ASSESSMENT OF THE SUSTAINABILITY OF FAÇADE REFURBISHMENT

by

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Dominant share of the residential stock in the European countries has an exploited service life and is in a need for façade refurbishment. This paper contributes with an establishment of a tool for assessment of the sustainability of design options for buildings` façade refurbishment. The tool is based on a multicriteria system, assessing four design criteria, relevant to the process of façade refurbishment. The criteria are evaluated by several surveyed participants by utilizing the Analytic-Hierarchic Process (AHP).The tool is applied on several façade refurbishment design proposals assessment on a case-study of a residential building situated in Skopje, Western Balkans, Europe. Each of the façade proposals is assessed regarding their energy performance, CO_2 emissions, investment costs and return of investment. Further, the results of the LCA analysis of the applied materials shows the contribution of each of them to the overall sustainability performance. The results of this research show that the use of wood and modified wood products as façade elements used for buildings` façade refurbishment can substantially decrease the greenhouse emissions and contribute to the carbon offset. However, due to the higher investment costs, the return of the investment is longer, leading to lower sustainability assessment ranking. It is concluded that the refurbishment of the façade with a conventional contact façade has the highest ranking on sustainability, followed by façade refurbishment with contact façade combined with only roof refurbishment/ glazing refurbishment or both. Also, the modified wood wall types show high sustainability ranking regarding their refurbishment potential.

Key words*: sustainability assessment, life-cycle assessment, energy performance, investment costs, return of investment, residential buildings, analitic-hierarchic proces*

Introduction

Most of the buildings in the EU are designed and built in an unsustainable manner, for which are accounted for nearly 40-50% of the global energy consumption, 36-40% of the CO_2 emissions [1, 2], as well as 55% of its electricity consumption [3]. Moreover, the materials used in construction of the buildings are of utmost importance, as they represent more than 50% of the embodied energy in buildings [4].

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The concept of sustainability proposes solutions to these problems by reducing the noxious impact of the building stock on the environment, decrease of the exploitation of resources, while considering the economic and the social aspects related to the buildings [5]. The integration of the sustainability in architecture has shown benefits in the creation of healthy built environment and benefits to the mental and physical health of the users [6, 7].

The improvement of the sustainability and energy performance of the buildings has been integrated in the European policy and legislation. For reduction of the energy performance of the buildings, two strategies are proposed, such as: reduction of the energy demand within the building and meeting the energy demand with on-site RES [8]. The novel Directive 2018/844 [9] of May 30, 2018 amends the Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency. Among other novelties for decarbonising the buildings, the Directive demands establishing "*a long-term renovation strategy to support the renovation of the national stock of residential and non-residential buildings, both public and private, into a highly energy efficient and decarbonised building stock by 2050, facilitating the cost-effective transformation of existing buildings into nearly zero-energy buildings*". Therefore, the renovation of existing buildings and improving their sustainability is of great importance for future sustainable development of the cities.

This paper focuses on the residential building sector with an aim to examine the possibilities for improving façades` sustainability by refurbishment. The chosen case-study is a referent example of a neighborhood with a same residential typology in the city of Skopje, R. of N. Macedonia, situated in the Western Balkans in Europe. Considering that the renovation of buildings` façade influences the buildings` performance regarding several criteria it is necessary to establish a multi-criteria decision making system for ranking the façade renovation solutions.

In the following section several refurbishment strategies are analyzed as well as the possibilities of wood and modified wood materials application as exterior façade elements for improvement of the buildings` sustainability. The research methodology is presented, afterwich an analysis and discussion of the obtained results is made, followed by the conclusions of the research.

Literature review

Sustainable refurbishment framework of the residential stock

Around 40% of the European building stock hold is built before 1960 and 90% before 1990 [10] and with a life-service of 60 years they have an operable life until 2050, even though the buildings have been in use beyond that life-service. It is noted that the rate of renovation of the existing residential buildings is projected to be at least 2-3% per year until 2030 as part of the EU's Resource Efficiency agenda [11].

According to the *Directive 2010/31/EU of the European Parliament* 'major renovation' means the renovation of a building where:

– the total cost of the renovation relating to the building envelope or the technical building systems is higher than 25% of the value of the building, excluding the value of the land upon which the building is situated, or
– more than 25% of the surface of the building envelope undergoes renovation [12].

The sustainable improvements for retrofitting, particularly large-scale measures, should take into account the embodied energy and environmental impacts from the material productions and refurbishment implementation [13]. Hence, for the delivery of sustainable buildings it is important to apply sustainable materials in order minimize the consumption of natural resources and to decrease the environmental impact.

The refurbishment design and construction process is influenced by multiple design aspects and the decision making process means balancing the user demands and possibilities. Additionally, it is a process that involves assessment and prioritization of the several design proposals and their performance. Authors state that the assessment of the quality of a building and to need to apply a certain measurement system in the design process is an important issue due to the different aspects of the building [14], especially in the design phase [15-17].

