POSSIBILITIES FOR AFFORDABLE, LOW ENVIRONMENTAL FOOTPRINT PASSIVE HOUSE IMPLEMENTATION IN REPUBLIC OF SERBIA

by

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Sustainable housing is a worldwide challenge, while the case of Serbia could be an example of how complex the circumstances can be and how difficult it is to see the path towards sustainability. This paper sets out to answer multiple challenges; can energy-efficient, low-impact housing enter the market and respond to the needs of its population, potentially contributing to a more affordable and future-proof housing reality in Serbia? And does this demand rather different measure than the ones conventionally explored in innovative housing approaches elsewhere? To answer these questions, the paper starts from the preview of circumstances, then the methodology is proposed and explained, after which the possible building materials and technical installations for pilot multi-apartment Passive House are selected, and in the end, results are given and conclusions are drawn. Since the building is intended for a housing co-operative, both the affordability of the proposed solution and the environmental footprint has been comprehended by the methodology proposed. In the end, by carefully balancing the benefits of individual measures – favouring those that are cost-effective and discouraging the implementation of measures that are not, a viable pilot project that could step into the market-oriented society is selected.

Key words*: passive house, low impact housing, affordable housing, co-operative housing*

Introduction

The UN Sustainable development goal 11.1 targets adequate, safe, and affordable housing and basic services for all [1]. The affordability part of the answer to this challenge has been studied by many authors: Chan and Adabre [2] have been looking into critical success criteria and how to bring sustainable and affordable housing closer. They suggested the criteria for affordable housing as housing in which the combined cost of transportation and housing is less than 45% of household income. Adabre and Chan [3] are pointing to *political will and commitment to affordable housing* and *formulation of sound housing policies* as one of the potentially most influential factors among 30 observed factors, adding that the success-

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ful implementation of the most significant factors will ensure a holistic, sustainable and affordable housing market. The scale on which affordable housing is developing in Mainland China was noticed in [4] as an important opportunity for the introduction of sustainability on a regional scale. Additionally, authors are advising that accepting local context, as well as the economic and social situation could be crucial. How to make affordable social Passive House resilient or futureproof with the help of multi-objective optimization was, in the UK context, studied in [5], analysing specific points of building envelope and HVAC and pointing to the importance of glazing, especially south-facing glazing.

Furthermore, the energy efficiency approach or strategy is an inevitable part of the same answer to the transition toward sustainable housing. Chegut *et al*. [6] emphasized that affordable energy-efficient dwelling, under highly developed market conditions such as Dutch, will sell at a premium and may be partially or fully compensated when a dwelling is sold. Similarly, Copiello [7] suggested that a building's energy efficiency could boost the feasibility of social housing transactions under circumstances prevailing in Italy, yet caution is necessary since the profit-oriented approach could fail. Low-energy *vs*. conventional energy-intensive house in the context of Lahore, Pakistan, was studied in [8] emphasising inadequacies of existing economically-driven models to meet the required levels of energy demand.

The adequate business model is expected to further help affordable housing to penetrate market, where a certain segment belongs to citizen-led bottom-up approaches such as co-operative housing. After conducting multiple online questionnaires in the UK based research, [9] concluded that a significant part of panellists felt confident and believed that self-build is *one of the few ways in which zero carbon homes can be delivered*, while the opinion of the experts is that *models of group self-build housing have the potential to support a more environmentally and socially sustainable built environment* which could result in both: empowered citizens and energy-efficient housing sector. Co-operative housing developments in Portugal were presented in [10] with the unexpected conclusion that an average supplement of only 4.2% to construction cost could result in sustainable characteristics when co-operative (or social) housing is approached systematically, opposite to the view that it is necessary to invest large assets in sophisticated or expensive equipment. Strengths and issues of the bottom-up approach under very specific conditions of post-disaster redevelopment were studied by [11] finding that, on the one hand, the outcomes of the bottom-up processes could be unpredictable, and on the other hand, that the needed sense of empowerment and mutual respect was experienced by all involved in the redevelopment project. Additionally, as it is seen by [9], when it comes to bottom-up self-build groups, the following should not be overlooked: their ability to advocate for zero-carbon home-building, which, if supported through policies, could form a movement.

The decision to select Passive House standard is consistent with the findings of [12], where it is claimed that the Passive House concept can be adapted to any climate zone, but as it will be shown in the following text, the cost-effectiveness of this undertaking is questionable. The majority of the elements considered in the cost-effectiveness analysis in this paper are listed in details in [13]: the building cost, the energy price at the time of building, the number of years within which the investor expects the extra costs to amortise, the future fuel price rise, an appropriate discount rate and the probability that the building will under- or over-consume energy.

The challenges posed by the local market and climate conditions (that are rather different than those prevailing in the most developed EU countries) have been addressed by a number of works. After studying the application of the Passive House concept in social housing in Brazil [14], the authors concluded that it is possible to apply Passive House standard to southern Brazilian climate conditions, with a great reduction of energy consumed. The concept could be economically viable only in one out of three bioclimatic zones, and in that one having the payback period just a bit shorter than the estimated dwelling's life cycle. The performance of a Passive House under subtropical climatic conditions was evaluated in [15] in the case of the first Passive House built in Cyprus. While this work does not indicate viability issues, it does suggest how to improve thermal comfort under the prevailing climate conditions. The discussion on Passive House application in the region surrounding the Persian Gulf is given in [16] indicating that the viability of this approach under arid climate is yet to be proved. The importance of pilot buildings as a tool for transparent promotion of energy-efficient buildings in Romania was emphasized in [12]. The economic model at the parametric level was proposed by [17] where authors concluded that additional investment in Passive House under the circumstances of Romania could pay off in 16-26 years for the best forecast of the economic conditions.

