also, another issue for not using wood in residential buildings nowadays is not taking enough care of the quality of the forests and the wood although there are efforts to certify the forests. The territory of Republic of Macedonia that's under forests is 988,835 ha, of which 82% are deciduous, 12% are coniferous and 6% are mixed forests [14]. The total wooden mass is 74,343,000 m^3, with an annual growth of 1,830,000 m^3, *i.e.* 2,02 m^3 per hectare [14]. The planned cuttable etat is around 1,300,000 m^3, 70% of it is used, and 80-85% is used as firewood. Although the country has a large forestry potential there are several factors that influence the low use of wood in construction, such as: low quality of the wooden mass beacuseof which most of it is used as a firewood and not as technical wood, lack of modern equipment and automatization systems etc.

2.1. Overview of modified wood technologies

With the advancement of the technology new possibilities emerged in a sense of improving the woods' characteristics and producing a new subtype of construction material - modified wood. The most accepted definition of modified wood is given by Hill [15], according to which "*wood modification involves the action of a chemical, biological or physical agent upon the material, resulting in a desired property enhancement during the service life of the modified wood. The modified wood should itself be nontoxic under service conditions, and furthermore, there should be no release of any toxic substances during service, or at end of life, following disposal or recycling of the modified wood. If the modification is intended for improved resistance to biological attack, then the mode of action should be non-biocidal*". The renewed interest for modified wood in the recent decades is due to the: awareness of the outstanding properties of rare species, restrictions in using environmentally hazardous chemicals, EU policies etc. [16].

There are mainly four main types of processes used for wood modification, such as [16]: chemical treatments; thermo-hydro (TH) and thermo-hydro-mechanical treatments; treatments based on biological processes; physical treatment with the use of electromagnetic irradiation or plasma.

The chemical modification involves the reaction of chemical groups on the wood polymers with the modification agent, such that new groups are formed and bonded directly to the wood polymers themselves. There are several types of chemical reactions which are not suitable for application due to the: potentially toxic reagents, need for solvents (anhydrides, epoxides, alkyl halides, aldehydes etc.), limited or temporary property improvements etc. [15]. Acetylation is an exception, however it does not alter the fire-resistance of the wood [17], and when placed outdoors the growth of fungi and mold change its color to give a typical weathered look [15]. The most common type of wood modified by acetylation is branded as Accoya, produced by Accys Chemicals PLC [18]. Impregnation is a passive modification process, *i.e.* impregnation of the cell wall of wood with certain chemicals in way in which it reacts and forms a materials which is "locked" into the wall of the cell [15]. Furfurylation is chemical modification which is considered safe for the environment [19]. It is a process in which the wood is treated with furfuryl alcohol and one such commercial product is Kebony [20].

The process of thermal modification means heating the wood to high temperatures of 170°C and above in the absence of oxygen in order to prevent the wood from catching fire. The exclusion of air/oxygen from the system could be achieved by using a steam or nitrogen atmosphere in the kiln or by immersion of the wood in hot oil [21]. The thermal modification is a relatively low-cost process which is dependent on the energy prices, there are no chemicals added, and can be applied to different species of wood, both on softwood and hardwood, with certain optimizations of the process as they require different treatment [21]. One of the most common thermal modified processes is ThermoWood process, which is a Finnish developed technology that uses specially designed high-temperature wood drying kiln and a steam atmosphere during a high temperature phase. Several studies show the increase of the dimensional stability of wood treated with ThermoWood process [22], other studies accent the behavior of different types of wood subjected to this process, regarding their modulus of elasticity, rupture and hardness [23]. Production companies state the decrease of thermal conductivity of ThermoWood by 20-25% compared to untreated coniferous tree [24]. Due to the need to protect the environment and to the promulgation of legislative in that direction several non-biocide alternatives are developed which are predicted to become more important in the next decades [19].

The wood-water interaction is examined by several authors [25], and others conclude that higher the treatment temperature and the longer the treatment time, the lower the amount of absorbed water [26]. It is shown that heat treatment decreases the water absorption of spruce and pine heartwood specimens, however pine sapwood heat-treated at temperatures below 230°C revealed higher water absorption [27]. Hakkou et al. [28] found that heat-treated wood specimens have lower wettability.

Considering that wood is a fire-risk material, in R. of Macedonia the design of timber structures and their performance under fire are calculated according to the standards МКС EN 1995-1-2:2004/AC, МКС EN 1995-1-:2012, where its fire resistance is defined in relation to the building type.

