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A Benchmark for a New Nearly Zero Energy Wooden Building in Europe

Referentna vrijednost za novu drvenu zgradu s gotovo nultom potrošnjom energije u Europi

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ABSTRACT • *To mitigate dangerous climate change, a drastic reduction of CO_2 emissions is needed by 2030. Buildings contribute significantly to emissions, with the use phase of existing buildings being responsible for the majority of energy consumption. In addition, environmental problems associated with the production of raw materials, construction, and the end of life of buildings are serious concerns that require urgent solutions. Life cycle assessment (LCA) and the EU-recommended Environmental Footprint (EF) are widely accepted tools to measure environmental impacts throughout a product life cycle. However, assessing the environmental performance of wooden buildings remains a challenge. This study presents a benchmark for an average new European wooden building fulfilling the European nearly Zero Energy Building (nZEB) requirement. The benchmark utilizes the recommended EU EF impact categories with normalization and weighting, allowing for easy and quick comparisons. The results communicate the average environmental impact per square meter of floor area over one year. This benchmark is a suitable comparison point for new wooden building designs and is used as an effective tool for architects and designers during the initial planning stages of wooden buildings. By using this benchmark, the environmental performance of the building can be improved, and the communication and interpretation of LCA results can be facilitated for customers and other relevant stakeholders.*

KEYWORDS: *benchmark; nearly zero energy building (nZEB); life cycle assessment (LCA); wood construction; environmental footprint*

SAŽETAK • *Kako bi se ublažile opasne klimatske promjene, do 2030. godine potrebno je drastično smanjiti emisiju CO_2. Tim emisijama znatno pridonose i zgrade, pri čemu je korištenje postojećim zgradama odgovorno za većinu potrošnje energije. Osim toga, ekološki problemi povezani s proizvodnjom sirovina, gradnjom i krajem životnog vijeka zgrada ozbiljni su problemi koji zahtijevaju hitna rješenja. Procjena životnog vijeka (LCA) i ekološki otisak proizvoda (EF) koji preporučuje EU široko su prihvaćeni alati za mjerenje utjecaja na okoliš tijekom njihova životnog vijeka. Međutim, procjena ekološke učinkovitosti drvenih zgrada ostaje izazov. Ovom je studijom predstavljena prosječna nova europska drvena zgrada referentne vrijednosti koja ispunjava europski zahtjev za zgradu gotovo nulte energije (nZEB). Za zgradu referentne vrijednosti primjenjuju se preporučene EU EF kategorije utjecaja s normalizacijom i ponderiranjem, što omogućuje jednostavne i brze usporedbe. Rezultati pokazuju prosječan utjecaj zgrade na okoliš po četvornome metru podne površine tijekom jedne godine. Zgrada referentne vrijednosti prikladna je točka za usporedbu drvenih zgrada novog dizajna i služi kao učinkoviti alat za arhitekte*

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i dizajnere tijekom početnih faza planiranja drvenih zgrada. Primjerom zgrade referentne vrijednosti može se poboljšati ekološki učinak novih zgrada a korisnicima i drugim relevantnim sudionicima olakšati komunikacija i tumačenje LCA rezultata.

KLJUČNE RIJEČI: *referentna vrijednost; zgrada gotovo nulte energije (nZEB); procjena životnog vijeka (LCA); drvena konstrukcija; ekološki otisak*

1 INTRODUCTION
1. UVOD

The Intergovernmental Panel on Climate Change (IPCC) recommends in their report *Global Warming of 1.5 °C* a drastic reduction of carbon dioxide (CO_2) emissions. This means roughly halving the CO_2 emissions from approximately 40+ billion tonnes today to 20 billion tonnes in the year 2030 and reaching zero-emission or net uptake of CO_2 by the year 2050 to hinder dangerous climate change (IPCC, 2018). Accordingly, among others, the European Commission has set tough policy goals for reducing global warming gases (GHG) like CO_2 (EU 2018/773).

In 2019, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) published a report stating that nature, which is vital for all life on Earth, is deteriorating worldwide (Diaz *et al*., 2019). In addition, bad air quality has a negative impact on health, life quality and length of life. Alone in the European Union, 400 000 people died each year prematurely because of the polluted air they breathe (EEA, 2019).

Part of these threats to nature and people are caused by buildings through their life cycle, with the raw material extraction, production of building materials, heating and cooling of air and water in the long use phase, and waste at the end of life of the buildings. According to the European Commission, the construction industry accounts for 15 % of all greenhouse gas emissions (European Commission, 2016). During their use phase, buildings use 80 % of the cradle-to-grave energy consumption (Lavagna *et al*., 2018), which contributes significantly to air pollution and other environmental impacts stemming from energy sourcing, distribution and transformation.

While energy consumption during the use phase is predicted to decrease as efficient buildings, like zero and near-zero energy buildings (nZEB), become more common, climate change and other environmental problems from the production of raw materials, construction and end-of-life remain serious concerns that need to be solved urgently. This calls for a lifecycle-based approach, taking into account the raw material extraction and production phase which need to be controlled when the buildings are made with more material to increase energy efficiency to evaluate the potential environmental consequences of a construction.

During the trial period of the EU Environmental Footprint initiative between 2013 and 2018, a mean reference point (average benchmark) proved highly beneficial for various categories of goods (Gül *et al*., 2015; Guiton and Benetto, 2018; Schau, 2019) in aiding the comprehension of outcomes derived from the life cycle assessment of products within their respective product groups.

Bejo (2017) performed a review investigating the operational energy and energy embodied in wood constructions, compered them to other materials and concluded that wood is significantly better in terms of energy efficiency and greenhouse gas emissions (Bejo, 2017).

Sinha *et al*. (2012) investigated how sustainable development relates to green buildings. They concluded that advance in the field of "green" buildings requires LCA analysis which should be applied to all product stages, from primary processing and use to disposal, and call for a multidisciplinary approach that involves scientists from engineering, material science, forestry, environmental science, architecture, marketing, and business (Sinha *et al*., 2012).

Menezes *et al*. (2019) reviewed 43 papers that integrated benchmark techniques with LCA results to improve communication and found that benchmark techniques for product oriented LCAs work best if combined with another harmonization strategy like product category rules as done for the EU Product Environmental Footprint (PEF). Ferrari *et al*. (2019) developed a sustainability benchmark for a building material (ceramic tiles) and integrated life cycle costing (LCC), LCA and Social LCA (S-LCA), which gives companies in this product group the possibility to integrate sustainability perspectives into their strategies and operation. Aschenback *et al*. (2018) created an LCA model of Life Cycle Inventory (LCI) data from 12 prefab timber house manufacturers focusing on the A1-A5 modules (Figure 4). The manufacturing of building materials (module A1) accounted for the highest impacts, while approximately 30 % of the Global Warming Potential (GWP) and Acidification Potential (AP) impacts were attributed to the prefabrication of building elements, their transportation, and processes at the construction site (A4-A5).

Lützkendorf *et al*. (2012) described a benchmark for buildings used in Germany. This system was built on the established criteria and sustainability performance of office buildings and then developed further for residential buildings with the support of the German Building Ministry. The benchmark covers large residential multi-family buildings with 6-100 flats of existing representative building types (Lützkendorf *et al*., 2012). Hollberg *et al*. (2019) investigated how top-down and bottom-up benchmarks can help designers and constructors in the early phase to evaluate if a building is „climate-friendly" and how the environmental performance can be improved. Spirinckx *et al*. (2019) gave recommendations on benchmarks for office buildings. Based on an EU Product Environmental Footprint of two office buildings, testing of benchmarks and classes of performance were performed. The results focused on the methodological aspects rather than on absolute values.

The potential (historical) environmental impact of current residences in Europe were presented by Lavagna *et al*. (2018) through their LCA study on typical dwellings. This publication is based on a comprehensive report by Baldassarri *et al*. (2017), that focuses on existing buildings in the EU and provides an average environmental footprint of a building in four different geographical zones based on the *Basket of Products* approach (cf. Notarnicola *et al*., 2017; European Commission, 2012). However, a considerable share of the buildings assessed were older than 70 years (Lavagna *et al*., 2018).

With the revised Energy Performance in Buildings Directive 2018/844 (EU, 2018), the European Union has introduced a stricter policy for buildings use of energy. Therefore, it is expected that the environmental impacts of buildings in Europe are decreasing in light of the actions taken to reduce the climate change.

Therefore, to summarize, we believe that a benchmark for to-be-constructed buildings is needed. It could be useful in the early planning phase of new buildings when changes and environmental optimization can still be done for a reasonable cost (Fabricky, 1991). In this work, an environmental benchmark for a near-zero energy wooden residential building (nZEB) is provided for new buildings built after 2020.

2 DATA AND METHOD
2. PODATCI I METODE

2.1 Background data for a typical (European average) wooden single-family house
2.1. Dosadašnji podatci za tipičnu (prosječnu europsku) drvenu obiteljsku kuću

To design a European average reference building, the following elements have to be considered: 1) the market situation in Europe regarding wooden houses (Currently, Scandinavia, Germany and the UK are the largest markets for building with wood.); 2) climate conditions, which are important for the level of insulation of the house and the energy used for heating in the use phase; and 3) the different levels of the energy requirement which is different in each country.

Based on market-based statistics from Eurostat (2019a), supplemented with national data where necessary (SSB, 2019), Table 1 contains apparent consumption of wood-based residential housing by country in Europe. The apparent consumption (Sala *et al.*, 2019) is what is consumed in each country and calculated based on production value plus import minus export (EUR). The apparent consumption is used for weighting the climate data and energy requirement data of the countries investigated to come to an average wooden residential building.

The diverse climates across European countries result in varying heating demands for residential buildings. Our assessment of country-level climatic conditions relies on the utilization of heating degree days (hdd), which is used as a metric for quantifying the annual heating requirements (Eurostat, 2019b; Enova, 2019) and correlates extremely well with the use of energy, like fuel wood, for heating (Petrović, 2021). According to Table 1, the (apparent consumption of wood-based residential housing weighted) average of heating degree days for European countries stands at 3500 hdd. To better reflect climate change in the analysis, we have utilized a 10-year dataset for climate conditions instead of the conventional 30-year span. This decision was motivated by two factors: Firstly, acquiring prefabricated building statistics spanning 30 years proved challenging (for data weighting). Secondly, and more significantly, climate patterns are shifting towards warmer conditions, leading to an observable decrease in heating degree days. For instance, the reference climate in Germany, during the period of 2008-2017, experienced 3000 heating degree days, which is 500 heating degree days fewer (i.e., warmer) compared to the reference data from 20 years ago (3500 hdd).