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, [17, 18], material efficiency, environmental impact, durability, affordability, social benefit [19], *etc.* Also, it is noted that the decisions of the homeowners to renovate are commonly influenced by economic and non-economic motives [20]. Certain studies have been focused on the influence of the window glazing on the buildings` sustainability, energy performance, however the costs and greenhouse emissions related to material production have not been taken into account [21-23].

Application of wood and modified-wood for buildings refurbishment

Wood as a construction material has certain limitations relating to the climatic conditions and its exposure to water and moisture however, considering its sustainable properties, it is gaining in popularity in the recent period. Additionally, the awareness of the outstanding properties of the wood and certain rare species, combined with EU policies and restrictions on using environmentally hazardous chemicals, among other, [24], has instigated larger interest. The increased application is supported by continuous research on improving its properties and durability producing a new subtype of construction material named - modified wood.

The most accepted definition of modified wood is given by Hill [25], 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*".

There are several modification methods for the increase of wood stability and durability, such as: Impregnation, Chemical Modification, Thermal modification and Coating [26], while other authors categorize them as [24]: chemical treatments; thermo-hydro and thermo-hydro-mechanical treatments; treatments based on biological processes; physical treatment with the use of electromagnetic irradiation or plasma.

ThermoWood [27] is produced in drying kilns under high temperature steam of up to 160-180°C, as well as up to 210°C, under several process steps and temperature phases. Kebony [28] is a type of modified wood treated with furfuryl alcohol in a process called furfurylation. This process enhances the load bearing properties of the wood [29]. Accoya is produced by Accys Chemicals PLC [30] and is chemically modified by the process of acetylation. This modification process does not improve the woods` fire-resistance [31], and when used outdoors has a potential for fungi and mold growth, as well as change of its color [25].

Authors have investigated wood in terms of refurbishing historic buildings and improving the buildings performance [32]. Several authors have analyzed the functional and design potential of wood as an element of ventilated façade systems and their energy efficiency [33]. The wood is also investigated as an element for façade reconstruction and its potential and limitations for improvement of buildings` energy efficiency [33, 34]. Considering that wood is a fire-risk material, in R. of N. Macedonia the design of timber structures and their performance under fire are calculated according to the standards MKC EN 1995-1-2:2004/AC, MKC EN 1995-1-:2012, and the fire resistance is regulated in accordance to the building type.

Methodology and analysis

The aim of this research is to assess the possibilities for sustainable refurbishment of façades` by utilizing multicriteria assessment system. The methodology of the research is conducted in several steps, such as:
- Obtaining climatological data from the software METEONORM;
- Developing nine design proposals for a façade refurbishment;
- Establishing multicriteria assessment system and assigning weight to the criteria: energy performance, life-cycle assessment, investment costs and return of investment.
- Assessment and ranking of design proposals regarding the energy performance, Life-Cycle Assessment, Investment Costs and Return of Investment.

Each of the methodological steps is further elaborated.

Case-study description

The residential building is built in the neighborhood of Vlae in Skopje, R. of N. Macedonia, after the catastrophic earthquake which occurred in the city in 1963 and caused a destruction of up to 65% of the built stock. Approximately 15.000 residential buildings were erected during the post-earthquake rebuilding of the city, among which is the neighborhood of Vlae. Considering that the buildings in the neighborhood are built 55 years ago they have a large potential for sustainability improvement by façade refurbishment, fig. 1. The chosen case-study is a typical representative of the neighborhood buildings which are prefabricated and of same typology. It is significant to explore the potential for refurbishment of the neighborhoods` buildings and prolonging their service life, but also to to preserve the existing way of housing, their typology and the ambient values of the neighborhood it has created throughout the years, which the residents deem it as positive. Hence, it is necessary to keep the architectural typology which is characteristic, which continues to bring a value in the residential city living and which contains a memory of the city`s development throughout the time.

Figure 1. Residential neighborhood Vlae in Skopje with prefabricated buildings [35]

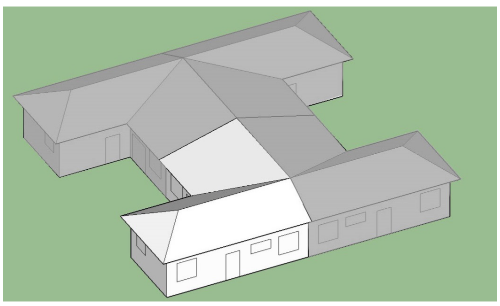


Figure 2. Model of the analyzed building

The building is part of a four-house typology, with an L-shape floor plan and flanked on two sides by its neighbors, fig. 2.