The housing sector in Serbia has additional particularities: it offers vast room for improvement as explained in [18, 19], supply and demand could be more balanced, there is substantial room for innovation, while the degree of diversity of available models for ownership or management is low. Large parts of the population are unable to meet basic housing needs through purchase or lease, which, in addition to other side effects, results in illegal or informal construction [19]. Only an estimated 15% of the population can buy an apartment without institutional support, 69% of young people (18-34) still live with their parents [20], and around 1% of public housing offers little resolve. Moreover, housing poses an increasing challenge to Serbia's residents: 66% of households allocate over 40% of their income to cover basic housing expenses (the highest rate in Europe) [21], with the result that a substantial number are under threat of disconnection from utilities (heating, electricity, *etc*.). It should be noted that, when talking about Serbia and its (almost non-existing) co-operative housing, as in most of the post-socialist countries, today there is strong support of the state towards homeownership that in turn results in a tenant's strong preferences of owner-occupation to the forms of rental housing, well explained in [22] on the Czech example. This requires extra attention and could hinder future propagation of co-operative or other bottom-up and non-owner-occupied models.

The approach proposed here aims to help decision-makers in assessing the viability of affordable Passive House implementation, with the emphasis on its environmental footprint, while the optimization issues are reduced, further recommendations on optimization can be found in [5]. The solution pursued by this paper is that of a knowledge-based, sustainable and affordable housing solution targeting people who are currently locked out of the housing market (not being served by finance institutions, or capable of affording soaring market rental prices). The proposed methodology, and how it is applied will be explained in detail on the "Smarter Building" case study.

Methodology

The first steps in the proposed methodology are multiple market scans, sometimes combined with an examination of the regulatory framework as shown in fig. 1. In parallel, initial building design is to be developed, all leading to a conceptual solution in which the number of floors, number of flats, total and heated area, the orientation of the building, HVAC, domestic hot water (DHW) system, materials, *etc*. are defined.

After completing those steps, the baseline scenario analogous to the local, everyday or conventional system of construction can be established. The following step is a simulation of baseline, and other scenarios, in the case of this paper, EnergyPlus has been used.

The net present value (NPV) analysis is limited to the part of the building that is common to all scenarios; *e.g.* in case of "Smarter Building", all analyses and price estimates cover exclusively the aboveground part of the building, fig. 2, more precisely, the first floor and up. Variables used for NPV analysis are discount rate, *d*, and the future price of energy. Data on discount rates range in the literature from 3% to as high as 20%, [13] has noted that ecologically oriented sources prefer low values with the explanation that future benefits to the environment should not be discounted, while the empirical studies prefer higher values. The discount rate, *d*, used in NPV analysis in this paper is varied through the range from 4 to 10%, while only the worst-case scenario has been observed under *d* = 20%.

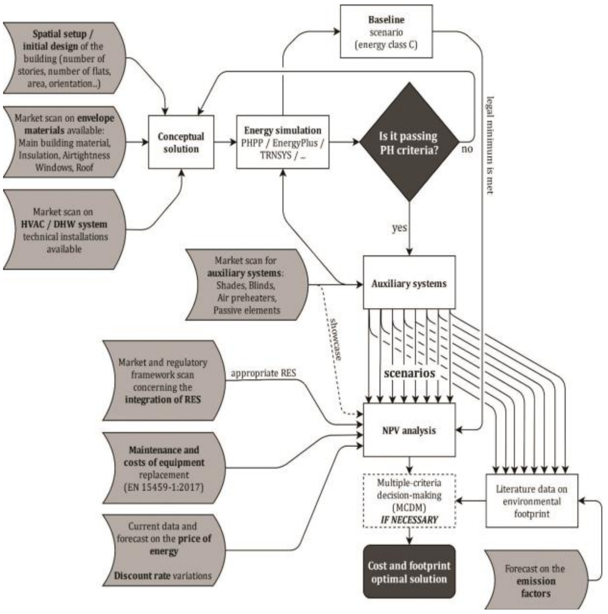

Figure 1. Flow diagram of the proposed optimization methodology

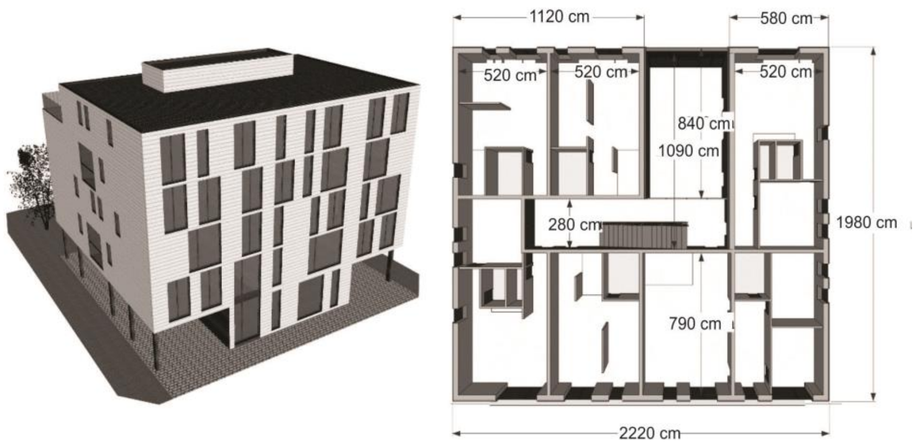

Figure 2. The spatial set-up and the floor plan of "Smarter Building"