3. Methodology and analysis

In this research a software simulation is performed on several models of a single-family building. The aim is to analyse the influence of construction materials onto the Life-Cycle performance and energy performance of the alternative models. The influence of the use of concrete, masonry, wood elements and modified wood products onto the improvement of the buildings' sustainability is of special interest.

The Life-Cycle Assessment (LCA) is a methodology standardized with ISO 14040 and ISO 14044 used to assess environmental impact of a product through its Life-Cycle, measured through a set of indicators. Hence, the indicators used in this research are: Global Warming Potential (GWP) that measures the carbon dioxide and methane emissions; Ozone Depletion Potential (ODP) that measures emissions of chemicals or substances that deplete the stratospheric ozone layer such as: CFCs, halons, methyl chloroform, carbon tetrachloride hydrochlorofluorocarbons (HCFCs) and methyl bromide; Acidification Potential (AP) that measures emissions that cause acidifying effects to the environment; Eutrophication Potential (EP) that measures the potential impact onto undesirable shift on aquatic and terrestrial ecosystems; Photochemical Ozone Creation Potential (POCP) - Smog, measures the emissions of precursors that contribute to the formation of ground level smog; Abiotic Depletion Potential (ADP) describes the consumption of non-renewable resources, which are described separately for the depletion of mineral resource elements (ADPE) and non-renewable fossil energy resources (ADPF).

According to the standard EN 15978, the building's life cycle is divided in several phases, such as: Product phase, Process phase, Use phase, End of life phase and Gains and Loads phase. Due to the lack of data for the construction materials for all of the phases, in this study only the data for the Product phase from the life cycle of the material are analyzed, a phase referred to as "cradle to gate". The mechanisms that triggers the forementioned emissions in the cradle to gate phase are related to the extraction pokes and the type of raw material, transportation and manufacturing process.

The case-study selected for this research is a single-family residential building in Skopje, the capitol of Republic of Macedonia, designed by the architecture design office MDC Architectonica [29]. The building is a part of a four-house city block, consisted of a ground floor and 1^{st} floor and is designed with a reinforced concrete load-bearing structure Fig. 1.

a. b.

c. d. e.

Figure 1. Case-study of residential building a. Views of the building b. perspective view c. ground-floor plan d. 1^{st} floor plan e. section of the building [29]

The chosen four-house block is a common typology in several neighborhoods with single-family residential in Skopje, built after the 1963 earthquake. Also, in the rebuilding of the city other building typologies are used for multi-family housing such as residential tower and block building, which are not considered in this paper.

In order to examine the influence of the choice of materials onto the energy performance and LCA, several different types of materials are used for the same construction element Tab.1. For the load-bearing structure are proposed two types, such as the conventional reinforced concrete and the wooden framing.