The case-study analyzed in this research is a single house of a four-house block, having a window orientationwards south and west. The building is prefabricated and the building envelope materials are shown in tab. 1. It is constructed from light weight porous concrete panels 15 cm thick. The existing floor is made as a reinforced concrete slab with a parquet layed over cement screed and insulation. The existing roof is made by wooden beams with insulation layed between them. The ceiling is constructed of 2.5 cm gypsum panels above which glass wool insulation is positioned.

Table 1 Construction elements of the case study

	Type of structure	d (cm)	U value
Roof (R0)	Metal sheeting, timber framing 2 × 2.5 cm, glasswool insulation 5 cm between timber framing, wooden batting 5 cm, gypsum board 1.25 cm.	37	U = 0.681 W/m^{2}K
Slab (S0)	Pine flooring 2.4 cm, screed 4 cm, PVC-U foil, thermal insulation 5 cm, hydroisolation, concrete 10 cm, cement creed 5 cm.	36	U = 0.286 W/m^{2}K
Glazing (G0)	Single glazing 4 mm, wooden framing [36]		U = 4.6 W/m^{2}K

For the purpose of this research the case study of the residential building, three façade systems for refurbishment F1-F3, are analyzed, shown in tab. 2, while the existing façade is titled as F0. The façade wall type F1 is a contact façade system while F2 and F3 are structural façades modified wood cladding, placed on a wooden batting in two opposite directions, on of each other, thus forming a ventilation layer behind the cladding that enables drying of the moisture in the cladding. The façade wall F1 and F2 have insulation placed on the external side of the existing concrete panel, while in F3 the insulation is positioned on both sides of the existing wall. The proposed window refurbishment option G1 is a double glazing with low emissivity and PVC-U frame with five chambers. In the roof type R1 an installment of additional insulation is considered above the existing modular ceiling panels, ammounting to 23 cm insulation thickness.

Table 2. **Building component types and their characteristics**

	External Wall	d (cm)	U-value
F0	Existing precast concrete panel 15 cm	15	U = 1.678 W/m^{2}K
F1	Acrylic façade mortar, EPS 10 cm, existing precast concrete panel 15 cm, interior mortar 1.5 cm, smooth coating, acrylic paint	27	U = 0.301 W/m^{2}K
F2	Accoya cladding 2.4cm, waterproof/vapour-permeable membrane, Knauf Rockwool 10 cm, wooden batting 2*5cm, existing precast concrete panel 15 cm, interior mortar 1.5 cm, smooth coating, acrylic paint	29	U = 0.282 W/m^{2}K
F3	Kebony façade cladding 2.4 cm, waterproof/vapour-permeable membrane, wooden batting 2*5 cm, Knauf Rockwool 10 cm, existing precast concrete panel 15 cm, wooden batting 5 cm, glasswool 5 cm, gypsum board 2*1.25 cm, smooth coating, acrylic paint	34	U = 0.211 W/m^{2}K
Glazing (G1)	Double glazing 6+12+6, Low-e, five chambers		U = 1.4 W/m^{2}K
Roof (R1)	Metal sheeting, timber framing 2x2.5 cm, glasswool insulation 8 cm between timber framing, wooden batting 5 cm, glaswool insulation 15 cm, gypsum board 1.25 cm.		U = 0.183 W/m^{2}K

The chosen material layers and details between the buildings envelope elements are designed with an aim to prevent the detrimental influence of the thermal and moisture diffusing processes through the buildings envelope. The thermal transmittance of the façade systems 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 [37]. All of the construction elements meet the required demands defined with the Rulebook on energy efficiency [36], tab. 2.

In the research several refurbishment models are analysed each consisted of different set of the building envelope elements, tab. 3. The baseline model M0 is consisted of the existing building envelope materials and their thermal properties. The index of each model describes the addition of a new envelope element to the baseline model. Therefore, the model M0G1 is improved version of the baseline model, where the windows are replaced with G1 double glazing, low emissivity and five chamber PVC-U frame. The models MF0G1R1 has a façade wall type F0, glazing type G1 and roof type R1 and the same nomenclature applies to the rest of the models.

Table 3 Refurbishment model characteristics

	M0	M0G1	M0R1	M0F1	MF-0G1R1	MF-1G1R0	MF-1G0R1	MF-1G1R1	MF-2G1R1	MF-3G1R1
Façade wall	F0	F0	F0	F1	F0	F1	F1	F1	F2	F3
Glazing	G0	G1	G0	G0	G1	G1	G0	G1	G1	G1
Roof	R0	R0	R1	R0	R1	R0	R1	R1	R1	R1

Multicriteria indicators for refurbishment assessment

Life-cycle assessment of the façade refurbishment proposals

Life cycle assessment (LCA) is a methodology established in the late 1960`s and is utilized to assess the energy use and emissions that occur during a product manufacturing process. The LCA of a product identifies, quantifies and characterizes the various potential environmental impacts associated with each of the stages of the life cycle of a product [38]. Hence, the LCA methodology enables identification of emissions and enables the possibilities to study different design options.