The discount rate, which will be considered as the most reliable for a here presented case study, is estimated at 5.75%. It is calculated bearing in mind that Serbian credit rating is BB+ (non-investment grade), and there are no treasury bonds that could be rated as risk-free in international financial markets (closest to the risk-free are state emitted short term T-bills or long term T-bonds, and the current interest rate on 20-year T-bonds is 3.5%). Assumed equity is 25%, and debt is 75% of the investment. The cost of equity is calculated as the product of expected inflation (3%), T-bond rate (3.5%), country risk premium (6.59), and S&P 500 adjusted mature market equity premium (1.5%). The cost of debt (75% of investment) is calculated according to a current Serbian interest rate on housing loans (2.8%).

The expected increase of the future price of electricity has been set in the range from 3% to 10% per annum, based on the rise of the price of household electricity of 4.5% per annum over the last five years (2015-2019) [23]. All sudden changes that can be noticed in the cash-flow related figures in the section *Results and discussion* result from maintenance costs and costs of equipment replacement after the end of their estimated life-span according to EN 15459-1:2017 standard.

The indoor temperature used for simulations is selected following ISO EN 7730, and ASHRAE standard 55 ˚C as 20 ˚C heating temperature, and a relatively high cooling temperature set to 26 ˚C (chosen for two reasons: firstly, the high outdoor temperatures and comfort-related issues, and secondly being potential for energy savings, especially important for co-operative housing).

The period considered was set to 35 years, while the estimated lifespan of the building is 50 years (used for the environmental footprint analysis). Footprint related facts are taken from the literature and adapted where necessary. The prices used in the paper are current market prices (for the year 2019).

A large number of scenarios is to be expected, so the multi-criteria decision making (MCDM) is proposed as a tool to help decision-maker. In here presented case study, the underdeveloped market and very high prices of technologies that are not used in everyday construction made decision-making easier, and results have been clear even without MCDM, as it will be shown later.

It should be noted that the comparison of the baseline building and Passive House building is to an extent biased, since the thermal comfort, the quality of the air, and the high level of the overall comfort of a Passive House is not usually achieved in everyday construction in Serbia.

The "Smarter Building" Case Study

The "Smarter Building", in its preliminary design, is a 19-unit, 4-story building. Planned heated floor area is 1.368 m^2, a total gross floor area is 1.582 m^2, external spaces totalling 375 m^2, 20 parking spaces and a roof terrace of 110 m^2. It incorporates a range of apartments for different living requirements, including single users, families and co-housing arrangements.

The "Smarter Building" will provide housing to 50-55 people that are currently underserved by the housing market. It aims at creating a robust community and includes approx. 10% of additional space (130 m^2) dedicated to shared resident facilities. Capitalization is planned through a joint investment from external lenders (80%) and from the co-operative members (20% of own equity).

Passive House and Serbian market conditions

Passive House is a new concept on the Serbian market. According to the [24] there are still no certified projects locally, while most people are sceptical of the concept, mainly since the initial investment is higher, and the public is insufficiently informed. This scepticism is partially justifiable, while in most northern and western European contexts this additional investment could pay off, this is not necessarily the case under the current market conditions that show no implementation nor favouring of the Passive House standard. Identified weaknesses of Serbian and/or South-East Europe conditions are:

– The significantly lower price of electricity as shown in fig. 3, as one of the limiting factors for the feasibility of energy efficiency projects [25].

- o With as a complicating factor a low diversity of local fuels/sources of energy (more than 70% of Serbian electricity is coming from lignite), resulting in:
  - ▪ *Dirty* electricity with emissions ranging from 0.5 to 1.8 kgCO_2/kWh depending on the source, and in any case significantly above the EU or world average emissions [26-29].
- – Lack of completed projects and associated know-how, an underdeveloped knowledge-base on the technologies and possibilities currently available.
- – Lack of will among potential suppliers/producers of materials/equipment to engage in projects that could result in the long-run energy savings and environmental benefits, yet not generating immediate revenue. They are predominantly profit-oriented on a confined market, looking for investments that will pay off instantly.