Each country set its own requirement for a nearly Zero Energy Building (nZEB), such that this is influenced not only by the climate but also by political ambitions. In this study, the maximum allowed energy use for new buildings (nZEB) in different countries is shown in Table 1 (European Commission, 2016; BPIE, 2015; D'Agostino *et al*., 2019; Kurnitski and Ahmed, 2018; NRW ÖkoZentrum, 2019; Schau *et al*., 2022).

The weighted average maximum energy allowed (nearly zero energy building) is 67.5 kWh/(m^2 year).

2.2 Design of a typical European (average) wooden single-family building
2.2. Projekt tipične europske (prosječne) drvene obiteljske kuće

Using the average climatic conditions (derived from Table 1, encompassing 3500 degrees heating days, akin to the approximate climate in regions such

Table 1 Apparent consumption (million EUR) of prefabricated wooden buildings, heat demand expressed as heating degree days, and maximum energy use for new buildings (nZEB) from 2021 in different countries
Tablica 1. Prividna potrošnja (u milijunima eura) montažnih drvenih zgrada, potražnja topline izražena kao stupanj dana grijanja i maksimalna potrošnja energije za nove zgrade (nZEB) od 2021. u različitim državama

Country *Država*	**Consumption**[1], million EUR *Potrošnja*[1], milijuni EUR	**Heat demand**[2] heating degree days/year *Potreba za toplinom*[2], *stupanj dana grijanja/godina*	**Max energy use, kWh/(m^2·year)]**[3] *Maksimalna potrošnja energije, kWh/(m^2·godina)*
Austria	583	3482	160.0
Belgium	56	2697	45.0
Bulgaria	5	2494	40.0
Croatia	11	2281	37.0
Cyprus*	1	691	100.0
Czechia	27	3309	57.5
Denmark	121	3244	20.0
Estonia	23	4224	75.0
Finland	414	5466	130.0
France	231	2380	52.5
Germany	1 658	3053	48.3
Greece	2	1546	57.5
Hungary	10	2668	61.0
Ireland	42	2821	45.0
Italy	615	1875	57.5
Latvia	5	4046	95.0
Lithuania	65	3854	77.5
Luxemburg	7	2906	57.5
Malta*	0.1	468	40.0
Netherlands	150	2721	57.5
Norway	544	4113	97.5
Poland	4	3370	67.5
Portugal	14	1201	57.5
Romania	30	2924	155.0
Slovakia	10	3173	43.0
Slovenia	25	2785	47.5
Spain	143	1742	57.5
Sweden	1 126	5221	52.5
United Kingdom	1 226	3033	44.0

*Cyprus and Malta are the only countries in the table where the need for cooling in summer (expressed as cooling degree days - cdd) are higher than the need for heating in winter. E.g. Cyprus had 710 cdd and Malta 618 cdd, while e.g. Greece had 343 cdd and Spain 243 cdd (Eurostat, 2019b). The focus of this article is on heating (Quintana-Gallardo *et al*., 2022). / *Cipar i Malta jedine su zemlje u tablici u kojima su potrebe za hlađenjem ljeti (izražene kao stupnjevi dana hlađenja – cdd) veće od potreba za grijanjem zimi. Cipar je, primjerice, imao 710 cdd, a Malta 618 cdd, dok je npr. Grčka imala 343 cdd, a Španjolska 243 cdd (Eurostat, 2019b). Fokus ovog članka je na grijanju (Quintana-Gallardo et al., 2022).*; [1](sources: Eurostat, 2019a; SSB, 2019); [2](sources: Eurostat, 2019b; Enova, 2019) (average per year in the period 2008-2017); [3](sources: European Commission, 2016; BPIE 2015; D'Agostino *et al*., 2019; Kurnitski and Ahmed, 2018; NRW ÖkoZentrum, 2019; Schau *et al*., 2022).

as Austria, South Germany, Slovenia, and Italy near the Alps) and energy demands (average maximum nZEB requirement), the initial stages of designing a wooden detached house were made as a reference model. The architectural layout of the house was based on prevalent blueprints and structures commonly offered by prefabricated wooden house construction companies in Austria and Slovenia. The benchmark dwelling encompasses three bedrooms, a living room, a cabinet, a toilet, a utility room, a staircase, and a bathroom, encompassing a total area of 100 m^2. The external dimensions of the house are 9.6 m × 6.7 m, with a maximum height of 7.72 m. The house boasts a sloping roof with an inclination of 35° and a 1.0 m overhang. The wooden windows (featuring triple glazing) and doors have a U_w value of 0.8 W/m^2K. The foundation of the house is made of 25 cm thick concrete slab. The walls are constructed using 8/16 cm wooden profiles, with stone wool insulation filling the gaps and an additional 10 cm layer of stone wool on the outer side, covered with a finishing plaster. The roof structure also consists of 8/16 cm wooden profiles, with mineral wool insulation in-between and an additional 10 cm layer on top. The roof covering is comprised of corrugated fibre cement roof tiles. The interior floors are adorned with parquet flooring on a floating screed, while ceramic tiles are employed in the sanitary areas. Figure 1 shows the east façade of the building. Figure 2 shows a section draw-

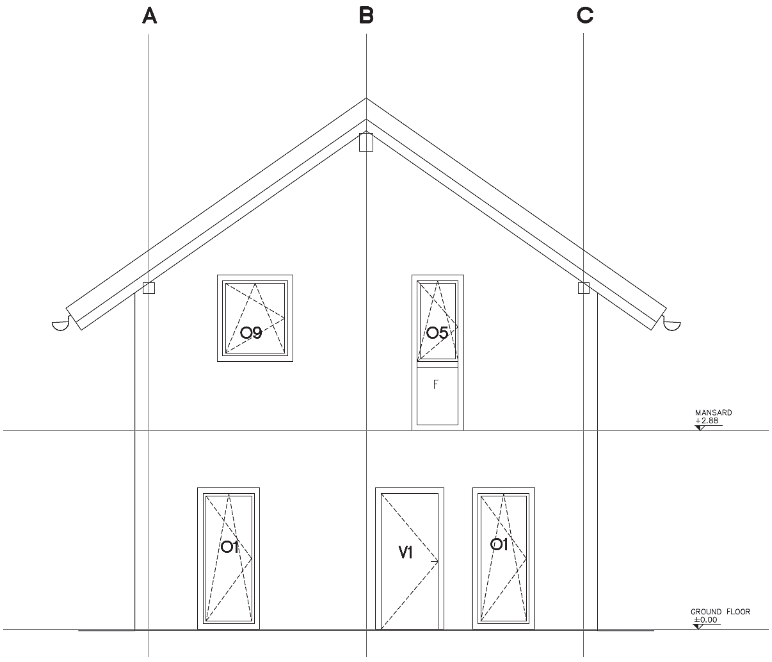

Figure 1 Drawing of east façade of benchmark house
Slika 1. Nacrt istočne fasade referentne kuće

ing of the house, while Figure 3 shows a schematic floor plan of the house. Further illustrations of the building can be found in Schau *et al*. (2022).

Once initial sketches were completed, a thorough assessment of the structural integrity of the edifice was conducted, resulting in necessary updates to the drawings. The composition of each building component was meticulously determined, and the U-values for the external enclosure were calculated using various online resources. Subsequently, an estimation of the house energy consumption was performed using a simplified building energy calculation method, specifically the Preliminary Passive House Planning tool (in German: *Passivhaus Vorprojektierung* - PHVP) (Feist *et al*., 2002), which is well-suited for the preliminary design stage. Given the building streamlined and compact design, with a deliberate avoidance of windows on the northern facade, the projected energy consumption (heat energy demand) was determined to be 26.9 kWh/m^{2}a. This value adheres to the nZEB requirement outlined in Table 1 for all countries, except Denmark, which imposes more stringent standards. Table 3 summarizes the single-family house with the main components and characteristics.

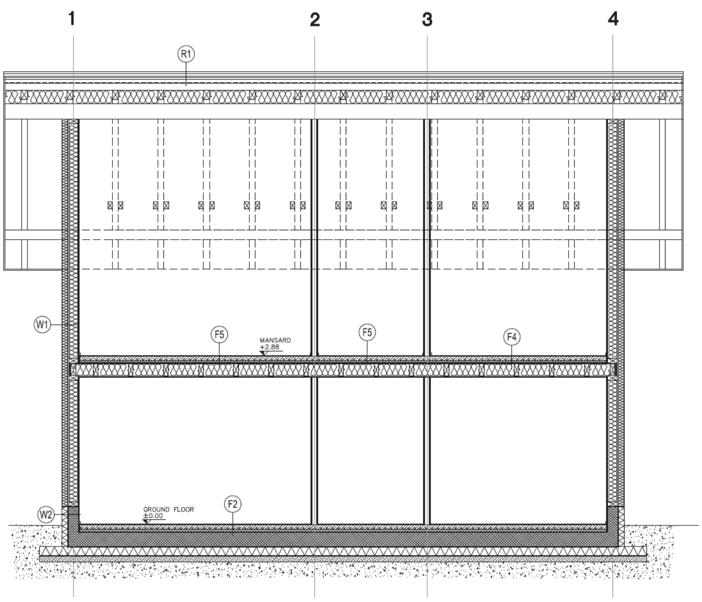

Figure 2 Drawing of section A – B of benchmark house
Slika 2. Prikaz presjeka A – B referentne kuće

