MODIFIED WOOD PRODUCTS FOR SUSTAINABLE HOUSING BUILDINGS IN R. OF MACEDONIA

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Abstract - The housing sector is one of the most intensive in terms consumption of materials and energy resources, thus responsible for the detrimentation of the environment and the production of large amount of emissions and waste. In Republic of Macedonia the largest part of the housing stock hold is built of conventional concrete and masonry structures. In order to improve the sustainability of the buildings and contribute to the sustainable development of the country it is of crucial importance to change the architectural and construction practice towards using more sustainable materials. The objective of this research is to show that wooden products can significantly improve the sustainability of houses, compared to conventional concrete and masonry buildings. Therefore, a case study of a typical house is selected and four alternatives are analyzed in terms of the influence of the chosen construction materials on the environment and their emissions Life-Cycle Assessment (LCA).The results show the emissions of a given construction element as well as their share to the overall emissions of the building. The authors would like to acknowledge the support of the FP1407 ModWoodLife Action for its excellent research and networking possibilities.

Keywords - Building simulation performance, Energy performance, Residential buildings, Sustainability.

I. 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 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. 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. The most accepted definition of modified wood is given by Hill [6], 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".

Several modification methods which are used during the wood processing in order to increase wood stability and durabilityare established, such as: Impregnation, Chemical Modification, Thermal modification and Coating [7]. Other authors categorize them as[8]: 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.

Kebony [9] is a type of modified wood treated with furfuryl alcohol in a process called furfurylation. It is a chemical modification process which is considered safe for the environment [10] involving furfurylation, i.e. impregnation of the monomer, furfuryl alcohol (FA) into dry wood along with a cross-linker and other additives. This process enhances the load bearing properties of the wood [11]. Accoya is produced by Accys Chemicals PLC [12] and is chemically modified, more specifically, by the process of acetylation.

In the common construction practice in Macedonia, reinforced concrete (RC) structures and masonry walls are generally used. The housing 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 [13]. 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 [14].

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) [15]. 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 [16]. 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. [17], as well as the necessity of managing the design process in a sustainable manner in order to produce more sustainable building design [18].

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 housing 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.

II. METHODOLOGY

In this research a software simulation is performed on several models of a single-family building. The aim is to analyses 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 that deplete the stratospheric ozone layer; 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 case-study selected for this research is a single-family housing building in Skopje, the capitol of Republic of Macedonia, designed by the architecture design office MDC Architectonica [19]. The building is a part of a four-house city block, consisted of a ground floor and 1st floor and is designed with a reinforced concrete load-bearing structure.

For the development of the four alternative models several different types of materials are used for the same construction element. For the load-bearing structure are proposed two types, such as the conventional reinforced concrete and the wooden framing. For the external walls three types are used in the analysis. 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 used in the alternative models is double glazing 4+16+4 mm, with a low-emissivity glass (Low-E Glass). The data for the materials are derived either from the manufacturers Environmental Product Declarations (EPD) or from the database ÖKOBAUDAT [20]. The bill of quantities of the materials are obtained from the design office of the housing building and is used for calculating the total emissions in the phase "cradle to gate".

III. RESULTS AND DISCUSSION

In Fig 1. is shown a comparison of the LCA results for the concrete works in the four models.

The emissions in the concrete works in Model 2 decrease by 4% when compared to Model 1, the emissions of the concrete works in Model 3 when compared to Model 1 are decreased by 9%, and the emissions of concrete works in Model 4 when compared to Model 1 are decreased by 46%.