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. The indicators which are used in this research are the: global warming potential (GWP) which shows the CO_2 and CH_4 emissions; ozone depletion potential (ODP) showing the emissions of chemicals or substances that deplete the stratospheric ozone layer such as: CFC, halons, methyl chloroform, carbon tetrachloride hydrochlorofluorocarbons (HCFC) and methyl bromide; acidification potential (AP) showing the emissions that cause acidifying effects to the environment; eutrophication potential (EP) which shows the the potential impact on undesirable shift on aquatic and terrestrial ecosystems; photochemical ozone creation potential (POCP) – smog, which shows the emissions of precursors that contribute to the formation of ground level smog; abiotic depletion potential (ADP) showing 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).

The data for the LCA analysis are obtained from the manufacturers` environmental product declarations (EPD) or from the OKOBAUDAT database [39], describing the production phase A1-A3 *cradle to gate*. It involves the resource extraction (cradle phase) and ends with the exit from the factory (gate phase). The total amount of emissions in the cradle to gate phase for each building component is calculated according to the bill of quantities of the case-study, for which EPD declarations and OKOBAU data are used.

For the comparison of the LCA performance of each of the design proposals, all of the abovementioned LCA indicators are used. However, further in the research, for the calculation of the sustainability of the refurbishment of the design proposals, only the GWP emissions indicator is used for the comparison of the façade refurbishment proposals. The remaining LCA indicators are not used due to the lack of consensus on performing their weighting [40].

Energy performance of the façade refurbishment proposals

There are multiple software tools available for the analysis of the energy performance of buildings, such as: DesignBuilder, TRNSYS, Ecotect, EnergyPlus, *etc.* EnergyPlus is often used among architects due to its integration with the OpenStudio software package within SketchUp [41]. and it is used for the calculation of the heating and cooling loads throughout the year necessary to maintain thermal control set points [42]. In this research, the task is to analyse how the changes in the buildings` envelope characteristics influence the energy performance of the observed case-study. The building occupancy and schedule of using the building are modeled according to the Statistical data of the countrys` State Statistical office [43]. The weather file and climatic data (file type TMY3) refer to the city of Skopje, obtained through the tool METEONORM [44], Tab. 4. The values of parameters such as infiltration rate, Heating Degree Days (HDD) and similar are defined with the national policy - Rulebook of energy characteristics of the buildings [37], Tab. 4, and are constant for all of the analyzed models. The energy performance is calculated for the heating and cooling load only, considering that the lighting and appliances are the same due to the identical occupancy patterns.

Table 4. Climatic and interior conditions for Skopje used in the calculations [37]

Latitude	Longitude	Altitude	Cooling temperature	Heating temperature	HDD	Infiltration
42.0º	21.47º	325 m	26ºC	20ºC	2.536	0.5 per hour

Economic calculations

For the economic dimension of the assessment of the refurbishment proposals, the criteria that are used are: the Investment cost of the refurbishment and the return of the investment (ROI). The investment costs are calculated according to the construction prices collected through a survey questionnaire between construction companies in the country. Those prices are then multiplied by the quantity of the refurbished element, *i. e.* with the surface area for the walls and roof and with the number of pieces for the windows. Because modified wood products are uncommon for the domestic market the available online prices were used [45], to which costs for transport and tax are added in consultation with a transportation company. The ROI is calculated regarding the investment cost of the design proposal and the pay-back period of the energy savings due to the refurbishment.

Assessment of indicators weights

The sustainable design process is based on the integration of the project indicators and considering that each of them has a certain influence on the projects outcome it is necessary to determine their influence. Therefore, an analytical hierarchy process (AHP) is utilized, [46], which is based on three principles – hierarchy of the indicators, prioritization and consistency. For assigning weights to the criteria a pair-wise comparison is conducted, meaning that for n number of criteria there are total of $n(n – 1)/2$ comparisons. For conversion of the qualitative values of the criteria into quantitative a scale of 1 to 9 is utilized. The AHP method is regarded as useful when there is a relatively moderate statistical sample and for large sample groups it is considered unpractical [47]. The statistical sample for this study was obtained with the assistance from the municipal authorities, that is from the municipal community representatives. Therefore, ten architects which are living or working in the municipality are chosen for the survey. Additionally, ten inhabitants were selected which are active in the municipal community and are well familiarized with the residential demands and needs of the inhabitants of the observed neighborhood, thus representing a relevant sample for this study. The criteria were assessed with a structured questionnaire according to the AHP method.