Table 1. Building component types and their characteristics

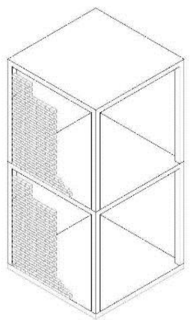
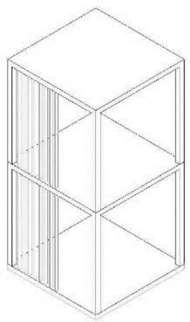
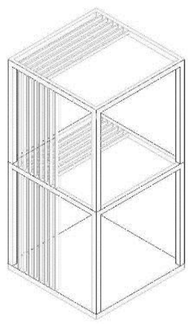
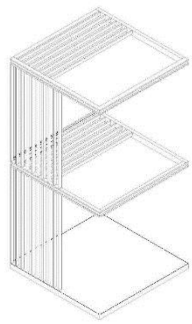
Construction	Type 1	Type 2	Type 3
Load-bearing structure	Reinforced concrete (RC)	Wooden framing (WF)	
External Wall (U-value)	EW1 - ETICS façade acrylic mortar 1 cm, EPS 10 cm, Ytong block 20 cm, Interior mortar 1.5 cm, smooth coating, acrylic paint U = 0.239 W/m^{2}K	EW2 - Kebony, wooden batting 2*2.5 cm, waterproof membrane, rockwool 5 cm, OSB board 2.4 cm, wooden framing 10 cm, glasswool 10 cm, vapor retardant membrane, gypsum board 2*1.25 cm, smooth coating, acrylic paint U = 0.220 W/m^{2}K	EW3 - façade mortar, rockwool 5 cm, OSB board 2.4 cm, wooden framing 10 cm, glasswool 10 cm, vapor retardant, gypsum board 2*1.25 cm, smooth coating, acrylic paint U = 0.220 W/m^{2}K
Internal Walls (U-value)	IW1 - acrylic paint, smooth coating and mortar 1.5 cm (double sided), Ytong block 12 cm	IW2 - acrylic paint, smooth coating and gypsum board 1.25 cm (double sided), timber framing 10 cm.	
Floor and slab (U-value)	F1 - oak flooring 2.5 cm, floor glue, cement screed 4 cm, EPS 2 cm, RC slab 14 cm, interior mortar 1.5 cm, acrylic paint U=1.071 W/m^{2}K	F2 - oak flooring 2.5 cm, expanded cork 1 cm, OSB board 2.4 cm, wooden framing 14 cm, rock wool 5 cm, wooden board 2.4 cm. U=0.518 W/m^{2}K	
Roof (U-value)	R1 - ceramic tiles 0.5 cm, hydro isolation, cement screed 10 cm, XPS 15 cm, vapor barrier, RC slab 14 cm, interior mortar 1.5 cm, smooth coating, acrylic paint U=0.222 W/m^{2}K	R2 - ceramic tiles, sand 5 cm, hydro isolation XPS 15 cm, vapor barrier, OSB board 2*2.4 cm, wooden framing 14 cm, rock wool 10 cm, wooden board 2.5 cm U=0.130 W/m^{2}K	
Glazing (U-value)	Double glazed Low-E Glass U=1.4 W/m^{2}K		

Three types of external walls are used in the analysis, where the type EW1 represents the most common wall type used in the construction nowadays made of lightweight porous masonry and ETICS (External Thermal Insulation Composite System) façade system. The second type - EW2, is a dry construction wall made of wooden framing and structural ventilated façade with an outside leaf of Kebony modified wood. Type 3 - EW3, is a combination of a wooden framing and ETICS system on the outside. The internal wall types are: IW1 made of conventional masonry with wet type of interior finish with mortar and IW2 made of dry construction with wooden framing and gypsum boards. The floors being analyzed are F1 which consists of reinforced concrete (RC) slab and floating floor made of cement screed, while the other type, F2 is considered as dry type of structure, made of wooden framing and prefabricated floor boards. Concerning the roof, there are two types, where R1 is a wet type of structure, while R2 is a dry type of structure with an extensive vegetation on the top. The glazing being used in the alternative models is double glazing 4+16+4, with a low-emissivity glass (Low-E Glass), as a most common type being used in the construction in the country.

Other types of glazing are not being considered due to the fact that they would significantly influence the energy performance of the building and the influence of the opaque structure could not be assessed. The heat transmission coefficients of the elements are calculated according to the Macedonian harmonized standards MKS EN ISO 6946 and MKS EN ISO 13370 and they comply with the prescribed values for each of the construction elements, [30].

For the purpose of this research the designed building is analyzed as Model 1 and three additional models are created Model 2, Model 3 and Model 4 (Table 2) created with the combination of the building constructions shown in Table 1. Therefore, total of four different of alternative models of the r building are assessed (Table 2).

Table 2. Building constructions used in the models

	Model 1	**Model 2**	**Model 3**	**Model 4**
Load bearing Structure	RC foundations, basement wall, columns, beams and slab 	RC foundations, basement wall, columns, beams and slab 	RC foundations, basement wall, columns and beams 	RC foundations, basement wall, Wooden framing (WF) 
Internal wall - IW	IW 1	IW 2	IW 2	IW 2
External wall - EW	EW 1	EW 2	EW 2	EW 3
Floor	F1	F1	F2	F2
Roof	R1	R1	R2	R2

The Model 1 is made of reinforced concrete load-bearing structure and masonry for the internal and external walls. The Model 2 is made of concrete load-bearing structure with wooden-framed internal and external walls. In Model 3 the columns and beams are made of reinforced concrete, while the slabs, internal and external walls are made of wooden framing studs, while in Model 4, the load-bearing as well as non-load bearing elements are made of wooden framing studs, Tab. 2.