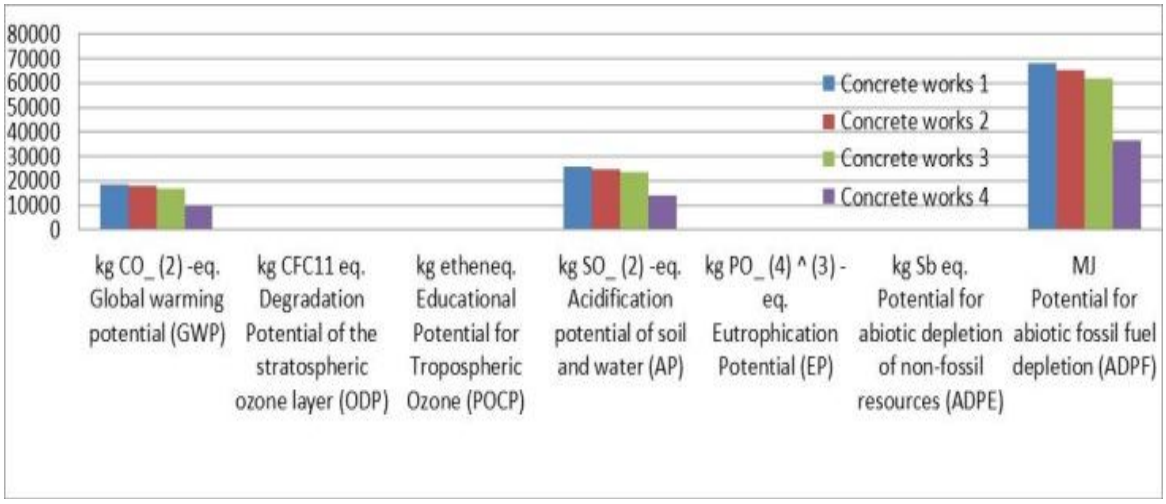


Fig. 1 Concrete works LCA results in four analyzed models

In Fig. 2 is shown a comparison of the LCA results for the steel works in the four models. The emissions in the concrete works in Model 2 decrease by 5% when compared to Model 1, the emissions of the concrete works in Model 3 when compared to Model 1 are decreased by 43%, and the emissions of concrete works in Model 4 when compared to Model 1 are decreased by 91%.

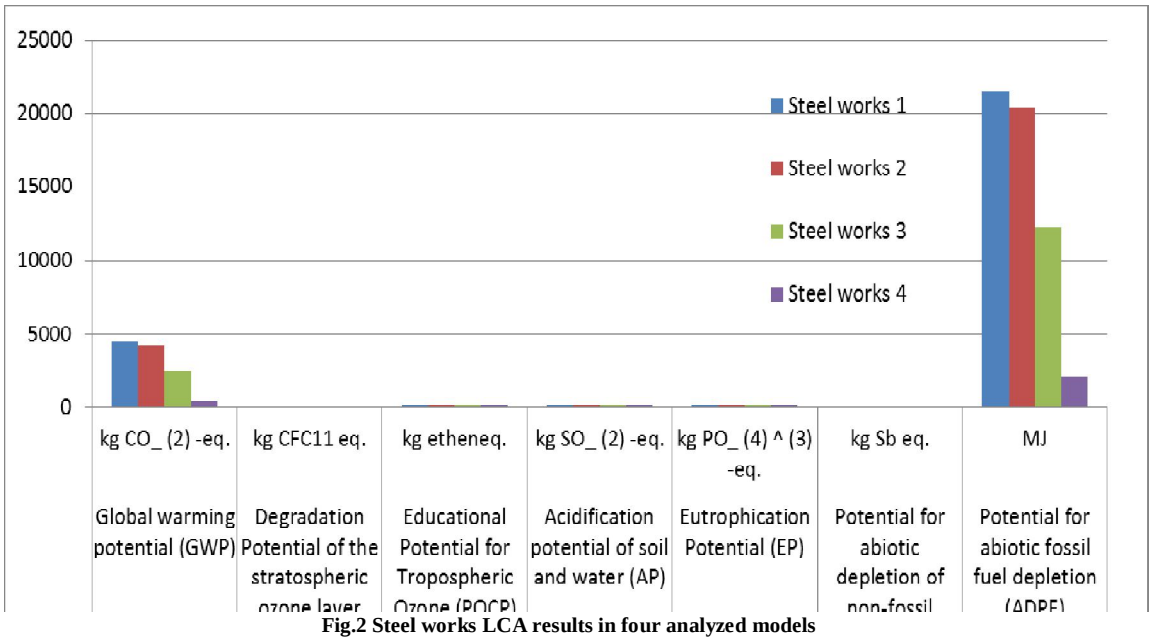


Fig.2 Steel works LCA results in four analyzed models

In Fig. 3 is shown a comparison of the LCA results for the interior wall works for the two interior wall types used in the analysis. The GWP emissions in the interior works in IW2 decrease by 148% when compared to IW1 and the ODP emissions in IW2 decrease by 88% compared to IW1. The POCP emission are increased in

IW2 for 524% compared to IW1, and the AP, EP and ADPE in IW2 are increased by 8%, 59% and 2412%, respectively, when compared to IW1. Regarding the potential for abiotic fossil fuel depletion (ADFP), in the case of IW2 is decreased for 36% compared to IW1.