The results are processed in the software tool expert choice 11 and the obtained results reflect the priorities of the surveyed participants, shown in tab. 5. Each of the chosen four criteria is paired with the remaining three criteria. Hence, the participants in the survey assessed 12 pairs of the criteria by using a quantitative scale from 1 to 9, where 1 means equal importance of the two criteria of the pair, 2 means equally to moderately preferred, 3 means moderately preferred, 4 means moderately to strongly preferred, 5 is strongly preferred, 7 is very strongly preferred, 8 is very to extremely strongly preferred and 9 is extremely preferred, meaning that one criteria of the pair is exclusively important and the other criteria of the pair is irrelevant. The integrals between 1 to 9 reflect the prevalence of one criteria over the other. A criteria matrix is developed, where the four criteria are placed in the row and column headers. The values for each comparison make the criteria matrix. Further, the value in each row is multiplied and a 4th root is calculated. The calculated roots in each row are summed up and further the priority vector is calculated by normalizing the criteria's values with the 4th root. The consistency ratio (CR) is calculated with informs the decision maker on how consistent are the values of the pair-wise comparisons. The CR of the results is 0.04, where less than 0.1 is deemed reasonable [46], meaning that the results are consistent and valid.

Table 5 Calculating criteria weights using AHP

Sustainability assessment criteria	Indicators` weight
Investment costs	0.34
Energy efficiency	0.26
GWP emissions	0.12
Return of investment	0.28
λ = 3.367, CR = 0,04, α = 0.1	

The sustainability assessment is calculated with the following formula represented in eq. (1):

$$S=\sum_{i=1}^{n} c_i w_i \tag{1}$$

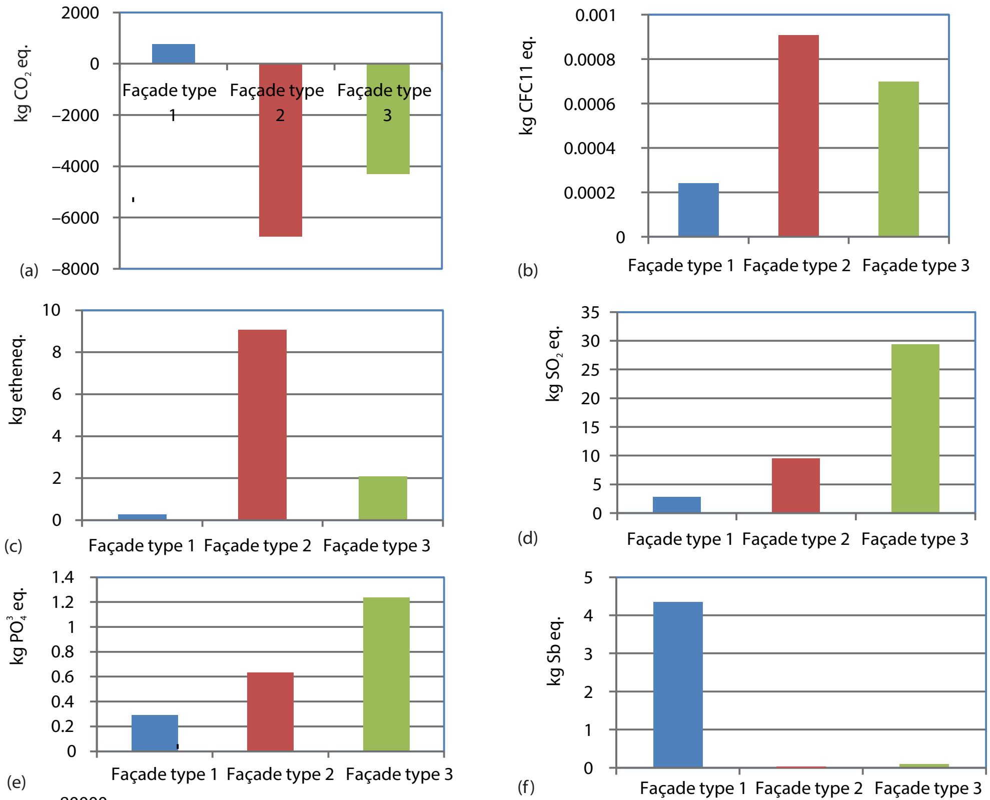
where c_i are the criteria of the matrix S, and w_i is the weight assigned to the i^{th} criterion.

Results and discussion

Life-cycle assessment of the models

The results of the LCA analysis for the investigated façade renovation systems are shown in fig. 3, according to their types of emissions. Largest contributors of GWP emissions in façade 1 are the EPS and the façade mortar with 56% and 34%, respectively. The analysis and comparison of the GWP shows that façade 2 and façade 3 have negative GWP emissions compared to façade type 1, due to the use of wood and modified wood products, fig. 3(a). The wooden batting contributes the most in the carbon offsetting in façade 2 with 69%, and by 57% in façade 3, followed by the Accoya and Kebony cladding with 17% and 19%, respectively.