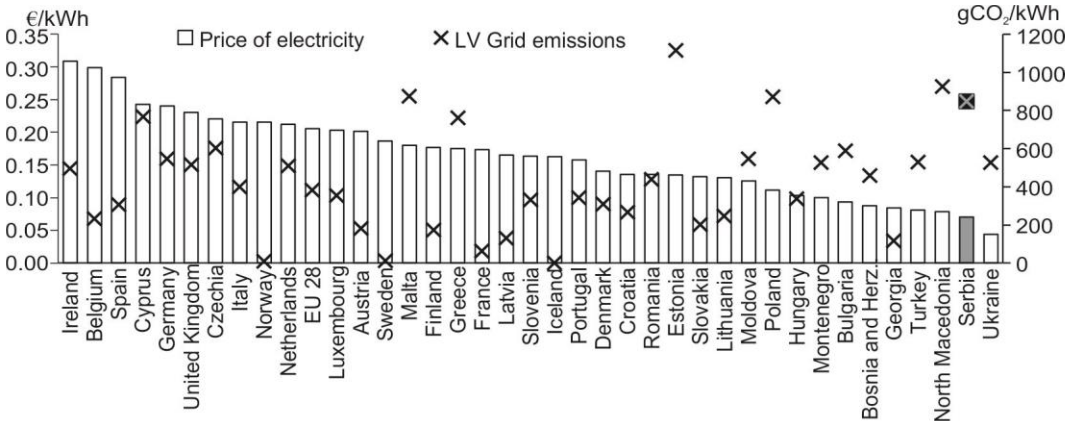

Figure 3. The average price of electricity in European households in the first half of 2019 all taxes and levies included [30] and CO_2 emissions of low voltage grid (gCO_2/kWh) according to [28]

Passive House surcharge

A Passive House is more expensive to build than a common building, and that difference in upfront costs is usually called premium or surcharge. According to [13] that cost is estimated at 5-15%, while a non-peer-reviewed report [31] places that surcharge between 7% and 15%. It is necessary to put the aforesaid percentages into perspective. According to the technical report [32] conventional low-rise apartments building costs in 2018 (including materials, labour cost, equipment, HVAC equipment, contractor's margin, and excluding site) is in the range from 415 €/m^2 in Istanbul to 3172 €/m^2 in London. The expected cost in Serbia is very close to 400 €/m^2.

Based on those data, one of the crucial advantages (besides the price of energy) of the Passive House markets in the highly developed world gets visible: the high price of the usual (conventional) system of construction results in higher chances that the 5-15% premium (in combination with the mentioned high price of energy) will be cost-effective. In other words: since the price of high-efficiency equipment and other energy efficiency measures is similar throughout Europe, the relative surcharge in low-cost markets is expected to be higher than 15%, making the cost-effectiveness more challenging. According to [12] a 26.7% more funding is needed to meet the Passive House requirements in comparison to current energy efficiency requirements in Romania. In the case of "Smarter Building", and its cheapest observed Passive House scenario, the difference between Passive House and building that meets the legal minimum is an alarming 31.4%. More unfavourable cases can be found in the literature, for example [14] stated that reaching the Passive House standard in Brazil requires additional investments in the range of 39-42%.

Passive House and Serbian or South-East Europe climate

The Passive House approach originated in the moderate and cool north-western European climate zones. Serbia (or South-East Europe) is characterized by a transitional climate between temperate and continental, having large temperature differences between the hot and the cold seasons [12], being more demanding in terms of both heating and, especially, cooling [33]. To provide deeper insights into the impact of location, the modelling results of simulations manipulating exclusively the EnergyPlus location/weather input data are given in fig. 4 under the following assumptions: *Autoclaved Aerated Concrete (AAC) Passive 3 (see tab. 1), geothermal heat pump, double glazed windows, without shades, heating temperature 20 ˚C, cooling temperature 26 ˚C.*

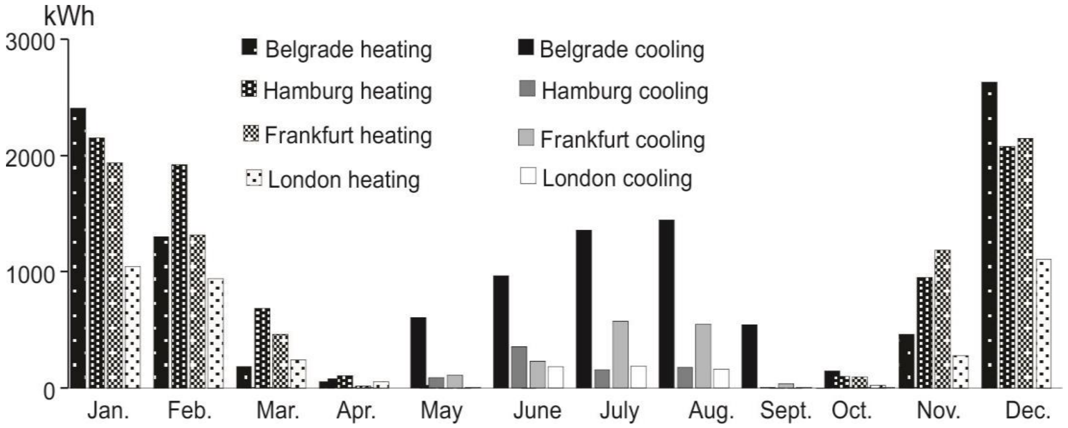

Figure 4. Modelling results of the impact of weather data/location on energy consumption (kWh) of "Smarter Building" building in four hypothetical cases; Belgrade, London, Hamburg, and birthplace of Passive House - Frankfurt

Possibilities for improvement of the design of "Smarter Building" are largely based on the aforementioned low price of labour and climate-related strengths:

- Airtightness of building envelope is a proven, cost-effective measure, even more attractive on the markets with a low price of labour.
- Solar insolation is higher than in the Western/Northern Europe, thus making it easier to collect solar (energy) gains or produce renewables on-site from the solar energy.
- The difference between day/night temperature on average is higher than in Western/Northern Europe, making both night-time cooling in the summer and solar gain in the winter easier to achieve.