The data for the materials are derived either from the manufacturers Environmental Product Declarations (EPD) or from the database ÖKOBAUDAT [31], which is compliant with the ISO 14025 and EN 15804. The data from the EPD's which are used in this research are extracted for the phase "cradle to gate", which is a partial assessment of a products life cycle. It considers the resource extraction (cradle) and ending with the the factory gate phase, before the transportation of the material to the construction site or the consumer. Thus, the use phase and disposal phase of the product are omitted in such an assessment. In the cradle to gate phase the embodied CO_2 emissions are calculated as well as the other pollutants defined with the standards ISO 14040 and ISO 14044. The bill of quantities of the materials are obtained from the design office of the residential building and is used for calculating the total emissions in the phase "cradle to gate". Hence, the total amount of emissions in the cradle to gate phase for each building component is calculated as a sum of the emissions of its constituent materials, for which EPD declarations and OKOBAU data are used.

The energy performance of the described models is completed by using the EnergyPlus energy Simulation software [32], and the final energy demand has been calculated. For the purposes of this research, the owner of the building has provided the schedules for using it during the day and throughout the year, also considering the period of vacations. The data used for model calculations is design climate data for the city of Skopje, Tab. 3, and typical meteorological year (file type TMY3) for conducting dynamic simulations (buildings dynamic behavior study). The weather file and climatic data is obtained through METEONORM [33], which is a meteorological database using calculation procedures for climatic data at any location in the world. Additionally, it needs to be commented that according to the Rulebook of energy characteristics of the buildings the Cooling Degree Days are not defined [30]. The infiltration rate is calculated according to the Rulebook of energy characteristics of the buildings in R. of Macedonia [30], and is constant for all of the analyzed models.

Table 3. Climatic and interior conditions for Skopje used in the calculations [30]

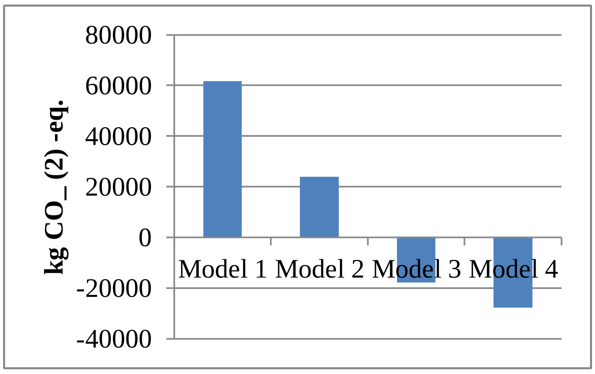
Latitude	Longitude	Altitude	Cooling temp.	Heating temp.	Heating Degree Days	Infiltration
42.0º	21.47º	325 m	26ºC	20ºC	2.536	0.5 per hour

4. Results and discussion

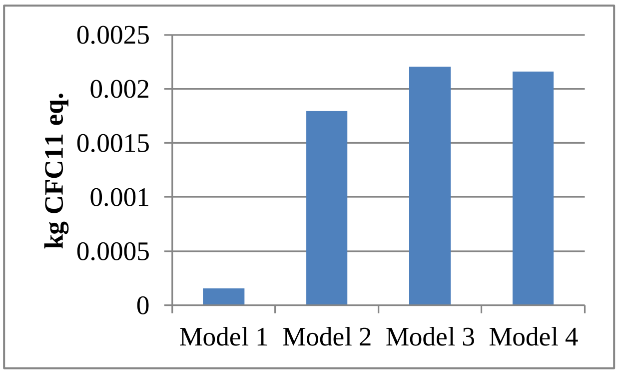
4.1. Life-Cycle Assessment of the models

The results from the conducted LCA of the four models according to the types of emissions is shown in Fig. 4. From the comparison of the Global Warming Potential (GWP) emissions it could be concluded that Model 2 has 61% less emissions when compared to Model 1, Model 3 has 130% less emissions compared to Model 1 and Model 4 has 145% less GWP emissions, Fig. 2.a.