The ODP emissions are higher in façade type 2 and façade type 3, compared to façade type 1, fig. 3(b). The ODP emissions in façade 2 are entirely caused by the EPS material. Largest contributors of ODP in the façade type 2 and 3 are the waterproof/vapor permeable membrane, with 59% and 76% share in the emissions, respectively. The Accoya cladding contributes with 41% and the Kebony with 24% in the ODP of the wall F2 and F3, respectively, fig. 3(b).



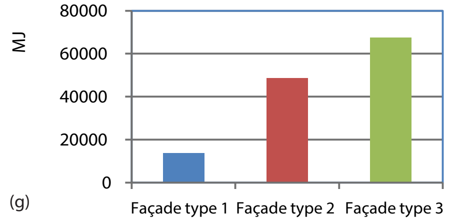


Figure 3. Comparison of LCA results of the façade types; (a) GWP emissions, (b) ODP emissions, (c) educational potential for tropospheric ozone, (d) acidificaton potential, (e) eutrophication potential, (f) abiotic depletion of non-fossil fuel resource, (g) abiotic depletion of non-fossil fuel resources

The photochemical ozone creation potential (POCP) emissions are lowest in façade type 1, compared to façade 2 and façade 3, fig. 3(c). The largest share of POCP emissions in façade 2 are due to the Accoya cladding, with 76% of the total emissions of the materials. In façade 3, the wooden batting contributes with 35%, followed by the waterproof/vapor permeable membrane and rockwool, each with 18%, fig. 3(c).

The AP is lowest in façade type 1, compared to façade 2 and façade 3, fig. 3(d). The AP emissions in façade 1 are 46% caused by the EPS, 28% by the façade mortar and 23% by the acrylic paint. The AP emissions in façade 2 are due to the use of rockwool, with a share of 42% in the emissions, followed by the wooden batting and the Accoya cladding with 28%. The largest part of AP emissions in façade type 3 are due to the Kebony cladding with a share of 70%, followed by the rockwool, with a share of 14% and the glasswool, participating with 5% of the emissions.

The EP is lowest in façade type 1, fig 3(e). The largest part of the EP emissions in façade type 1 are because of the use of EPS, with 46% and the façade mortar with 47%. In the EP emissions in façade type 2, the wooden batting is the largest contributor with 45%, while the Accoya is offsetting the EP emissions by 17%. The EP emissions in façade type 3, are caused by 26% to the use of wooden batting, 20% to the use of rockwool, the gypsum board with 19% and the glasswool with 15%.

The Potential for abiotic depletion of non-fossil resources (ADPE) is significantly lower in façade type 2 and 3, compared to façade 1, by as much as 100%, fig 3(f). The highest ADPE emissions are in façade type 1 due to the use of EPS in the façade system, while in façade 2 are due to the Accoya, contributing with 79% in the emissions of these to wall types. In façade 3, 75% of the emissions are caused by the gypsum boards and 16% by the glasswool.

The Potential for abiotic fossil fuel depletion (ADPF) is lowest in façade type 1, fig. 3(g). The APDF in façade type 1 is in largest part due to EPS, with 58% share. In the façade 2, the Accoya is contributing with 46%, the rockwool has a 27% share, the wooden batting 18% share, *etc.* In façade 3, the Accoya cladding contributes with 45%, the rockwool with 20%, *etc.*

The GWP emissions of the façade proposals are aggregated according to their constituent materials, fig. 4. The results show that the rockwool and the gypsum boards are the largest contributors to the GWP emissions overall, compared to each material of the three proposed façade types, followed by the windows and doors. It is evident that the wooden elements overall, such as the wooden batting structure, the Accoya and Kebony cladding all have negative GWP emissions, thus having a positive impact on the environment.

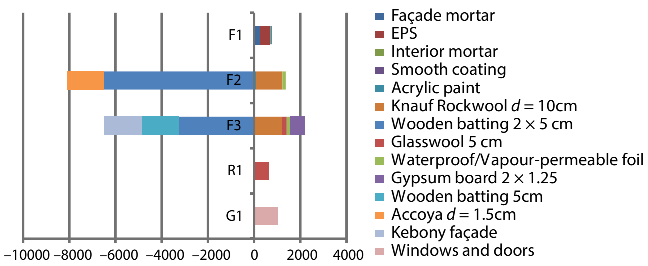


Figure 4. Aggregated GWP emissions according to the constituent materials of the façades

Energy performance assessment of the models

The energy performance of the proposed models which is calculated in OpenStudio by using the EnergyPlus engine is shown in tab. 6. The energy demand values are shown per floor area of the building and on a yearly basis. The latter results enable calculating the costs of the energy consumption of each of the observed models on a yearly basis according to the current energy price of 0.077 €/kWh (4.773 MKD/kWh) [48]. Also, the savings in energy and costs can be observed, where the monetary savings are calculated in relation M0 as a reference.