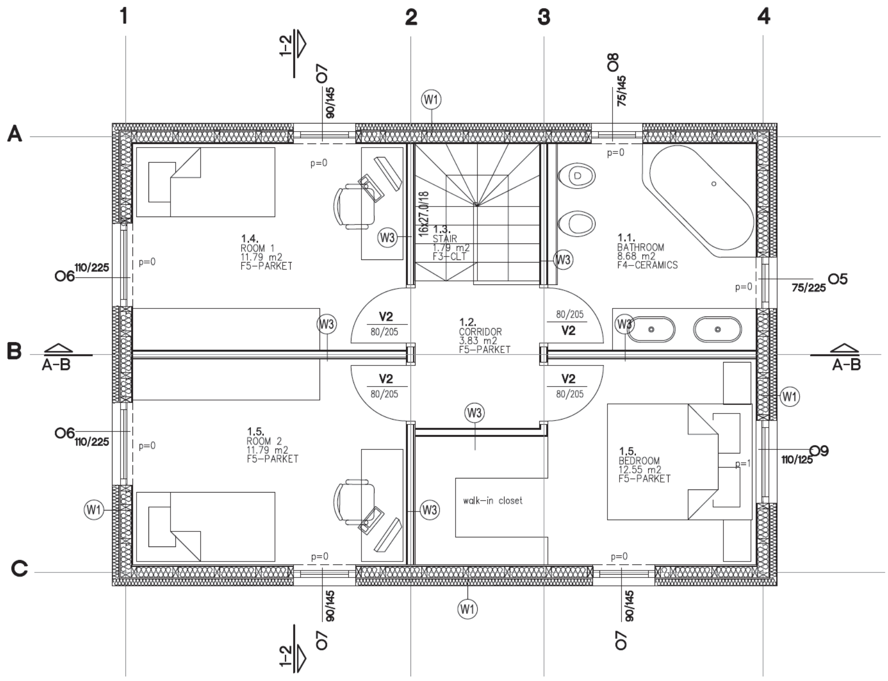

Figure 3 Drawing of the 1st floor of benchmark house
Slika 3. Prikaz prvog kata referentne kuće

3 LIFE CYCLE ASSESSMENT OF A TYPICAL (EUROPEAN AVERAGE) WOODEN SINGLE-FAMILY HOUSE
3. PROCJENA ŽIVOTNOG VIJEKA TIPIČNE (PROSJEČNE EUROPSKE) DRVENE OBITELJSKE KUĆE

3.1 Goal and scope
3.1. Cilj i opseg

The goal of conducting a life cycle assessment (LCA) for an average wooden single-family dwelling is to establish a benchmark that can serve as a reference point for the design of new wooden houses that aim to achieve near-zero energy consumption. This benchmark is intended to assist architects and designers in the early planning stages, when modification is still possible, to enhance the environmental performance of wooden buildings. Additionally, the LCA aims to facilitate the interpretation and communication of LCA outcomes to customers and other stakeholders involved in wooden construction. This is particularly valuable when comparing the environmental impact of various materials or building components, such as the facade.

The functional unit, which serves as the standard reference unit in LCAs, is defined as a single-family house with a projected lifespan of 100 years. This is a long time, but numerous existing wooden buildings that are centuries old (Hill *et al.*, 2022 for some examples) show that a 100-year service life is no problem with regular maintenance. Although our specific dwelling encompasses a living area of 100 m^2, the results are presented per square meter per year in accordance with the EN 15978:2011 and EN 15804:2012 standards, allowing for straightforward comparisons with LCA results from other building designs.

The system boundaries are cradle to grave, starting with the production of the raw materials, like seedling production (i.e. cultivation of plant seeds in a nursery) for trees and forest management for the wood products. The system ends with the final waste treatment of the waste from the deconstructed house, e.g. incinerated. In the case of landfill, the management of the landfill is included in the system boundaries (Module C: End of life). The system is divided into modules based on the EN 15978:2011 and EN 15804:2012 standards (Figure 4 and the Results section 4).

3.2 Life cycle inventory
3.2. Popis stavki koje se uzimaju u obzir pri procjeni životnog vijeka

The house only exists as a model, and therefore, only scenarios - (also for A1 to A3 modules) have been developed. The Modules A1-A3 are the best developed, where detailed drawings of the house have been used to calculate the life cycle inventory. The construction phase (A4-A5) has been calculated based on assumptions in Baldassarri *et al.* (2017) and Lavagna *et al.* (2018). The use stage is based on regular maintenance intervals of 30 and 50 years, resulting in one and two rounds of maintenance, following Baldassari *et al.* (2017) and Lavagna *et al.* (2018).

For the end-of-life and recycling of waste materials (Module C and D), a rather conservative approach is followed, including the transportation to the waste treatment centre (50 km), the treatment at the sorting

Table 2 Summary description of detached house
Tablica 2. Sažeti opis samostojeće kuće

Building typology *Tipologija zgrade*	**Detached house** *Samostojeća kuća*	**Insulation** *Izolacija*	**Mineral wool (10 + 16 cm)** *Mineralna vuna* (10 + 16 cm)
Number of floors *broj katova*	2	External walls finishes *završne obrade vanjskih zidova*	Plaster *gips*
Lifetime of the building, years / *životni vijek zgrade,* godine	100	Windows *prozori*	Wood frame, triple glassed *drveni okvir, trostruko staklo*
Climate *klima*	Moderate (average European) / *umjerena (prosječna europska)*	Roof insulation *izolacija krova*	Pitched, mineral wool (16 + 10 cm) / *nagib, mineralna vuna (16 + 10* cm)
Heating degree days *stupanj dana grijanja*	3500	Bottom floor insulation *izolacija donjeg kata*	(hard + soft) mineral wool (4 + 20 cm) *(tvrda + meka) mineralna vuna (4 + 20* cm)
Year of construction *godina gradnje*	After 2020 *nakon 2020.*	Roof finishes *izolacija krova*	Cement tiles *cementne pločice*
Model dwelling size, m^2 *veličina modela stana,* m^2	100	Internal walls *unutarnji zidovi*	Wood frame *drveni okvir*
Number of inhabitants *broj stanara*	Typically 2 – 4 (2.36*) *obično 2 – 4 (2,36*)*	Internal walls finishes *završne obrade unutarnjih zidova*	Plasterboard *gipsane ploče*
Internal height, m *unutarnja visina,* m	2.5	Flooring *podovi*	Ceramic tiles and wood *keramičke pločice i drvo*
Window-to-wall ratio *odnos prozora i zida*	0.21	U-value walls, W/(m²K) *U-vrijednosti zidova,* W/(m²K)	0.154**
Construction technology *tehnologija gradnje*	Light, dry assembly *lagana, suha montaža*	U-value roof *U-vrijednost krova*	0.132
Foundations *temelji*	Reinforced concrete *ojačani beton*	U-value windows *U-vrijednost prozora*	0.8 ***
Load bearing elements *nosivi elementi*	Timber frame *drveni okvir*	U-value bottom floor *U-vrijednost donjeg kata*	0.175
Floors (structure) *podovi (struktura)*	Timber frame + board *drveni okvir + ploča*	Heating energy consumption, kWh/(m^2·year) *potrošnja energije za grijanje,* kWh/(m^2·godina)	29.7
Stairs *stubišta*	Timber frame *drveni okvir*	Heating systems *sustavi grijanja*	Boiler and electricity *bojler i struja*
External walls *vanjski zidovi*	Timber frame *drveni okvir*		

*Statistical value based on dwelling size (100 m^2 and average floor occupancy in Europe) / *statistička vrijednost na temelju veličine stana (100* m^2 *i prosječna veličina poda u Europi)*
**Weighted average of the U-value for the walls / *ponderirani prosjek U-vrijednosti za zidove*
***Assumed U-Values; glass 0.7 and frame 1.0 as in PHVP 2.0 (Feist *et al.* 2002) / *pretpostavljene U-vrijednosti; staklo 0,7 i okvir 1,0 kao u PHVP 2.0* (Feist *et al*., 2002.)

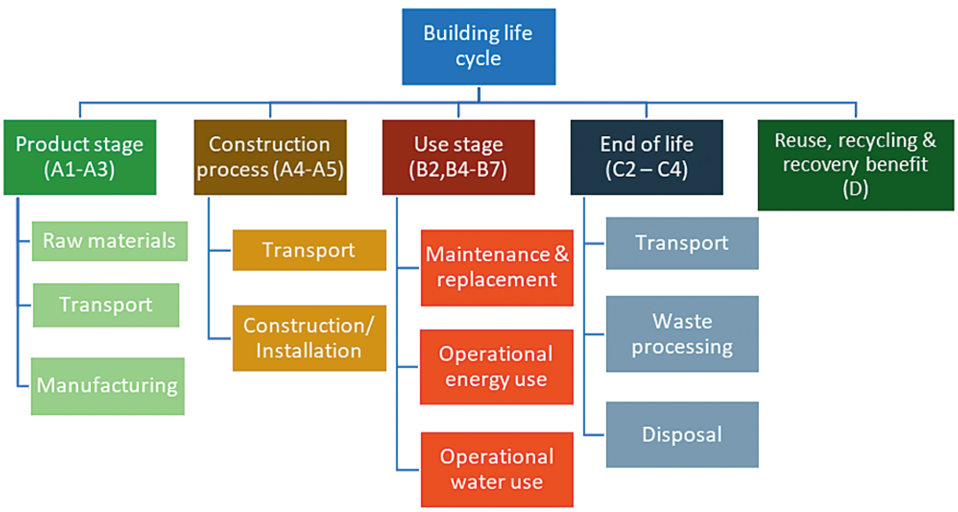

Figure 4 System divided into modules based on EN 15978:2011 and EN 15804:2012 standards
Slika 4. Sustav podijeljen na module prema standardima EN 15978:2011 i EN 15804:2012.

plant (machines for handling, electricity demand, emissions from handling) and any impacts of landfill disposal (residual inert masses), as well as impacts and benefits associated with recycling operations, according to Baldassarri *et al*. (2017) and Lavagna *et al*. (2018). After treatment, the sorted materials can be landfilled, incinerated or recycled (Lavagna *et al*., 2018). In Module D, the benefits from the materials that are considered recycled (avoided production) and energy recovery (incineration with energy production) are reported.

Building services appliances like boilers, pipes, and ducts are excluded from the analysis.

The impact categories chosen are from the EU-recommended Environmental Footprint (EF) method, with 16 impact indicators. Version 2.0 (as available in SimaPro, Pre Consultants, 2019) was applied, with the following adjustment: The climate change indicator is further subdivided into three sub-indicators – fossil, biogenic and land use/transformation (see Results section). To better assess the different life cycle stages from a climate change perspective and to best fit the Ecoinvent database as implemented in SimaPro, we changed the climate change sub-indicator biogenic to -1 for the uptake of CO_2 (air raw) and the emissions of $CO_{2,biogenic}$ to +1 (which are both set to 0 in the EF method). This is in line with EN 15804:A2 (2019). For even more transparency on the climate change indicator, we also included two additional indicators; 1) *climate change, biogenic, emissions* (where biogenic CO, CO_2 and methane emissions are calculated and 2) *climate change, biogenic, uptake* (where biogenic CO_2 uptake, mainly by the growing tree in the sustainable managed forest is calculated. However, these changes and additions do not impact the results from cradle to grave, nor are they considered for the normalization and weighting.