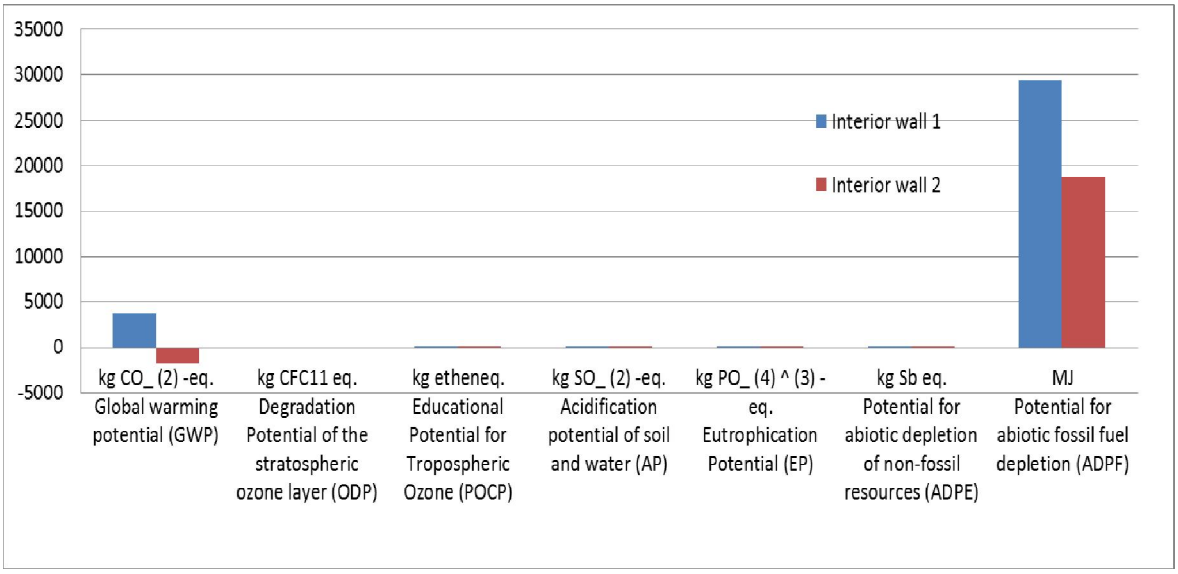


Fig. 3 Interior walls LCA results in four analyzed models

In Fig. 4 is shown a comparison of the LCA results for the exterior wall works for the three exterior wall types used in the analysis. The GWP emissions in the exterior wall EW2 decrease by 212% when compared to EW1 and for 154% when compared EW3 and EW1. The ODP emissions in the exterior wall EW2 increase by 9535% when compared to EW1 and for 1188% when compared EW3 and EW1. The POCP emissions in the exterior wall EW2 decrease by 10% when compared to EW1 and for 23% when compared EW3 and EW1. The AP emissions in the exterior wall EW2 increase by 138% when compared to EW1 and for 66% when compared EW3 and EW1. The EP emissions in the exterior wall EW2 increase by 216% when compared to EW1 and for 103% when compared EW3 and EW1.

The ADPF emissions in the exterior wall EW2 decrease by 33% when compared to EW1 and for 57% when compared EW3 and EW1.