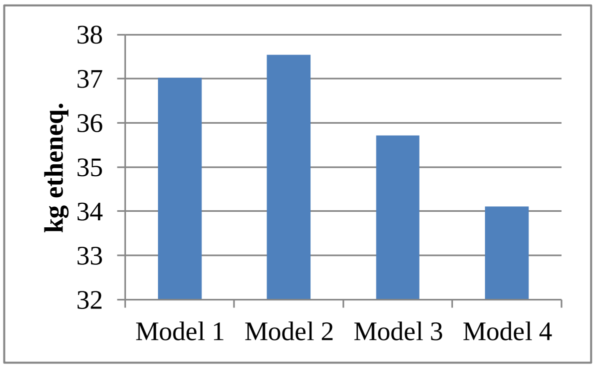
From the results of the Global Warming Potential (GWP) of Model 1 it can be concluded that the largest share of the CO_2 emissions from the materials in the "cradle to gate" phase is from the concrete, amounting over 60%. In Model 2, with the introduction of the internal (IW1) and external wooden walls (EW2, EW3) there is a negative CO_2 emission for 30%. With the placement of wooden frame slab, instead of a concrete one in Model 3, the negative emissions of CO_2 are up to 59%. In Model 4, the negative emissions of CO_2 from the Interior Wall 2, Exterior Wall 3, Floor 2 and Roof 2, amounts to 65%, Fig. 2.a.

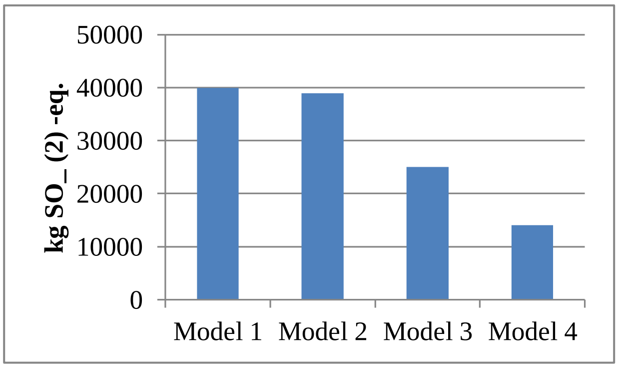


a) GWP emissions

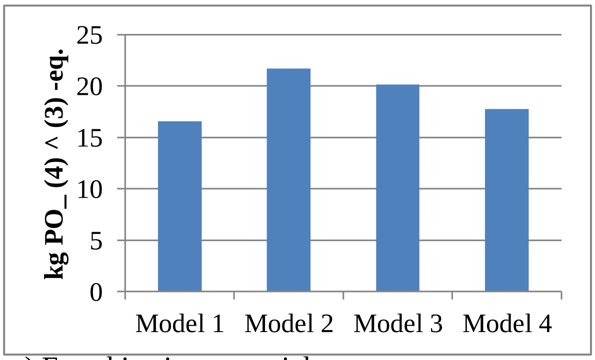


b) ODP emissions

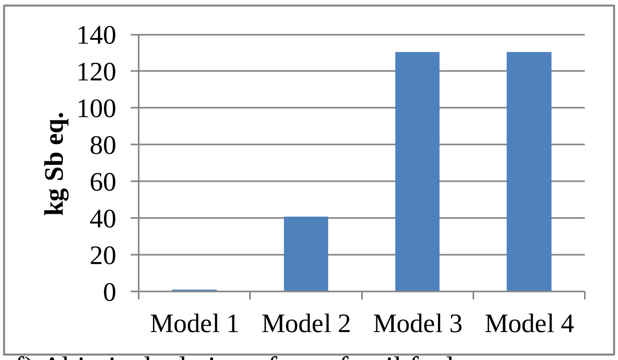




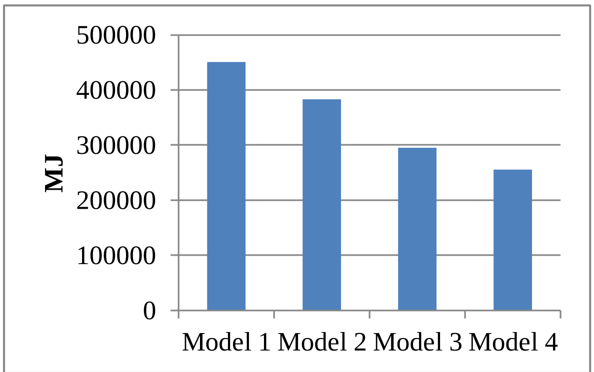
c) Educational potential for Photochemical ozone (POCP) d) Acidificaton potential



e) Eutrphication potential



f) Abiotic depletion of non-fossil fuel resources



g) Abiotic depletion of fossil fuel resources

Figure 2. Comparison of Life-Cycle Assessment (LCA) results of the four models

The Ozone Depletion Potential (ODP) emissions are slightly larger in Model 2 due to the waterproof membrane and the Kebony product in External wall 2, while in Model 3 the increase is due to the larger values of the OSB and wooden boards in the Floor 2, Fig. 2.b.