Also, as the three toxicity impact categories directly taken over from the International Reference Life Cycle Data System (ILCD) impact categories are not considered stable, and newer background data for these are underway, we limit our results to the 13 other impact indicators.

Data collection, which is the starting point for the life cycle inventory, was based on the detailed architectural drawings of the house (see Figures 1-3). Table 2 shows an example of data collection for one element of the house, the external walls (W1), while Table 3 shows the external walls with ceramics in bathrooms (W1’). The full material lists can be found in Supplementary Material (SM) 2.

In the supplementary material, Table SM1 shows the complete area calculation based on the architectural drawings, and Table SM2 shows the calculations of all the material quantities.

Table 3 First example of data collection for external walls (W1)
Tablica 3. Prvi primjer prikupljanja podataka za vanjske zidove (W1)

W1 – exterior walls (dimension) / *W1 – vanjski zidovi (dimenzije)*	**Quantity** *Količina*	**Unit** *Jedinica*
Gypsum plasterboards (1.25 cm) / *gips-kartonske ploče (1,25 cm)*	131.32	m^2
OSB plate (1.2 cm) / *OSB ploče (1,2 cm)*	131.32	m^2
Stone wool between the load-bearing construction profiles (16 cm) *kamena vuna između nosivih građevnih profila (16 cm)*	21.01	m^3
Load-bearing construction profiles (8/16 cm) / *nosivi građevni profili (8/16 cm)*	5.25	m^3
Gypsum fibreboard (1.5 cm) / *gips-vlaknaste ploče (1,5 cm)*	131.32	m^2
Stone wool (10 cm) / *kamena vuna (10 cm)*	13.13	m^3
Reinforcing mortar, mesh and finishing plaster (0.6 cm) *ojačani mort, mrežica i završna žbuka (0,6 cm)*	131.32	m^2

Table 4 Second example of data collection for external walls with ceramics in bathrooms (W1‘)
Tablica 4. Drugi primjer prikupljanja podataka za vanjske zidove s keramikom u kupaonicama (W1‘)

W1‘ – exterior walls – ceramics in bathrooms (dimension) *W1’ – vanjski zidovi – keramika u kupaonicama (dimenzije)*	**Quantity** *Količina*	**Unit** *Jedinica*
Ceramic plates (1 cm) / *keramičke pločice (1 cm)*	10.73	m^2
Glue for ceramic plates (0.5 cm) / *ljepilo za keramičke pločice (0,5 cm)*	10.73	m^2
Hydro-isolating layer (0.3 cm) / *hidroizolacijski sloj (0,3 cm)*	10.73	m^2
Gypsum plasterboards (1.25 cm) / *gips-kartonske ploče (1,25 cm)*	10.73	m^2
OSB plate (1.2 cm) / *OSB ploče (1,2 cm)*	10.73	m^2
Stone wool between load bearing construction profiles (16 cm) *kamena vuna između nosivih građevnih profila (16 cm)*	1.72	m^3
Load bearing construction profiles (8/16 cm) / *nosivi građevni profili (8/16 cm)*	0.43	m^3
Gypsum fibreboard (1.5 cm) / *gips-vlaknaste ploče (1,5 cm)*	10.73	m^2
Stone wool (10 cm) / *kamena vuna (10 cm)*	1.07	m^3
Reinforcing mortar, mesh and finishing plaster (0.6 cm) *ojačani mort, mrežica i završna žbuka (0,6 cm)*	10.73	m^2

Table 5 Material quantities used for construction and maintenance (own data, c.f. supplementary materials) in addition to waste handling scenario (Baldassari *et al*., 2017; Lavagna *et al*., 2018)
Tablica 5. Količine materijala upotrijebljene za izgradnju i održavanje (vlastiti podatci, c.f. dodatak) uz scenarij rukovanja otpadom (Baldassari *et al*., 2017.; Lavagna *et al*., 2018.)

Material *Materijal*	**Quantities for construction** *Količine za gradnju,* kg	**Quantities for maintenance** *Količine za održavanje,* kg	**Waste handling scenario** *Scenarij postupanja s otpadom*		
			% to landfill *Postotak za odlagalište*	**% to incineration** *Postotak za spaljivanje*	**% to recycling** *Postotak za recikliranje*
Concrete / *beton*	57621	0	40		60
Gypsum / *gips*	9922	17186	85		15
Wood / *drvo*	12707	5354	35	34	31
Sawnwood / *piljeno drvo*	7419	821			
Window frame, wood *prozorski okvir, drvo*	1681	3122			
OSB	1502	0			
Fibreboard / *ploča vlaknatica*	423	987			
Glued laminated timber *lamelirana drvna građa*	1258	0			
Door, inner, wood *unutarnja vrata, drvo*	356	356			
Door, outer, wood-glass *vanjska vrata, drvo-staklo*	67	67			
Insulation, stone wool *izolacija, kamena vuna*	4355	10161	100		
Cement / *cement*	4342	2466	38.8		61.2
Gravel / *šljunak*	5858	0	40		60
Ceramic / *keramika*	1439	1923	40		60
Glass /*staklo*	1019	1892	90		10
Plastic / *plastika*	660	806	90		10
Steel / *čelik*	1286	41			100
Insulation, polystyrene *izolacija, stiropor*	288	673	100		
Glue / *ljepilo*	395	547	91.6	1.9	6.5
Bitumen / *bitumen*	591	0	50	50	
Copper / *bakar*	23	23			100
Aluminium / *aluminij*	12	0			100

Table 4 shows an overview of the materials used for construction and maintenance of the benchmark house in addition to the waste handling scenario applied for each of the different material groups. Based on common practice, we assumed that over the course of the building's 100-year lifetime, a maintenance interval of 30 years will necessitate two maintenance events. A 50-year maintenance interval will require only one. For some materials, typically the foundation and well protected structural component, no replacements during the 100-year service life is foreseen. Weathering exposed building components, like windows with frames of wood and glass sheets, are expected to be changed after 30 and 60 years and therefore, the quantities for the maintenance might be higher than that of the initial construction.

The life cycle inventory data and modelling follow closely the data and life cycle inventory modelling for the environmental impact of housing in Europe; *Consumer Footprint – Basket of Products indicator on Housing* (Baldassarri *et al*., 2017; Lavagna *et al*., 2018), where the Ecoinvent database v 3.2. was used. We use Ecoinvent version 3.5 (Ecoinvent Centre, 2018) with allocation, cut off by classification, as implemented in SimaPro v 9.0 (Pré Consultants, 2019) for the background data. Transport of materials for maintenance is assumed to be over a distance of 100 km and with a Euro 6 lorry (16 – 32 metric ton), while transport of waste is assumed to be over a distance of 50 km. Regarding energy for heating and warm water, we assumed a mix consisting of 25 % natural gas, 25 % biomass (e.g. wood pellets), 25 % electricity (e.g. heat pumps) and 25 % district heating (other than natural gas). This differs from a typical house, which usually relies on one or two energy sources. However, the use of four different energy sources is applicable for our model of an average wooden house used as a benchmark in this study. Heating with oil, a method still in use today, was not included in our considerations. This is due to its phase-out in several countries, such as Germany and Norway. Consequently, it is believed to hold minor relevance for new buildings.

4 RESULTS
4. REZULTATI

The findings highlighted in Table 5 provide a comprehensive overview of the assessment results, shedding light on the various stages that significantly contribute to the environmental impact of the house. Notably, the operational stage (Module B6 and B7) emerges as a dominant factor due to the substantial energy consumption required for heating and water usage. It is during this use-phase that the house's environmental footprint is most pronounced.

However, it is crucial to recognize that the impact categories related to land use and resource utilization, particularly minerals and metals, are primarily influenced by the earlier product stages (modules A1-A3 Production). This implies that decisions made during the production phase, such as the extraction and processing of raw materials, have lasting consequences on the overall environmental performance of the house.

In addition, maintenance activities (B2 and B4-B5) also have a significant influence on the environmental footprint results. The extensive utilization of materials over the 100-year maintenance period leads to notable impacts in terms of land use and resource consumption. Specifically, the management and transformation of land for obtaining wood products, sourced from forest management areas, contribute to the overall land use impacts observed.

Also, the *climate change* impact category is dominated by the operational use phase (especially the heating demand in Module B6) caused by fossil fuel and electricity for heating. For *climate change – biogenic*, the end-of-life (C2-C4) waste treatment with landfill and incineration are most important. The production phase (A1-A3) provides a considerable negative contribution to *climate change – biogenic*. We can see from the additional impact categories *biogenic, emissions* and *biogenic, uptake* that this is caused by the uptake of CO_2 from the atmosphere, mainly in the production of wood in the forest. These two additional impact categories reveal that in the Use phase, biogenic energy sources are used for heating and warm water (with CO_2 uptake when growing and release when incinerated, e.g. wood pellets). For the so-called recycling benefit in Module D, this is not a benefit for *climate change – biogenic* as recycled wood from the building is assumed to replace other wood that would have taken up CO_2 from the atmosphere. *Climate change – land use* and *land transformation*, are of minor importance for the benchmark house compared to the other climate change impact categories.

These findings underscore the importance of considering the entire life cycle of the house when assessing its environmental impact. By comprehensively evaluating the operational stage, product stages, and maintenance activities, a more holistic understanding of the house's sustainability performance can be obtained. This knowledge can inform decision-making processes and guide efforts toward reducing the environmental burdens associated with each stage, ultimately fostering the development of more environmentally responsible and resource-efficient housing solutions.