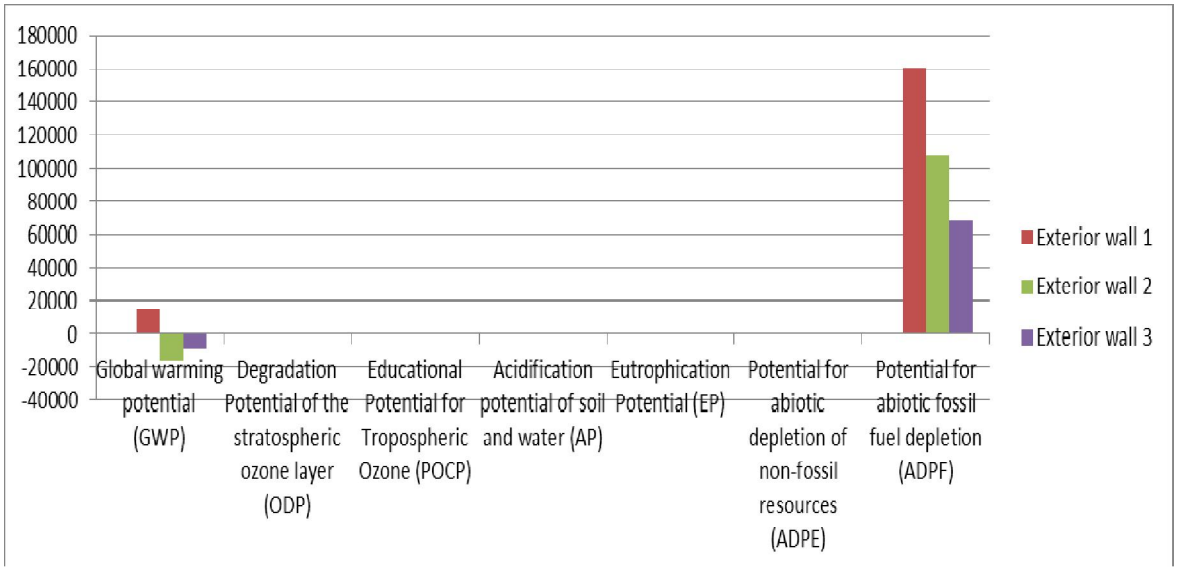


Fig. 4 Exterior walls LCA results in four analyzed models

In Fig. 5 is shown a comparison of the LCA results for the floor works for the two floor types used in the analysis. The GWP emissions in the floor F2 decrease by 258% when compared to F1. The ODP emissions in F2 increase by 1144% compared to F1. The POCP emissions are decreased in F2 for 7% compared to F1 and the and the AP in F2 is decreased by 100%. The EP emissions in F2 are the same as in the floor F1. The ADPF emissions in F2 decrease by 52% compared to F1.