Regarding the energy performance, the model MF1G1R1, which has most insulation compared to the other types of façades has the lowest heating and cooling demand. The window replacement in M0G1 improves the energy performance compared to the baseline model M0 by 2.89%. The addition of insulation only of the roof in model M0R1 improves the energy efficiency by 7.59%, while adding insulation only at the façade walls improves the energy efficiency by 64%.

Table 6. Energy performance and energy savings

	Energy demand [$kWhm^{-2}a^{-1}$]	Total energy consumption [kWha]	Total yearly cost [€]	Yearly savings [€]
M0	328	24600	1906.5	
M0G1	318.5	23887.5	1851.3	55.2
M0R1	303.1	22732.5	1761.8	144.7
M0F1	118	8850	685.9	1220.6
MF0G1R1	293	21975	1703.1	203.4
MF1G1R0	108.1	8107.5	628.3	1278.2
MF1G0R1	95.6	7170	555.7	1350.8
MF1G1R1	84.5	6337.5	491.2	1415.3
MF2G1R1	78.8	5910	458.0	1448.5
MF3G1R1	65.5	4912.5	380.7	1525.8

The difference between the model MF3G1R1 and MF2G1R1 is 16.8%, while between the MF3G1R1 and MF1G1R1 is 22.48%. The overall improvement between the baseline model M0 and the most energy efficient model MF3G1R1 is 81%.

Investment costs and ROI analysis

The total investment cost and ROI for each of the design proposals is shown in Table 7. The total energy costs are calculated according to the current energy price of 0.077 €/kWh (4.773 MKD/kWh) [48].

Table 7. Investment cost and ROI

	Renovation cost (eur)	Monthly rate (eur)	Total interest (eur)	Total payment (eur)	Yearly savings (eur)	ROI
M0G1	1780	28	236	2016	55.2	36.5
M0R1	1800	28	216	2061	144.7	14.2
M0F1	4508	71	604	5112	1220.6	4.2
MF1G1R0	6288	97	756	6984	203.4	19.8
MF0G1R1	3580	56	452	4032	1278.2	5.5
MF1G0R1	6308	99	820	7128	1350.8	5.3
MF1G1R1	7508	117	916	8424	1415.3	6.0
MF2G1R1	15096	236	1896	16992	1448.5	11.7
MF3G1R1	16062	251	2010	18072	1525.8	11.8

For covering the investment costs, several banking credit possibilities have been examined, which target the residential sector. There are certain credit options targeting energy efficiency improvement of the residential buildings which have slightly better interest rates.

The bank interest rate in euros is 4% and the payment period in the calculation is 72 months. The simple ROI is calculated as a quotient of the total payment value and the yearly energy savings. The savings from the energy efficiency of the design proposals and the investment costs show that the fastest Return of Investment has façade 2. The significantly longer ROI in façade 3 is due to the high costs of the Accoya cladding.

Sustainability assessment of the façade renovation types

For the sustainability assessment of the proposed refurbishment façade types, the values of the four indicators are normalized and interpolated on a scale from 1 to 10 where the result of an assessment of an indicator is subtracted with the indicator with the lowest numerical value and their result is divided with the results from the subtraction of the indicators with the maximum and minimum values. Such normalized values are presented in tab. 8.

Table 8 Normalized values of the sustainability renovation criteria

	M0G1	M0R1	M0F1	MF-0G1R1	MF-1G1R0	MF-1G0R1	MF-1G1R1	MF-2G1R1	MF-3G1R1
Investment costs	10.00	9.99	8.28	8.87	7.16	7.15	6.39	1.61	1.00
Energy performance	1.04	1.58	8.14	1.94	8.49	8.93	9.33	9.53	10.00
GWP	2.42	2.89	3.07	1.63	1.80	2.27	1.00	10.00	6.98
ROI	1.27	7.28	10.00	5.78	9.66	9.71	9.52	7.96	7.93

Further, the normalized matrix in tab. 8 is weighted by the values shown in tab. 6 and is calculated according to eq. 1. The results of the sustainability assessment for each of the façade refurbishment types are shown in tab. 9 and are graphically presented in fig. 5 as a commonol for presenting multicriteria analysis.