To come to the normalized results shown in Table 7, the characterized results are divided by the reference unit, that is, the impact for each impact category is di-

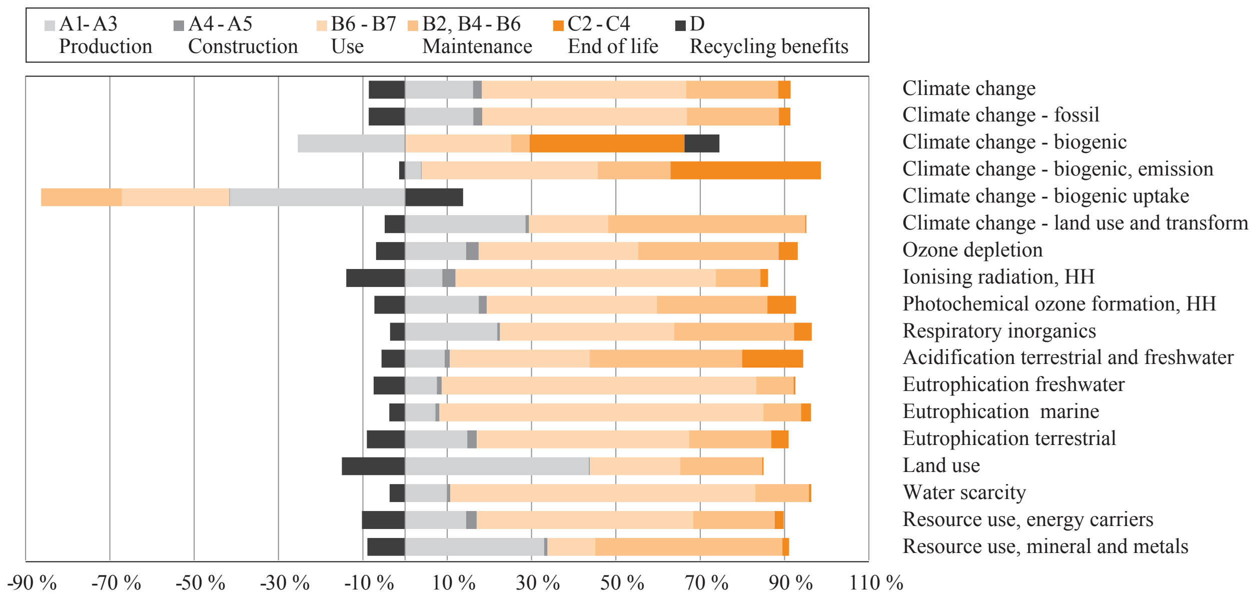

Figure 5 Characterized results showing contribution of different life cycles for impact indicators and sub-indicators investigated
Slika 5. Obrađeni rezultati koji pokazuju djelovanje različitih životnih ciklusa na ispitane pokazatelje utjecaja i podindikatore

Table 6 Characterized results (per m² and year) broken down to different stages/modules
Tablica 6. Obrađeni rezultati (po m² i godini) raščlanjeni na različite faze/module

Impact category *Utjecajne kategorije*	**Unit** *Jedinica*	**A1 - A3 Production** *Proizvodnja*	**A4 - A5 Construction** *Gradnja*	**B6-B7 Use** *Uporaba*	**B2, B4-B6 Maintenance** *Održavanje*	**C2 - C4 End of life** *Kraj životnog vijeka*	**D Recycling benefits** *Prednosti recikliranja*	**Total** *Ukupno*
Climate change / *klimatske promjene*	kg CO_2 eq	2.99E+00	3.90E-01	8.98E+00	4.06E+00	5.36E-01	-1.59E+00	1.54E+01
Climate change – fossil *klimatske promjene – fosilne sirovine*	kg CO_2 eq	2.97E+00	3.88E-01	8.89E+00	4.00E+00	5.00E-01	-1.58E+00	1.52E+01
Climate change – biogenic (adapted) *klimatske promjene – biogene sirovine (prilagođene)*	kg CO_2 eq	-3.96E+00	6.66E-03	3.91E+00	6.76E-01	5.71E+00	1.29E+00	7.64E+00
Climate change - biogenic, emission *klimatske promjene – biogene sirovine, emisije*	kg CO_2 eq	6.05E-01	2.30E-02	6.70E+00	2.77E+00	5.72E+00	-2.22E-01	1.56E+01
Climate change - biogenic, uptake *klimatske promjene – biogene sirovine, apsorpcija*	kg CO_2 eq	-4.56E+00	-1.64E-02	-2.79E+00	-2.09E+00	-4.02E-03	1.51E+00	-7.96E+00
Climate change - land use and land, transformation *klimatske promjene – zemljišta i iskorištavanje zemljišta, transformacija*	kg CO_2 eq	1.92E-02	5.54E-04	1.26E-02	3.14E-02	1.90E-04	-3.25E-03	6.07E-02
Ozone depletion / *oštećenje ozonskog omotača*	kg CFC11 eq	2.60E-07	5.31E-08	6.79E-07	5.98E-07	8.10E-08	-1.23E-07	1.55E-06
Ionising radiation, HH / *ionizirajuće zračenje, HH*	kBq U^{235} eq	1.42E-01	5.04E-02	9.89E-01	1.69E-01	2.90E-02	-2.23E-01	1.16E+00
Photochemical ozone formation, HH *fotokemijsko stvaranje ozona, HH*	kg NMVOC eq	1.24E-02	1.34E-03	2.87E-02	1.87E-02	4.84E-03	-5.17E-03	6.08E-02
Respiratory inorganics *respiratorni anorganski utjecaji*	disease inc.	5.35E-07	1.60E-08	1.01E-06	6.96E-07	1.03E-07	-8.69E-08	2.27E-06
Acidification terrestrial and freshwater *zakiseljavanje kopna i slatkih voda*	mol H^+ eq	1.95E-02	2.52E-03	6.87E-02	7.50E-02	3.00E-02	-1.16E-02	1.84E-01
Eutrophication freshwater / *eutrofikacija slatke vode*	kg P eq	1.95E-04	2.94E-05	1.93E-03	2.28E-04	1.15E-05	-1.92E-04	2.20E-03
Eutrophication marine / *eutrofikacija mora*	kg N eq	3.23E-03	4.38E-04	3.45E-02	4.00E-03	1.06E-03	-1.68E-03	4.15E-02
Eutrophication terrestrial / *eutrofikacija kopna*	mol N eq	4.34E-02	6.67E-03	1.48E-01	5.74E-02	1.20E-02	-2.66E-02	2.41E-01
Land use / *upotreba zemljišta*	Pt	7.97E+02	4.07E+00	3.90E+02	3.57E+02	5.68E+00	-2.74E+02	1.28E+03
Water scarcity / *nestašica vode*	m^3 depriv.	1.06E+00	8.24E-02	7.69E+00	1.35E+00	6.02E-02	-3.89E-01	9.86E+00
Resource use, energy carriers *iskorištavanje resursa, nositelji energije*	MJ	4.13E+01	7.11E+00	1.46E+02	5.52E+01	6.05E+00	-2.91E+01	2.27E+02
Resource use, mineral and metals *iskorištavanje resursa, minerali i metali*	kg Sb eq	3.19E-05	7.82E-07	1.09E-05	4.29E-05	1.53E-06	-8.64E-06	7.95E-05

Table 7 Normalized results – Global 2010 (unitless per m^2 and year) broken down to different stages/modules
Tablica 7. Normalizirani rezultati – globalno u 2010. (bez jedinica po m^2 i godini) raščlanjeni na različite faze/module

Impact category *Utjecajne kategorije*	**A1 - A3 Production** *Proizvodnja*	**A4 - A5 Construction** *Gradnja*	**B6-B7 Use** *Uporaba*	**B2, B4-B6 Maintenance** *Održavanje*	**C2 - C4 End of life** *Kraj životnog vijeka*	**D Recycling benefits** *Prednosti recikliranja*	**Total** *Ukupno*
Climate change *klimatske promjene*	3.86E-04	5.02E-05	1.16E-03	5.23E-04	6.91E-05	-2.05E-04	1.98E-03
Ozone depletion *oštećenje ozonskog omotača*	1.11E-05	2.27E-06	2.91E-05	2.56E-05	3.47E-06	-5.28E-06	6.63E-05
Ionising radiation, HH *ionizirajuće zračenje, HH*	3.36E-05	1.19E-05	2.34E-04	4.01E-05	6.87E-06	-5.29E-05	2.74E-04
Photochemical ozone formation, HH *fotokemijsko stvaranje ozona, HH*	3.06E-04	3.30E-05	7.06E-04	4.59E-04	1.19E-04	-1.27E-04	1.50E-03
Respiratory inorganics *respiratorni anorganski utjecaji*	8.41E-04	2.52E-05	1.59E-03	1.09E-03	1.62E-04	-1.37E-04	3.57E-03
Acidification terrestrial and freshwater *zakiseljavanje kopna i slatkih voda*	3.51E-04	4.54E-05	1.24E-03	1.35E-03	5.40E-04	-2.08E-04	3.32E-03
Eutrophication freshwater *eutrofikacija slatke vode*	7.63E-05	1.15E-05	7.56E-04	8.93E-05	4.50E-06	-7.53E-05	8.62E-04
Eutrophication marine *eutrofikacija mora*	1.14E-04	1.55E-05	1.22E-03	1.41E-04	3.75E-05	-5.94E-05	1.47E-03
Eutrophication terrestrial *eutrofikacija kopna*	2.45E-04	3.77E-05	8.36E-04	3.24E-04	6.79E-05	-1.50E-04	1.36E-03
Land use / *upotreba zemljišta*	5.97E-04	3.05E-06	2.93E-04	2.67E-04	4.25E-06	-2.05E-04	9.59E-04
Water scarcity / *nestašica vode*	9.23E-05	7.18E-06	6.71E-04	1.18E-04	5.25E-06	-3.39E-05	8.59E-04
Resource use, energy carriers *iskorištavanje resursa, nositelji energije*	6.33E-04	1.09E-04	2.24E-03	8.45E-04	9.27E-05	-4.46E-04	3.48E-03
Resource use, mineral and metals *iskorištavanje resursa, minerali i metali*	5.51E-04	1.35E-05	1.89E-04	7.42E-04	2.64E-05	-1.49E-04	1.37E-03