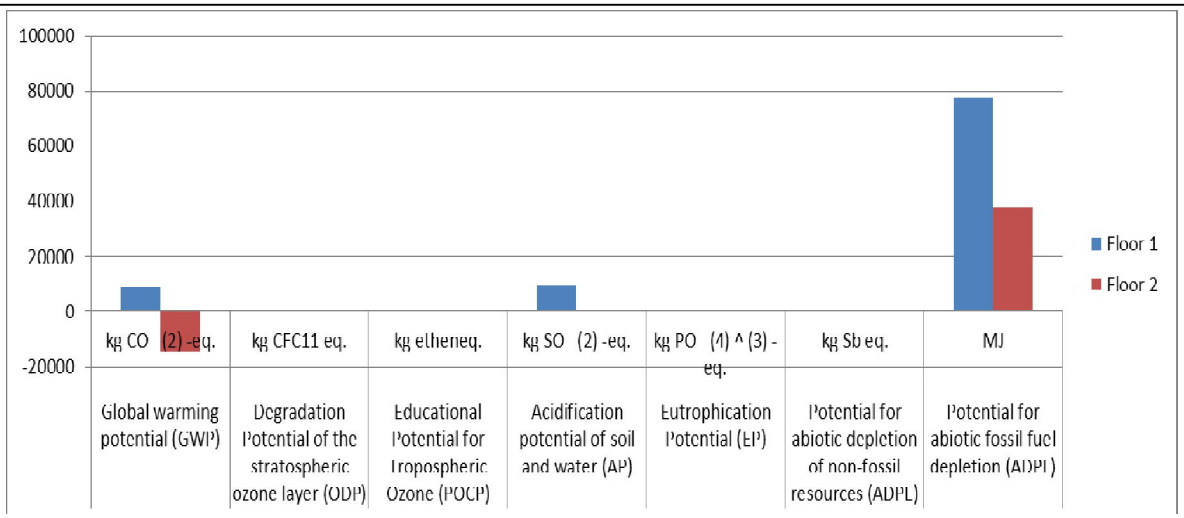


Fig. 5 Floor works LCA results in four analyzed models

In Fig. 6 is shown a comparison of the LCA results for the roof works for the two roof types used in the analysis. The GWP emissions in the roof R2 decrease by 149% when compared to R1. The ODP emissions in R2 increase by 1067% compared to R1. The POCP emissions are decreased in F2 for 18% compared to R1 and the and the AP in R2 is decreased by 99%. The EP emissions in F2 are decreased by 40% compared to the roof type R1. The ADPF emissions in F2 decrease by 52% compared to F1.

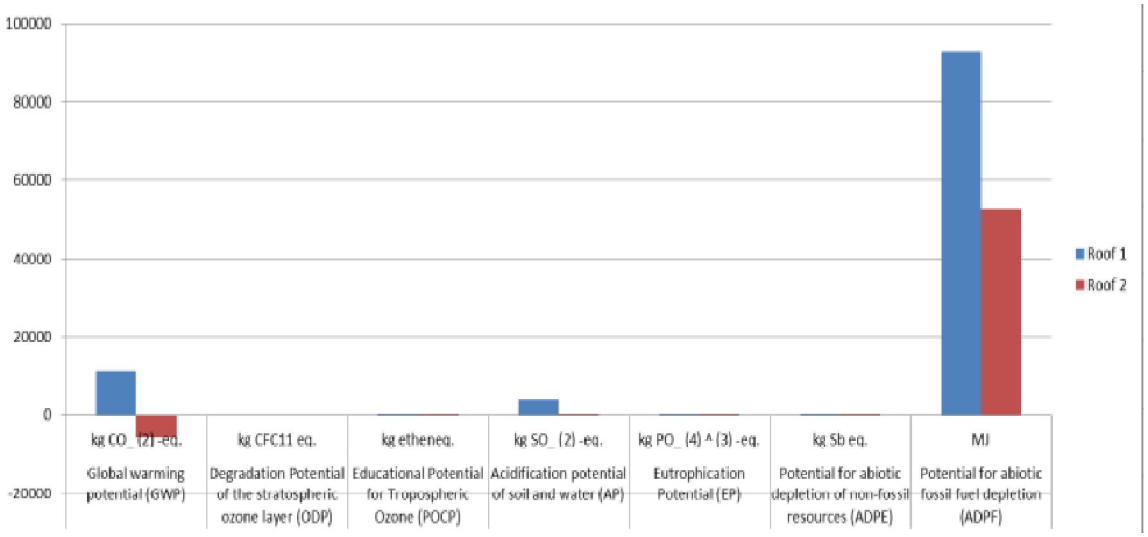


Fig. 7 Roof works LCA results in four analyzed models

CONCLUSIONS

The objectives of this study are to increase the application of wooden products in Macedonia as well as to increase the application of modified wood. The aim is to show that buildings with wooden products, as well as modified wood, outperform conventional concrete and masonry buildings. Therefore in this research a comparison is made between four models of a single-family house in order to examine the influence of the choice of materials onto Life-Cycle Assessment (LCA) performance. Each of the analyzed models consisted of different construction materials such as: reinforced concrete, wooden-framing systems and masonry. From the obtained results it is concluded that the models with wooden and modified wood products, with regard to LCA performance, significantly outperform the conventional buildings made of concrete and masonry constructions. The GWP emissions, i.e. the CO_2 emissions are by the largest percentage declined in Model 4, as compared to the other three models, which is a building made out of wooden elements for the load-bearing structure, slabs, walls and roof, except the foundations, which are made out of reinforced concrete (RC). Model 4 has 145% less GWP emissions compared to Model 1, which is completely made out of concrete and masonry. Also, the ADPF emissions in Model 4 are decreased by significant 43% overall compared to Model 1. Further research is needed to investigate the influence of the chosen materials on the energy performance of the building as well as to conduct cost-benefit analysis to investigate the economic benefits. From the results it

is evident that the higher acceptance of wood and modified wood products among architects and constructors in R. of Macedonia will contribute towards more sustainable buildings and communities.

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