Main construction material

The starting hypothesis of this research was that the main construction material should be: Adequate for achieving the Passive House standard; Affordable; Adequate for a four-story building; Environmentally acceptable and locally sourced. After an extended market survey, three main construction materials are proposed: *AAC*, cross laminated timber (*CLT*), and prefabricated wood composite panelling (*PWCP*).

Table 1. Economic aspects of main building materials

Type	Description of proposed construction	Note	The cost for "Smarter Building"
AAC C Class *(Baseline scenario)*	Low energy AAC blocks (30 cm) without insulation, 15 cm roof rockwool insulation	Price covers building material and installation Airtightness is not required	**83 €/m^2 Total: € 131,400**
AAC Passive 1	Low energy AAC blocks (37.5 cm) with 10 cm rock wool insulation, 30 cm roof rock wool insulation	Airtightness know-how could be an issue	**28.9% increase compared to baseline**
AAC Passive 2	Low energy AAC blocks (30 cm) with 10 cm rock wool insulation, 30 cm roof rock wool insulation	Airtightness know-how could be an issue	**21.6% increase compared to baseline**
AAC Passive 3	Low energy AAC blocks (20 cm) with 15 cm rock wool insulation, 30 cm roof rock wool insulation	Airtightness know-how could be an issue	**20.4% increase compared to baseline**
CLT Supplier 1	10 cm thickness for internal walls 15 cm for building envelope walls 18 cm floor-boards of the building	Airtightness know-how could be an issue	**304% increase compared to baseline**
CLT Supplier 2	10 cm thickness for internal walls and building envelope 18 cm floor-boards of the building	Passive House Institute (PHI) supports possible Airtightness know-how exists Blower door test included	**226% increase compared to baseline**
PWCP type 1	Prefabricated Wood-Based Panels with **wood wool** insulation	PHI supports possible Airtightness know-how exist Blower door test included	**128% increase compared to baseline**
PWCP type 2	Prefabricated Wood-Based Panels with **rock wool** insulation		**63.9% increase compared to baseline**

Economic aspects of proposed materials

Eight scenarios were analysed (cost includes blocks, façade and internal wall treatment, ceilings, flat roof, workers salary, with separation walls between apartments and without separation walls inside apartments, excluding VAT), tab. 1.

Environmental footprint

Following the (recent) global trends, and knowing that the construction industry is one of the main sources of greenhouse gases, one of the main demands of "Smarter Building" is that its environmental footprint should be lower than of conventional construction. Footprints of the main construction materials were calculated for the "Smarter Building" pilot building according to different literature sources and expressed in tonnes of CO_2 (tCO_2) [34-37]. After understanding the footprint of the building construction, the values are compared with the value of CO_2 generated from electricity consumption during the assumed lifetime of the building (50 years). The estimated amount of CO_2 as the initial embodied energy of main building materials for AAC and CLT construction (reinforced concrete is given as a hypothetical building material), compared with the amount of CO_2 generated during the 50 years of assumed building lifetime on a 60 kWh/m^2 annual rate and with a presumed emission of 1.055 $kgCO_2$/kWh (UNDP), is shown on fig. 5.

The first conclusion is that the main part of the emission arises from electricity consumed rather than from the chosen construction material, very similar to the conclusions presented in [38].

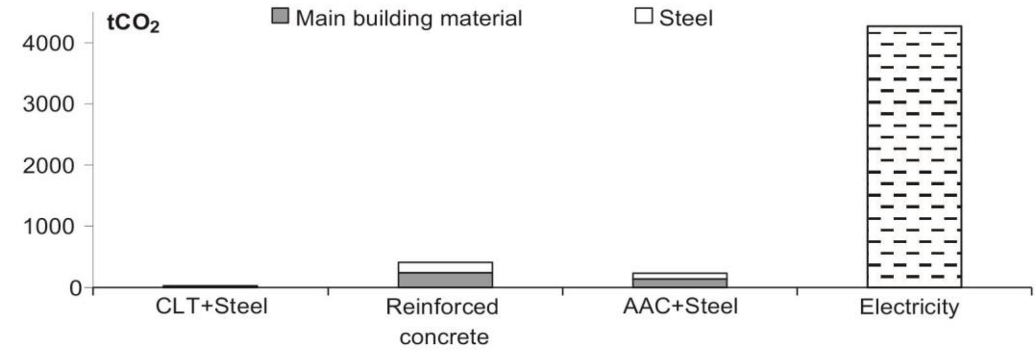

Figure 5. Comparison of the carbon footprint of the construction with the footprint of electricity used over "Smarter Building" lifetime

Since Serbia did not declare a coal phase-out strategy, and it belongs to developing countries heavily dependent on domestic lignite, with new coal-fired plants under construction, we considered two simplified hypothetical scenarios: phasing out coal until 2055 and until 2070, fig. 6.