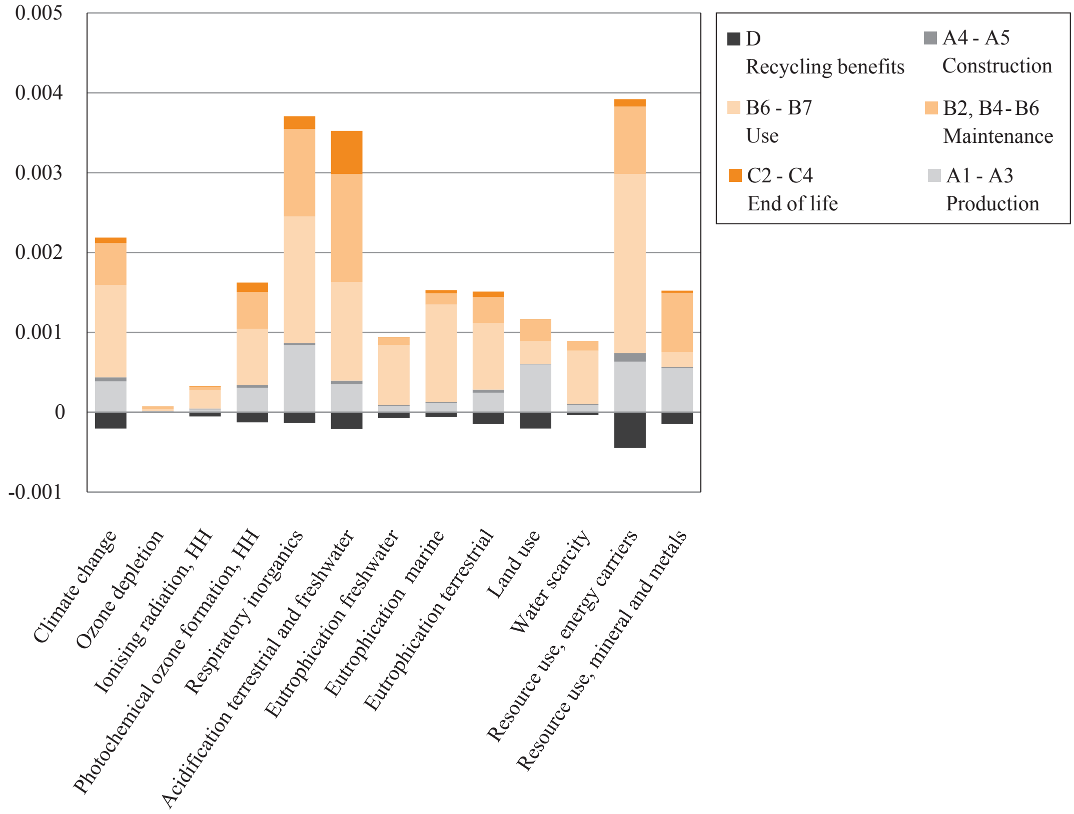

Figure 6 Normalized results Global 2010 (unitless, per m² and year)
Slika 6. Globalni normalizirani rezultati u 2010. (bez jedinica, po m² i godini)

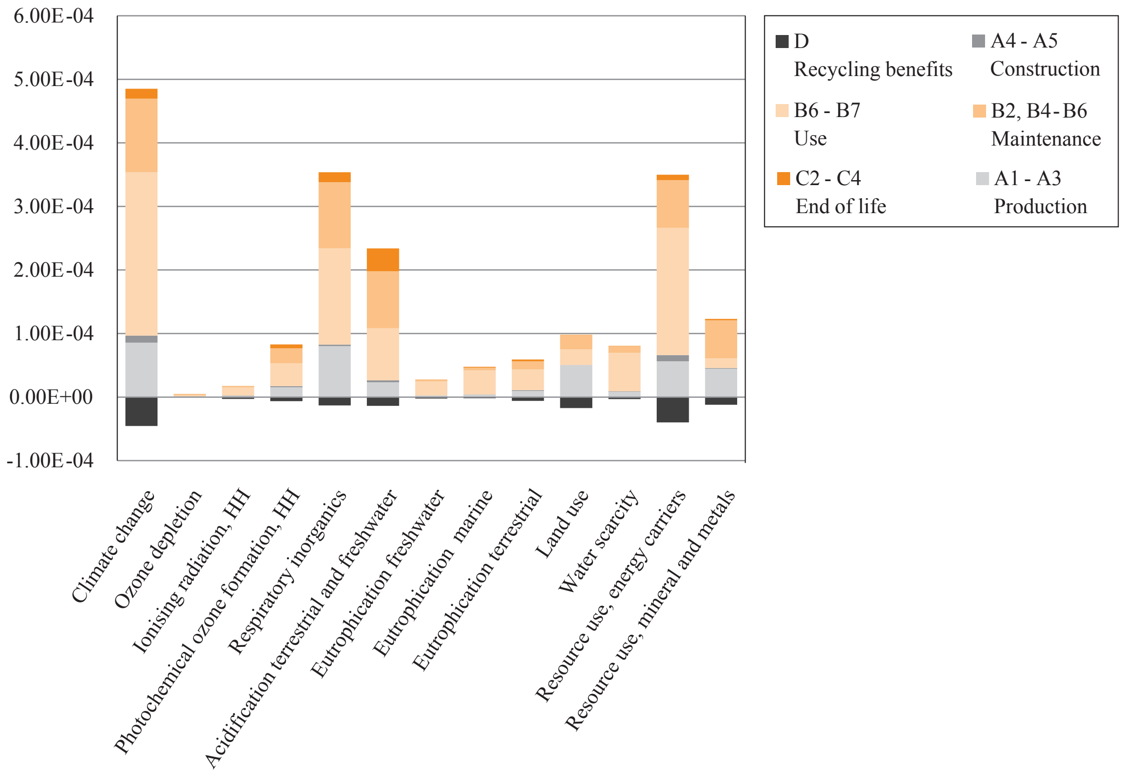

Figure 7 Weighted results (weighting points per m² and year)
Slika 7. Ponderirani rezultati (ponderi, po m² i godini)

Table 8 Weighted results and total (weighting points per m^2 and year)
Tablica 8. Ponderirani i ukupni rezultati (ponderi, po m^2 i godini)

Impact category *Utjecajne kategorije* **Units: pt** *Jedinice: bod*	**A1 - A3 Production** *Proizvodnja*	**A4 - A5 Construction** *Gradnja*	**B6-B7 Use** *Uporaba*	**B2, B4-B6 Maintenance** *Održavanje*	**C2 - C4 End of life** *Kraj životnog vijeka*	**D Recycling benefits** *Prednosti recikliranja*	**Total** *Ukupno*
Climate change *klimatske promjene*	8.56E-05	1.11E-05	2.57E-04	1.16E-04	1.53E-05	-4.55E-05	4.40E-04
Ozone depletion *oštećenje ozonskog omotača*	7.52E-07	1.53E-07	1.96E-06	1.73E-06	2.34E-07	-3.57E-07	4.47E-06
Ionising radiation, HH *ionizirajuće zračenje, HH*	1.80E-06	6.42E-07	1.26E-05	2.16E-06	3.69E-07	-2.84E-06	1.47E-05
Photochemical ozone formation, HH *fotokemijsko stvaranje ozona, HH*	1.56E-05	1.68E-06	3.60E-05	2.34E-05	6.08E-06	-6.49E-06	7.63E-05
Respiratory inorganics *respiratorni anorganski utjecaji*	8.02E-05	2.40E-06	1.51E-04	1.04E-04	1.55E-05	-1.30E-05	3.41E-04
Acidification terrestrial and freshwater *zakiseljavanje kopna i slatkih voda*	2.33E-05	3.02E-06	8.21E-05	8.97E-05	3.59E-05	-1.38E-05	2.20E-04
Eutrophication freshwater *eutrofikacija slatke vode*	2.25E-06	3.40E-07	2.23E-05	2.63E-06	1.33E-07	-2.22E-06	2.54E-05
Eutrophication marine *eutrofikacija mora*	3.56E-06	4.84E-07	3.80E-05	4.41E-06	1.17E-06	-1.85E-06	4.58E-05
Eutrophication terrestrial *eutrofikacija kopna*	9.58E-06	1.47E-06	3.27E-05	1.27E-05	2.66E-06	-5.88E-06	5.32E-05
Land use / *upotreba zemljišta*	5.03E-05	2.57E-07	2.46E-05	2.25E-05	3.58E-07	-1.73E-05	8.08E-05
Water scarcity / *nestašica vode*	8.33E-06	6.49E-07	6.06E-05	1.06E-05	4.74E-07	-3.06E-06	7.76E-05
Resource use, energy carriers *iskorištavanje resursa, nositelji energije*	5.64E-05	9.71E-06	2.00E-04	7.54E-05	8.27E-06	-3.98E-05	3.10E-04
Resource use, mineral and metals *iskorištavanje resursa, minerali i metali*	4.45E-05	1.09E-06	1.53E-05	6.00E-05	2.13E-06	-1.21E-05	1.11E-04
Total / *ukupno*	3.82E-04	3.30E-05	9.34E-04	5.26E-04	8.86E-05	-1.64E-04	1.80E-03

vided by the average world inhabitants in the year 2010 (Fazio *et al*., 2018; Pre Consultants, 2019). The normalized results show that the respiratory inorganics impact category, closely followed by resource use, energy carriers and acidification terrestrial and freshwater are the dominant impact categories before weighting. The ozone depletion impact category is of minor importance.

The weighted results in Table 8 and Figure 7 show that the impact category climate change is most important, followed by resource use, energy and respiratory inorganics. The impact category ozone depletion is less relevant, as expected also in the weighted results.

5 DISCUSSION
5. RASPRAVA

This study presents the outcomes of a comprehensive life cycle assessment (LCA) conducted on a typical residential wooden building in Europe.

Despite incorporating design improvements, such as enhanced insulation and reduced windows areas towards the north, the results underscore the continued significance of the Use phase, particularly in relation to heating, as a primary contributor to the investigated environmental impact categories. It is within this stage that considerable environmental effects are observed.

Among the various impact categories examined, climate change emerges as the most prominent and influential. This finding highlights the substantial role played by the residential building sector in contributing to climate-altering greenhouse gas emissions and emphasizes the urgent need for sustainable solutions to mitigate these effects. However, three further impact categories, namely respiratory inorganics (particulate matter), resource use - energy carriers and acidification terrestrial and freshwater are also important.

By comprehensively assessing the cradle-to-grave life cycle of the average wooden residential building, this study provides valuable insights into the environmental implications associated with its construction and use. The findings underscore the importance of continually improving building designs and technologies to minimize the environmental impact of the use phase, particularly in terms of energy consumption for heating. Furthermore, the focus on climate change as the key impact category serves as a reminder of the pressing global challenges and the imperative to adopt eco-friendly practices in the construction and operation of residential buildings.