The Photochemical Ozone Creation Potential (POCP) emissions is 1% larger in Model 2, when compared to Model 1, while the difference between Model 3 and Model 1 is 4%, and Model 4 and Model 1 is 8% less in favor of the prior model, Fig. 2.c. The Acidification potential between Model 2 and Model 1 is 3%, between Model 3 and Model 1 is 41% and between Model 4 and Model 1 is 65% less in favor of the Model 1, Fig. 2.d. The difference in the Eutrophication Potential varies from 7-31% less in favor of Model 1 when compared to the other three models, Fig. 2.e.

There is a significant difference in the consumption of non-fossil fuels, meaning that the production of materials based on wood is more oriented towards using this type of resources. On the contrary, the consumption of fossil fuels is largest in Model 1 and Model 2, which are mostly based on reinforced concrete, whose production is mostly based on non-renewable resources, Fig. 2.f. Hence, the depletion of fossil fuels in Model 2 i 15% less than in Model 1, Model 3 has 35% less demand compared to Model 1 and Model 4 has 43% less depletion of fossil fuels compared to Model 1, Fig. 2.g.

4.2. Energy performance assessment of the models

The models are placed in the area of Skopje, which belongs to the Second climatic zone in Macedonia, has 2.536 Heating Degree Days (HDD) and the climatic data for the region are inputted in EnergyPlus (Table 2). The interior project temperature in the simulation is 22ºC. Because of the different types of construction elements, such as the masonry, which has a high thermal mass, and the wooden framing which has a lower thermal mass, the lag effect can also affect the energy used for heating, dependent of the climatic region and the insulation. The results from the energy analysis of the existing residential building, Model 1, and the proposed alternatives for improvement of the energy and LCA performance, such as the Model 2, 3 and 4 are shown in Tab. 4.

Table 4. Energy performance results

kWh/m^{2}year	Model 1	Model 2	Model 3	Model 4
Heating energy demand	41.2	33.4	26.4	26.4
Cooling energy demand	15.0	12.1	9.7	9.7
Lighting	4.2	4.2	4.2	4.2
Appliances	18.1	18.1	18.1	18.1
Hot water system	6.3	6.3	6.3	6.3
Yearly energy consumption	84.8	74.1	64.7	64.7
Number of PV's needed	47	41	36	36

It is noticeable that Model 2 compared to Model 1 has 13% less energy demand while both Model 3 and Model 4, due to their same thermal properties, outperform Model 1 by 24%. Regarding the heating energy, Model 2 has l9% less energy demand compared to Model 1, while Model 3 and Model 4 have 36% heating energy demand compared to Model 1. The cooling energy demand in Model 2 is 23% less compared to Model 1, while Model 3 and Model 4 have 35% less cooling energy demand compared to Model 1. It is concluded that the largest savings in the alternative models are in the heating energy demand because there are more heating days than cooling days.

The higher energy performance of Model 3 and Model 4 is because of the possibility for insertion of thermal insulation between the wooden studs of the lightweight walls and slabs. Besides, due to the lower thickness of the façade walls EW2 and EW3 compared to façade wall EW1, the alternative models that use the wooden wall systems provide larger usable area in the residential building, thus increasing its value.

In the area of Skopje, every neighborhood has different types of heating systems. In certain areas, especially the central ones, have up to 95.6% coverage by central heating. In other parts of the city the most common heating types are firewood and electrical energy, while in a smaller percentage coal, natural gas and light oil for households are used [34].

Filkoski et al. [34], conclude that in the case of a city block with four buildings, such as the reference model used in this research, justified heating types in terms of techno-economic optimum are the: central hot-water heating system, individual heating with inverter air conditioners (which offer lower quality thermal comfort and cannot adapt to a centralized heat supply) and heating with heat pumps [34]. Due to the fact that each of the heating systems has different CO_2 emissions and primary energy conversion, further research is needed to have an insight on how much the operational energy contributes to the CO_2 emissions compared to the embodied CO_2 emissions of the materials.