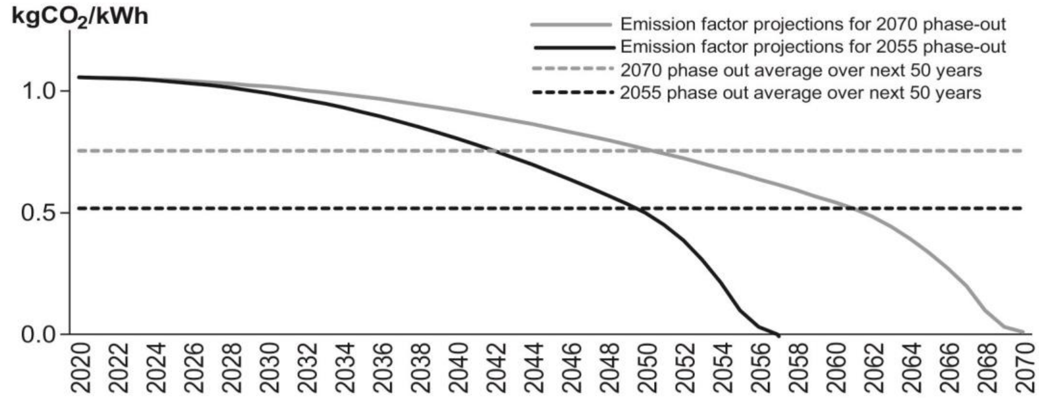

Figure 6. The CO_2 emission factor projections for Serbia for the next 50 years for coal-based electricity phase-out, until 2070 (powerplants lifetime) and until 2055 (early or optimistic)

The scenario in which Serbia is phasing-out coal until 2070 (with a new average over 50 years of 0.75 $kgCO_2$/kWh), results in a relatively small difference of 12% between AAC and CLT over the 50 years project lifetime. This means the impact is firmly on the side of the electricity consumption, suggesting that the best way to lower the footprint of "Smarter Building" is to invest in its energy efficiency, envelope airtightnening or on-site generation of renewables, rather than investing large assets into low-impact construction materials.

Results and discussion

Results from NPV analysis are shown in the following figures. Where appropriate, results will be compared with the baseline scenario (the building that meets the minimum required by Serbian certification guideline), corresponding to energy class C according to [39] with an annual amount of final energy required for heating of 65 kWh/m^2.

The impact of the main building material on cash flow is shown in fig. 7 under the following assumptions: *heating temperature 20 ˚C, cooling temperature 26 ˚C, double glazed windows, geothermal electricity-driven heat pump, fixed shades on the south side, 20 kW photovoltaic (PV) plant without net-metering, d = 8%, initial price of electricity 0.088 €/kWh, increase in the price of electricity 6% per year*.

The descriptions of the following pictures only list the differences to these initial conditions.

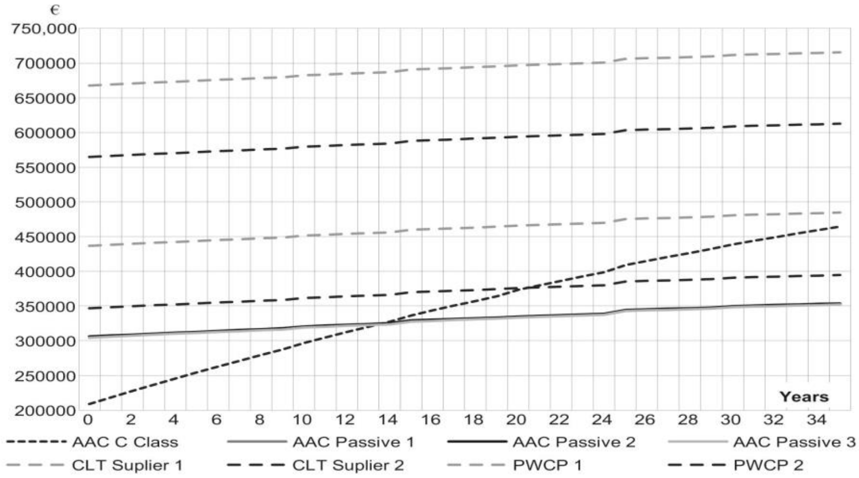

Figure 7. Impact of the main building material on the cash flow of "Smarter Building"

It can be noted that all lines are close to parallel (except AAC C Class) since the energy consumption of all buildings is very similar (defined by Passive House standard). The high initial investment eliminates both CLT suppliers. PWCP with wood wool insulation is also not cost-effective under these conditions, while PWCP with rock wool could be feasible under specific market circumstances, and piloting sustainability-oriented co-operative multi-apartment building could be one of those circumstances. For all other, general purposes, AAC is the only reasonable and viable solution.

The impact of the chosen HVAC cash flow is shown in fig. 8.