The Modules A4-A5 Construction phase is of minor importance compared to the whole life cycle but relies on assumptions based on literature ((Baldassarri *et al*., 2017; Lavagna *et al*., 2018). Waste handling at end of life has little impact on the total contribution. This is partially achieved by reuse and material recycling of some of the waste material from the demolition of the house. In practice, waste handling will occur decades or years into the future, and it is difficult to develop realistic future waste scenarios. However, waste handling is modelled based on the present situation. The connected recycling benefits (Module D) compensate to a certain degree some of the environmental impacts. Reuse and material recycling are believed to increase a lot in line with the EU circular economy policy, but as this is a long-lived house with a modelled 100-year lifetime, the positive effects are something to wait for decades, so that a conservative approach was followed.

6 CONCLUSION
6. ZAKLJUČAK

In making the assessment, the recommended Environmental Footprint (EF) indicators were used as prescribed by the European Union to explore the entire cradle-to-grave life cycle of the wooden single-family house, encompassing Modules A1 to D. The aim was to establish the house as a benchmark for evaluating environmental performance.

Despite design improvements, the Use phase, particularly heating, remained a significant contributor to the environmental impact categories examined. Climate change emerged as the most prominent impact category, underscoring the urgent need for sustainable practices in the construction and operation of residential buildings. Other important impact categories included respiratory inorganics (particulate matter), resource use, energy carriers, and acidification terrestrial and freshwater.

The study highlights the importance of continually improving building designs and technologies to minimize the environmental impact of the Use phase. It also emphasizes the global challenges associated with climate change and the necessity of adopting eco-friendly practices in the residential building sector.

The Construction phase had a minor impact compared to the overall life cycle, and waste handling at the end of life had little influence on the total contribution. Assumptions based on literature and current waste handling practices were made, but future waste scenarios are uncertain. However, the potential benefits of reuse and material recycling in line with the EU circular economy policy were acknowledged, although their effects may take decades to be fully realized.

Overall, this study sheds light on the environmental considerations of residential wooden buildings and underscores the importance of sustainable approaches throughout their life cycle. It serves as a reminder of the need for continuous improvement and the adoption of environmentally sound practices in the construction and use of buildings to mitigate climate change and minimize overall environmental impacts.

Future studies should apply the new EU Environmental Footprint method v.3, including the new toxicity impact indicators, such that these can be included, as this was not yet implemented in the software used at the time of our impact assessment calculations. Also, a better estimation of both the actual heating demand and the heat source mix for future buildings should be determined. Different scenarios for waste handling, and especially recycling rates, should be investigated as these might lower the total environmental burden.

The results could be used to compare to existing housing but mainly to design more environmentally sound single-family houses and establish and compare the reference houses in specific countries. Other building types, like multi-family houses and other buildings made of wood, could be investigated based on the same life cycle assessment concept and calculations.

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SUPPLEMENT – DODATAK

Table SM1 Calculation of areas based on architectural drawings
Tablica SM1. Izračun površina na temelju arhitektonskih nacrta

W1 – exterior walls / *Vanjski zidovi*					
	L, m	*h*, m	*A*_full wall, m²	*A*_openings, m²	*A*_total, m²
W1_A	9.63	4.78	46.03	2.69	36.89
W1_C	9.63	4.78	46.03	8.45	37.58
W1_1	6.70	5.85	39.20	8.66	30.53
W1_4	6.70	5.85	39.20	8.60	26.33
W1_Total					131.32

W1' – exterior walls – ceramics in bathrooms / *Vanjski zidovi – keramika u kupaonicama*					
	L, m	*h*, m	*A*_full wall, m²	*A*_openings, m²	*A*_total, m²
W1'_gf_A	1.04	2.00	2.08	0.30	1.78
W1'_1f_A	2.88	2.00	5.76	1.09	4.67
W1'_1f_4	2.98	2.00	5.96	1.69	4.27
W1'_Total					10.73

W2 – exterior walls – ground floor bottom / *Vanjski zidovi – prizemlje dolje*					
	L, m	*h*, m	*A*_full wall, m²	*A*_openings, m²	*A*_total, m²
W2_A	9.63	0.69	6.64	0.00	6.64
W2_C	9.63	0.69	6.64	0.00	6.64
W2_1	6.70	0.69	4.62	0.00	4.62
W2_4	6.70	0.69	4.62	0.00	4.62
W2_Total					22.54

W3 – inner walls / *Unutarnji zidovi*					
	L, m	*h*, m	*A*_full wall, m²	*A*_openings, m²	*A*_total, m²
W3_gf_A'	1.06	2.67	2.83	1.44	1.40
W3_gf_B	5.06	2.67	13.51	3.28	10.23
W3_gf_2	5.14	2.67	13.72	0.00	13.72
W3_gf_3.1	1.70	0.67	1.14	0.00	1.14
W3_gf_3.2	4.39	2.67	11.72	1.64	10.08
W3_gf_3'	1.83	0.67	1.23	0.00	1.23
W3_1f_B.1	3.96	4.16	16.47	0.00	16.47
W3_1f_B.2	3.02	2.16	6.52	0.00	6.52
W3_1f_B'	1.93	3.77	7.28	0.00	7.28
W3_1f_2	6.09	3.40	20.71	3.28	17.43
W3_1f_3	4.23	3.40	10.32	3.28	7.04
W3_Total					92.54

W3' – inner walls – ceramics in bathrooms / *Unutarnji zidovi – keramika u kupaonicama*					
	L, m	*h*, m	*A*_full wall, m²	*A*_openings, m²	*A*_total, m²
W3'_gf_3	1.7	2.00	3.40	0.00	3.40
W3' gf_3'	1.83	2.00	3.66	0.00	3.66
W3'_1f_B.2	3.02	2.00	6.04	0.00	6.04
W3'_1f_3	2.03	2.00	4.06	0.00	4.06
W3'_Total					17.16

R1 – roof / *Krov*					
	L, m	*h*, m	*A*_full wall, m²	*A*_openings, m²	*A*_total, m²
R1	11.61	5.31	61.65	0.00	61.65
R2	11.61	5.31	61.65	0	61.65
R1_Total					123.30

Table SM1 continuation
Tablica SM1. nastavak

F – ground floor / *Prizemlje*					
					*A*_total, m^2
F1					19.17
F1/A					1.53
F2					34.20
F3					3.58

F – 1st floor / *Prvi kat*					
					*A*_total, m^2
F4					9.54
F5					41.78

Windows / *Prozori*			
	b, m	*h*, m	*A*, m^2
O1	0.9	2.05	1.85
O2	1.72	1.25	2.15
O3	2.58	2.05	5.29
O4	0.6	0.5	0.30
O5	0.75	2.25	1.69
O6	1.1	2.25	2.48
O7	0.9	1.45	1.31
O8	0.75	1.45	1.09
O9	1.1	1.25	1.38

Doors / *Vrata*			
	b, m	*h*, m	*A*, m^2
V1	0.9	2.05	1.85
V2	0.8	2.05	1.64
V3	0.7	2.05	1.44

Table SM2 Calculation of material quantities
Tablica SM2. Proračun količina materijala

	W1 – exterior walls / *Vanjski zidovi*	**Quantity** *Količina*	**Unit** *Jedinica*	**Volume, m³** *Volumen,* m³	**Density, kg/m³** *Gustoća,* kg/m³	**Mass, kg** *Masa,* kg
1	gypsum plasterboards – 1.25 cm	131.32	m^2	1.642	900	1477.4
2	OSB plate – 1.2 cm	131.32	m^2	1.576	650	1024.3
3	stone wool between the load bearing construction profiles – 16 cm	21.01	m^3	21.012	40	840.5
4	load bearing construction profiles – 8/16 cm	5.25	m^3	5.253	420	2206.2
5	gypsum fibreboard – 1.5 cm	131.32	m^2	1.970	1200	2363.8
6	stone wool – 10 cm	13.13	m^3	13.132	80	1050.6
7	reinforcing mortar, mesh and finishing plaster – 0.6 cm	131.32	m^2	0.788	1900	1497.1

	W1‘ – exterior walls – ceramics in bathrooms / *Vanjski zidovi – keramika u kupaonicama*	**Quantity** *Količina*	**Unit** *Jedinica*	**Volume, m³** *Volumen,* m³	**Density, kg/m³** *Gustoća,* kg/m³	**Mass, kg** *Masa,* kg
1	ceramic plates – 1 cm	10.73	m^2	0.107	1850	198.4
2	glue for ceramic plates – 0.5 cm	10.73	m^2			53.6
3	hydro-isolating layer – 0.3 cm	10.73	m^2	0.032	1400	45.0
4	gypsum plasterboards – 1.25 cm	10.73	m^2	0.134	900	120.7
5	OSB plate – 1.2 cm	10.73	m^2	0.129	650	83.7
6	stone wool between the load bearing construction profiles – 16 cm	1.72	m^3	1.716	40	68.6
7	load bearing construction profiles – 8/16 cm	0.43	m^3	0.429	420	180.2
8	gypsum fibreboard – 1.5 cm	10.73	m^2	0.161	1200	193.1
9	stone wool – 10 cm	1.07	m^3	1.073	80	85.8
10	reinforcing mortar, mesh and finishing plaster – 0.6 cm	10.73	m^2	0.064	1900	122.3

	W2 – exterior walls – ground floor bottom / *Vanjski zidovi – prizemlje dolje*	**Quantity** *Količina*	**Unit** *Jedinica*	**Volume, m³** *Volumen,* m³	**Density, kg/m³** *Gustoća,* kg/m³	**Mass, kg** *Masa,* kg
1	gypsum plasterboards – 1.25 cm	22.54	m^2	0.282	900	253.5
2	reinforced concrete – 16 cm	3.61	m^3	3.606	2400	8653.6
3	Hydro isolation: polymer-bitumen, one layer Like ORION FC 160 – 0.4 cm	22.54	m^2	0.090	1400	126.2
4	XPS insulation – 12 cm	2.70	m^3	2.704	35	94.6
5	reinforcing mortar, mesh and finishing plaster – 0.6 cm	22.54	m^2	0.135	1900	256.9

	W3 – inner walls / *Unutarnji zidovi*	**Quantity** *Količina*	**Unit** *Jedinica*	**Volume, m³** *Volumen,* m³	**Density, kg/m³** *Gustoća,* , kg/m³	**Mass, kg** *Masa,* kg
1	gypsum plasterboards – 1.25 cm*2 = 2.5 cm	92.54	m^2	2.313	900	2082.1
2	load bearing construction profiles – 6/10 cm – 10 cm	1.85	m^3	1.851	420	777.3
3	stone wool like Knauf Insulation DP-5 Venti (between wooden construction) – 10 cm	9.25	m^3	9.254	30	277.6
4	gypsum plasterboards- 1.25 cm*2 = 2.5 cm	92.54	m^2	2.313	900	2082.1