Further, in order to improve the buildings' sustainability integration of photovoltaic (PV) modules is proposed. Studies on the potential of solar electricity generation in the European Union member states and candidate countries shows that PV can already provide a significant contribution to a mixed renewable energy portfolio [35]. Photovoltaic energy power systems take place as the most dominant source among renewable energy technologies [36] and an extensive review of the factors affecting operation and efficiency of photovoltaic is conducted [37]. However, as it is noted, PV`s can contribute towards significant lifecycle carbon emissions and this fact should be considered in the overall emissions of the building [38].

The PV's are positioned on the top of the flat roof of the building. The chosen photovoltaic is the model Samsung LPC250SM, with dimensions 1.63/0.982 m, with an active area of 1.60 m^2 per module [39]. It generates nominal power of 0.25kW per module, *i.e.* 0.156 kW/m^2. Taking into consideration the surface of the roof, it is possible to place 42 panels, with a total area of 67.2 m^2, enabling production of 10.5kW, or 6.552 kW/m^2. Therefore in case of the existing building, Model 1, it is not possible to fully satisfy the energy demands of the building. In case of Model 2 and especially in Model 3 and Model 4, the energy demands could be covered by the energy production of the PV's in dependence to the weather conditions, Tab. 4.

However, there is an energy surplus during the summer months which could be either stored in batteries, such as Tesla PowerWall, for which an economical viability assessment needs to be made, considering their cost. The other options is to return the energy surplus to the electricity grid, however this option is not legislatively regulated in the country. Also, during the winter months there is a lack of energy needed for heating, which can be resolved by increasing the number of PV modules. Further analysis needs to be made regarding the energy produced from the PV in accordance to the site conditions of the analyzed model as well as their economic viability.

Additionally, regarding lowering the energy load in a residential building, authors [40] state the importance of the behavior of the building occupants. It has been stated that the type of heating system has a significant part regarding the energy performance of the building as well as the economic viability [41]. These aspects emphasize the need for informing and educating the users in terms of building use, its operation and maintenance.

5. Conclusions

In this study a comparison is made between software models of a single-family house in order to examine the influence of the choice of materials onto the energy and Life-Cycle Assessment (LCA) performance. The simulation has been conducted for the existing building and for three other models, each consisted of different construction materials such as: reinforced concrete, wooden-framing systems and masonry. The focus of the analysis is to investigate how the implementation of wooden products and modified wood can increase the buildings performance and overall sustainability.

It is concluded that the models with wooden and modified wood products, with regard to energy efficiency and LCA, significantly outperform the conventional buildings made of concrete and masonry constructions. The CO_2 emissions in Model 2, which has reinforced concrete (RC) load bearing structure and wooden framed walls, are decreased by 61%, compared to Model 1 which has reinforced concrete load bearing structure and masonry walls. The CO_2 emissions in Model 3 which has reinforced concrete columns and beams and wooden walls and slabs has 130% less CO_2 emissions compared to Model 1. The CO_2 emissions in Model 4 which has wooden load bearing structure and walls are decreased by 145% compared to Model 1. Therefore, the choice of materials significantly contribute towards lowering the embodied carbon emissions of the building.

This study also stresses the need to assess the buildings environmental impact during its design phase and emphasizes the importance of choosing sustainable materials. Therefore, it is necessary to utilize the Life-Cycle Assessment (LCA) method during the design stage that can assist the architects during the decision making process. Conducting a full Life-Cycle Assessment (LCA) of a product is a costly, time-consuming and a highly specialized task with which most of the architects are not familiarized with. Therefore, the use of generic data, Environmental Product Declarations (EPDs) and available databases could significantly alleviate this process.

Also, by having in mind the tendency for creation of nZEB's in the following decade, that is, by decreasing the operative energy demand, the embodied energy becomes more important, emphasizing the importance on using sustainable construction materials. Also, by decreasing the operating energy in Model 3 and Model 4 it is possible to fully satisfy the demand by installing photovoltaics (PV's) on the buildings flat roof and thus offsetting the CO_2 emissions that occur during the buildings occupation, contributing towards creation of carbon free building.

This study contributes to the creation of knowledge regarding the use of wood and modified wood components in the residential buildings. It arguments the need for higher acceptance of wood and modified wood products among architects and constructors and the findings confirm the need for increased use of wooden and modified wood elements in residential buildings. The chosen model for a residential building is a representative example of a larger neighborhood of family houses, thus accenting the importance of this study for a wider application of the findings from the research towards the improvement of the sustainability of a city area and creation of sustainable communities.

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