Table 9. Weighted points for the façade proposals

	M0G1	M0R1	M0F1	MF-0G1R1	MF-1G1R0	MF-1G0R1	MF-1G1R1	MF-2G1R1	MF-3G1R1
Investment costs	3.40	3.40	2.82	3.01	2.43	2.43	2.17	0.55	0.34
Energy performance	0.27	0.41	2.12	0.50	2.21	2.32	2.42	2.48	2.60
GWP	0.29	0.35	0.37	0.20	0.22	0.27	0.12	1.20	0.84
ROI	0.36	2.04	2.80	1.62	2.70	2.72	2.67	2.23	2.22
sum	4.32	6.19	8.10	5.33	7.56	7.74	7.38	6.45	6.00

From the results it is evident that the most sustainable design solution is the model M0F1, meaning that only the façade is refurbishment with a façade wall type F1. The highest ranking of the model M0F1 is due to the lower investment costs, leading to faster ROI, accompanied with a significant improvement of the energy performance. Second ranked is the model MF1G1R0, which has a refurbished façade and glazing with façade wall type F1 and glazing G1, while the roof is not renovated. The third sustainable solution is the model M1F-1G1R1, which compared to the previous has the roof refurbished with a roof type R1. The remaining models have lower sustainability assessment ranking due to the high investment costs as in model MF2G1R1 and MF3G1R1, or poor GWP and ROI results such as M0G1 and M0R1. The established weighing system reflects the demands of the occupants and prioritizing the investment cost and ROI when choosing a most appropriate and sustainable design solution in a holistic manner.

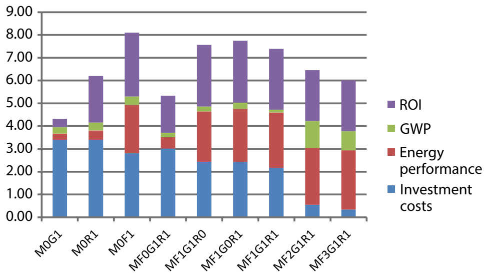


Figure 5. Graphical representation of the weighted results for sustainable renovation

It is important to note that there is an expected tendency for increase of the price of the electricity after the liberalization of the energy market. This will have implications on the yearly energy savings and the pay-back period for the investment.

In order to increase the number of renovated buildings it is suggested that the Governments must create more favorable conditions for energy efficiency investments [49] by delivering broader offer of financial instruments [50].

Furthermore, in order to achieve nZEB buildings by renovation, measures for façade refurbishment should stimulate the application of wood as sustainable material, opposed to masonry or even concrete [51]. However, to target the passive house standard a major refurbishment is needed regarding the heating and cooling systems, lighting, appliances [52], as well as changing the behavior of the occupant.

Integration of photo-voltaic panels

Furthermore, the improvement of the buildings' sustainability in this research is made by the integration of photo voltaic (PV) modules. They can provide a mixed renewable energy portfolio [53] and hence are noted as the most dominant source among renewable energy technologies [54]. The chosen PV system is the model Samsung LPC250SM, with dimensions 1.63/0.982 m and an active area of 1.60 m^2 per module [55]. It generates nominal power of 0.25kW per module, *i. e.* 0.156 kW/m^2.

The panels are positioned on the south-side of the roof of the building, where it is possible to place only 8 PV panels, with a total area of 12.8 m^2, enabling production of 2 kW, or 1.248 kW/m^2. With such an energy production it is not possible to fully meet the buildings` energy demand in neither of the analysed building models shown in tab. 6, but it can significantly contribute in offsetting the CO_2 emissions by introducing clean energy.

Due to the numerous sun hours in the summer months there is an energy surplus in the PV system. That surplus can be stored in batteries, however, the ROI of this system is not fully economically viable, considering their cost and need for replacement after five years of operation. However, starting from 2019, in the country, it is expected to be legislatively regulated to return the energy surplus to the electricity grid, which would be more appropriate for the domestic users. The PV`s can be a powerful tool for improving the buildings sustainability and through appropriate policies their increased use in the residential sector needs to be stimulated.

Conclusions

In this study a comparison is made between nine models for refurbishment of a residential building that examine the influence of the choice of materials for façade refurbishment on the energy and environmental performance. The simulation has been conducted for the existing building used as a baseline model on which three types of façade systems are applied and varied with the application of refurbishment of the glazing and the roof. For the wall refurbishment, three types are proposed, such as: contact façade system and two types of structural façade with modified wood. The objective of the research is to investigate how the implementation of wooden products can contribute to the buildings performance and sustainability. It is concluded that the model based on timber structure and wooden products outperforms the remaining analyzed models regarding the energy and environmental performance. Also, the modified wood wall types show relatively high sustainability ranking regarding their refurbishment potential. The modified wood refurbishment has lower sustainability results compared to the contact façade type, due to the high price of such products, leading to lower ROI. For a broader implementation of such products it is necessary to decrease the production costs and be competitive with other systems for façade refurbishment. The most sustainable option is refurbishment of the façade with a contact façade system, followed by façade refurbishment with contact façade combined with only roof refurbishment/ glazing refurbishment or both.

The proposed method for assessment of renovation is based on quantitative criteria. Considering that buildings can be described in quantitative but also qualitative aspects it is necessary to establish a system that integrates them and which is able to assess numerical as well as linguistic values.

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