Table SM2 continuation
Tablica SM2. nastavak

	W3' – inner walls – ceramics in bathrooms / *Unutarnji zidovi – keramika u kupaonicama*	**Quantity** *Količina*	**Unit** *Jedinica*	**Volume, m³** *Volumen,* m³	**Density, kg/m³** *Gustoća,* kg/m³	**Mass, kg** *Masa,* kg
1	gypsum plasterboards – 1.25 cm*2 = 2.5 cm	17.16	m^2	0.429	900	386.1
2	load bearing construction profiles – 6/10 cm - 10 cm	0.34	m^3	0.343	420	144.1
3	stone wool like Knauf Insulation DP-5 Venti (between wooden construction) – 10 cm	1.72	m^3	1.716	30	51.5
4	gypsum plasterboards – 1.25 cm*2 = 2.5 cm	17.16	m^2	0.429	900	386.1
5	hydro-isolating layer – 0.3 cm	17.16	m^2	0.051	1400	72.1
6	glue for ceramic plates – 0.5 cm	17.16	m^2			85.8
7	ceramic plates – 1 cm	17.16	m^2	0.172	1850	317.5

	R1 – roof / *Krov*	**Quantity** *Količina*	**Unit** *Jedinica*	**Volume, m³** *Volumen,* m³	**Density, kg/m³** *Gustoća,* kg/m³	**Mass, kg** *Masa,* kg
1	wooden boards – 2 cm	123.30	m^2	2.466	420	1035.7
2	wooden laths 3x4 cm – 3 cm	0.59	m^3	0.592	420	248.6
3	reinforced ALU foil – 0.2 cm	123.30	m^2			12.3
4	mineral wool between the load bearing construction profiles – 16 cm	12.33	m^3	12.330	35	431.5
5	load bearing construction profiles (rafters) 8/16 cm – 16 cm	1.98	m^3	1.978	420	830.6
6	additional structural wooden beams	2.42	m^3	2.424	420	1018.2
7	stone wool like Rockwool Roofrock – 10 cm	12.33	m^3	12.330	80	986.4
8	roof foil like Tyvek, Eternit Meteo or similar – 0.2 cm	123.30	m^2			12.3
9	wooden laths 5x5 cm – 5 cm	0.92	m^3	0.925	420	388.39
10	wooden laths in opposite direction 3x5 cm – 3 cm	0.33	m^3	0.333	420	139.82
11	roof cover: wave fiber cement roof tiles – 0,5 cm	123.30	m^2			2465.96

	F1 – ground floor – ceramics / *Prizemlje – keramika*	**Quantity** *Količina*	**Unit** *Jedinica*	**Volume, m³** *Volumen,* m³	**Density, kg/m³** *Gustoća,* kg/m³	**Mass, kg** *Masa,* kg
1	ceramic plates – 1 cm	19.17	m^2	0.192	1850	354.6
2	glue for ceramic plates – 0.5 cm	19.17	m^2			95.9
3	concrete screed C20/25 with floor heating pipes – 7.6 cm	1.46	m^3	1.457	2250	3278.1
4	PE foil – 0.2mm	19.17	m^2			1.9
5	hard mineral wool acoustic insulation – 4 cm	0.77	m^3	0.767	80	61.3
6	reinforced concrete – 25 cm	4.79	m^3	4.793	2400	11502.0
7	XPS insulation – 15cm	2.88	m^3	2.876	35	100.6
8	Hydro isolation: polymer-bitumen, one layer, like ORION FC 160 – 0.4 cm	19.17	m^2	0.077	1400	107.4
9	bottom concrete – 10 cm	1.92	m^3	1.917	2400	4600.8

Table SM2 continuation
Tablica SM2. nastavak

	F1/A – ground floor – ceramics in bathrooms (1 cm height) / *Prizemlje – keramika u kupaonicama (visina – 1 cm)*	**Quantity** *Količina*	**Unit** *Jedinica*	**Volume, m^3** *Volumen,* m^3	**Density, kg/m^3** *Gustoća,* kg/m^3	**Mass, kg** *Masa,* kg
1	ceramic plates – 1 cm	1.53	m^2	0.015	1850	28.3
2	glue for ceramic plates – 0.5 cm	1.53	m^2			7.7
3	thin hydro-isolating layer based on hydraulic binders and elastomer additives – 0,3 cm	1.53	m^2	0.005	1400	6.4
4	concrete screed C20/25 with floor heating pipes – 7.6 cm	0.12	m^3	0.116	2250	261.6
5	PE foil – 0.2 mm	1.53	m^2			0.2
6	hard mineral wool acoustic insulation – 3 cm	0.05	m^3	0.046	80	3.7
7	reinforced concrete – 25 cm	0.38	m^3	0.383	2400	918.0
8	XPS insulation – 15cm	0.23	m^3	0.230	35	8.0
9	Hydro isolation: polymer-bitumen, one layer, like ORION FC 160 – 0.4 cm	1.53	m^2	0.006	1400	8.6
10	bottom concrete – 10 cm	0.15	m^3	0.153	2400	367.2

	F2 – ground floor – parquet / *Prizemlje – parket*	**Quantity** *Količina*	**Unit** *Jedinica*	**Volume, m^3** *Volumen,* m^3	**Density, kg/m^3** *Gustoća,* kg/m^3	**Mass, kg** *Masa,* kg
1	parquet – 1.1 cm	34.2	m^2	0.376	700	263.3
2	glue – 0.3 cm	34.2	m^2			51.3
3	concrete screed C20/25 with floor heating pipes – 7.6 cm	2.60	m^3	2.599	2250	5848.2
4	PE foil – 0.2mm	34.2	m^2			3.4
5	hard mineral wool acoustic insulation – 4 cm	1.37	m^3	1.368	80	109.4
6	reinforced concrete – 25 cm	8.55	m^2	2.138	2400	5130.0
7	XPS insulation – 15cm	5.13	m^3	5.130	35	179.6
8	Hydro isolation: polymer-bitumen, one layer, like ORION FC 160 – 0.4 cm	34.2	m^2	0.137	1400	191.5
9	bottom concrete – 10 cm	3.42	m^3	3.420	2400	8208.0

	F3 – stair – CLT / *Stepenice CLT*:	**Quantity** *Količina*	**Unit** *Jedinica*	**Volume, m^3** *Volumen,* m^3	**Density, kg/m^3** *Gustoća,* kg/m^3	**Mass, kg** *Masa,* kg
1	CLT plates, coated – 10 cm	0.36	m^3	0.358	480	171.8

	F4 – 1st floor – ceramics (1 cm height) / *Prvi kat – keramika (visina – 1 cm)*	**Quantity** *Količina*	**Unit** *Jedinica*	**Volume, m^3** *Volumen,* m^3	**Density, kg/m^3** *Gustoća,* kg/m^3	**Mass, kg** *Masa,* kg
1	ceramic plates – 1 cm	9.54	m^2	0.095	1850	176.5
2	glue for ceramic plates – 0.5 cm	9.54	m^2			38.2
3	thin hydro-isolating layer based on hydraulic binders and elastomer additives – 0.3 cm	9.54	m^2	0.029	1400	40.1
4	concrete screed C20/25 with floor heating pipes – 7.6 cm	0.73	m^3	0.725	2250	1631.3
5	PE foil – 0.2 mm	9.54	m^2			1.0
6	hard mineral wool acoustic insulation – 3 cm	0.29	m^3	0.286	80	22.9

Table SM2 continuation
Tablica SM2. nastavak

7	OSB plates – 1.5 cm	9.54	m^2	0.143	650	93.015
8	load bearing construction profiles 20x12 cm – 20 cm	0.54	m^3	0.544	420.00	228.39
9	mineral wool between the load bearing construction profiles – 20 cm	1.43	m^3	1.431	30.00	42.93
10	wooden laths 3/2 cm – 2 cm	0.02	m^3	0.017	420.00	7.21
11	gypsum plasterboards – 1.25 cm	9.54	m^2	0.119	900	107.33

	F5 – 1st floor – parquet / *Prvi kat – parket*	**Quantity** *Količina*	**Unit** *Jedinica*	**Volume, m^3** *Volumen,* m^3	**Density, kg/m^3** *Gustoća,* kg/m^3	**Mass, kg** *Masa,* kg
1	parquet – 1.1 cm	41.78	m^2	0.460	700	321.7
2	glue – 0.3 cm	41.78	m^2			62.7
3	concrete screed C20/25 with floor heating pipes – 7.6 cm	3.18	m^3	3.175	2250	7144.4
4	PE foil – 0.2 mm	41.78	m^2			4.2
5	hard mineral wool acoustic insulation – 4 cm	1.67	m^3	1.671	80	133.7
6	OSB plates – 1.5 cm	41.78	m^2	0.627	650	407.355
7	load bearing construction profiles 20x12 cm – 20 cm	2.38	m^3	2.381	420	1000.21
8	mineral wool between the load bearing construction profiles – 20 cm	6.27	m^3	6.267	30	188.01
9	wooden laths 3/2 cm – 2 cm	0.08	m^3	0.075	420	31.59
10	gypsum plasterboards – 1.25 cm	41.78	m^2	0.522	900	470.03

	Windows (wooden frames) – triple glazed (thickness 92 µm) / *Prozori (drvene okvirnice) – tri sloja premaznog materijala (debljina 92 µm)*	**Quantity** *Količina*	**Unit** *Jedinica*
1	O1 – 90x205 cm	4	pcs
2	O2 – 172x125 cm	1	pcs
3	O3 – 258x205 cm	1	pcs
4	O4 – 60x50 cm	1	pcs
5	O5 – 75x225 cm	1	pcs
6	O6 – 110x225 cm	2	pcs
7	O7 – 90x145 cm	3	pcs
8	O8 – 75x145 cm	1	pcs
9	O9 – 110x125 cm	1	pcs

	Doors / *Vrata*	**Quantity** *Količina*	**Unit** *Jedinica*
1	V1 – 90x205 cm	1	pcs
2	V2 – 80/205 cm	7	pcs
3	V3 – 70x205 cm	1	pcs