The integration of renewable sources in a Passive House is a part of the standard approach for the improvement of the building's energy performance and its environmental footprint. The new primary energy renewable (PER) standard for Passive Houses foresees building-integrated production of renewable energy, hopefully converting tenants into prosumers as seen by [40]. Observing the situation in the Serbian market, besides geothermal, the only sound RES is the integration of a PV solar plant, so three different capacities of a roof-mounted PV plant are observed: 15 kW, 20 kW, and 25 kW. Besides varying installed capacity, scenarios with and without net-metering are observed, as well as different future prices of electricity and different discount rates.

At the moment of writing this paper, the price of PV plants is 0.8 €/kW for a complete plant including its installation. Also, at the moment, there are no net-metering and subsidies for PV panels in place, while net-metering is announced with a yet unknown data of implementation. The price of the plant is estimated to be 0.7 €/kW including VAT in 2021, according to the estimation proposed by [41].

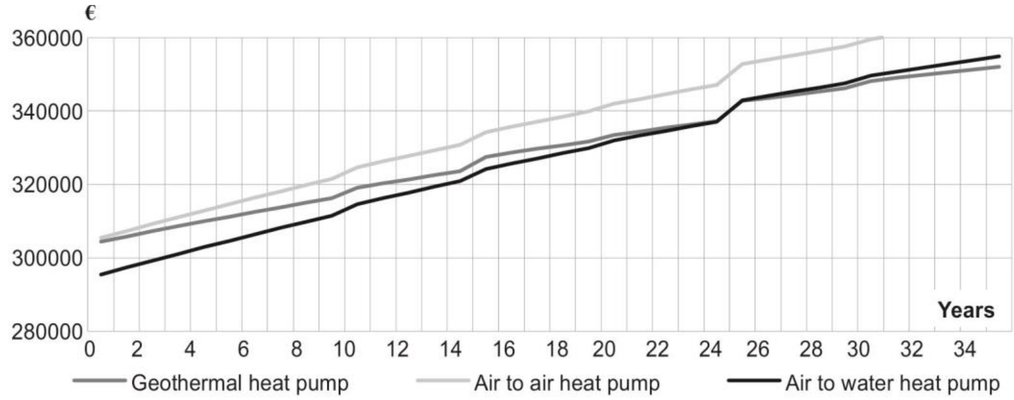

Figure 8. Impact of the HVAC system on the cash flow on "Smarter Building"

Using the PV GIS [42] (based on location Belgrade, orientation south, optimised panel angle 35°, total system losses 14%) the three different sized roof-mounted PV solar plants have been examined.

The results of the modelling for the impact of the PV plant are shown in fig. 9 under the following assumptions: *AAC Passive 3, inverter price in 2030 is assumed to be 3500 €, inverter lifetime 10 years, PV panels lifetime 25 years, maintenance costs 0.1 €/kW/year*.

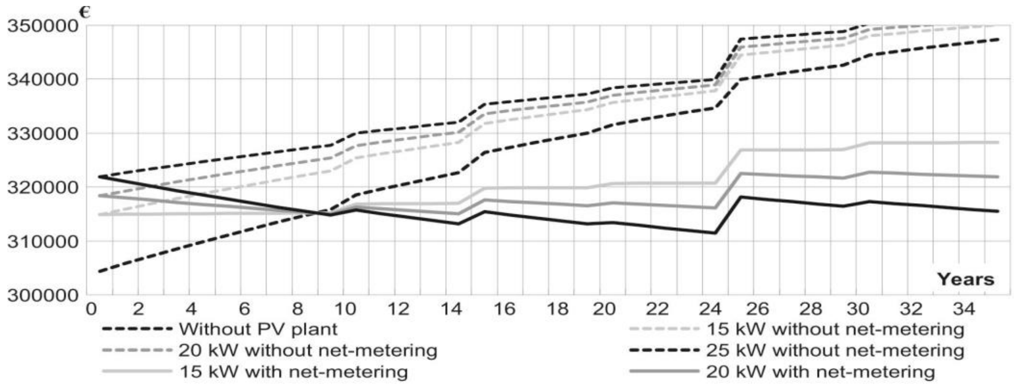

Figure 9. Impact of the PV power plant on the cash flow on "Smarter Building"

There are many possible conclusions to be drawn from fig. 9, most important being about net-metering and its decisive impact on this project, also there are scenarios in which PV plant will never pay off economically (*e.g.* if net metering is not introduced, or if it is introduced, yet the plant capacity of 15 kW is selected, combined with a slow increase of the price of electricity (3% per annum), the discount rate of 10%, *etc.*), so it is obvious that the net-metering has a decisive impact on the PV plant profitability.

Additionally, besides the impact of HVAC system or PV plant, different strategies to improve overall energy efficiency and thermal comfort have been considered:
- The possibilities for the reduction of building's form-factor.
- Seasonal thermal storage.
- Solar thermal panels.

– Solar chimney, as a way to deal with heat accumulated during summer heats.
– Ground-to-air heat exchanger and thermodynamic solar panels as a way to improve the heat pump's COP.
– Low-tech fixed shades (in two orientations setups - on South façade and on East, South and West façade) and in three different sizes.
– Motorized venetian blinds, also in two orientation setups.

It can be unequivocally concluded that the solutions are acceptable only if the investment is very low, so:

– Capital intensive solutions such as seasonal thermal storage or ground to air heat exchanger are dismissed as non-cost-effective.
– Low-cost solutions are proposed, such as:
  - Optimization of building's form-factor.
  - Low-tech fixed shades, predominantly as a measure for the improvement of the comfort rather than significant improvements of energy efficiency, and only on the South façade.
  - Solar chimney and only if it can be implemented as a low-cost addition to building's envelope.

The impact of the increase in the price of electricity is shown in fig. 10.

The points of the intersection of the lines with the same colour should be understood

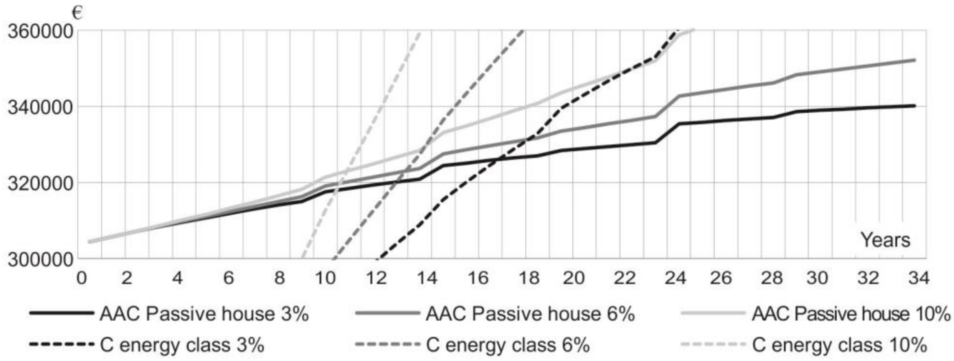

Figure 10. Impact of an increase in the price of electricity on the cash flow of "Smarter Building"

as payback time. Clearly, the Passive House favours a higher price of future energy in comparison with conventional building.

The impact of the discount rate is shown in fig. 11 under the assumptions: *an increase in the price of electricity 6% per year except for coloured lines which correspond to 3% per year.*

On the crossing of the lines of the same colour we get repayment periods, so the differences between the scenarios are clearly visible. The red lines show in fig. 11 illustrates the combined influence of both – the slow rise of the price of electricity (3% per year) and high discount rate (10%) resulting in a 23-year payback period which could be unacceptable for the majority of the investors.

The selected discount rate could be even higher, as explained by [13], thus 20% is shown as a dark blue line which, combined with the slow rise of the price of electricity (3% per year), is the worst-case scenario observed, resulting in an investment that will never pay off economically.

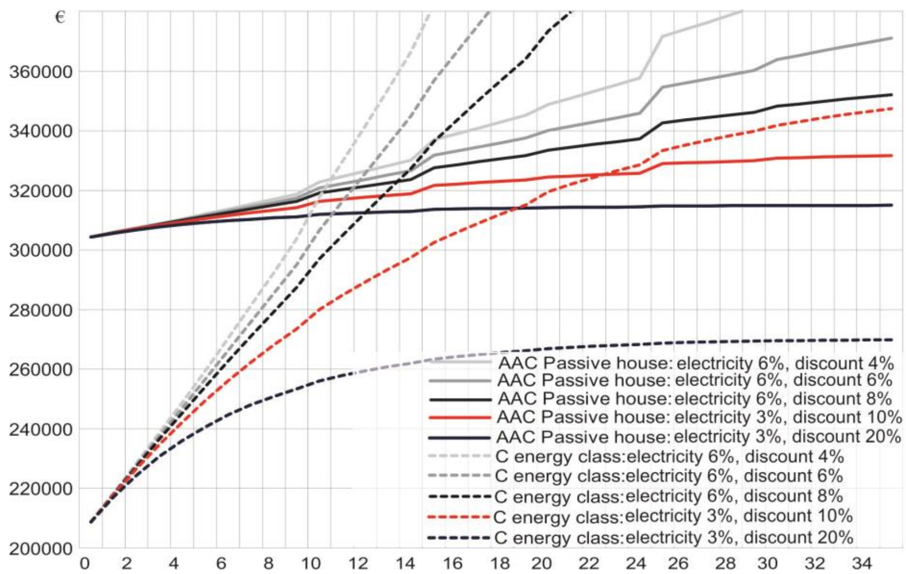

Figure 11. Impact of the discount rate on the cash flow of "Smarter Building" combined with the impact of the electricity price rise (*for color image see journal web site*)

Conclusions

Sustainable, affordable housing should be an urgent goal in both developing and developed countries [3]. This paper explored the viability of multi-apartment Passive House implementation in Serbia through the development named "Smarter Building". The "Smarter Building" being a pioneering project, special care was taken to identify obstacles and risks – as well as the most viable approaches to mitigate these and ensure the successful launch of such a highly energy-efficient, low impact building.

When exploring possibilities for the implementation of "Smarter Building", the following issues emerged:

- A sustainable building should be a part of an energy-independent society, *i.e.* it should rest on domestic energy sources. Therefore, and after taking into consideration the possibilities of integrating different technologies and different energy sources to achieve the desired level of comfort, the proposed solution is all-electric.
- All-electric in the case of Serbian electricity will result in an undesirably high environmental footprint with the current energy mix and energy transition strategy (or lack thereof).
- To lower that impact, great emphasis should be placed on energy-efficient equipment and inclusion of renewable energy generation.
- Highly efficient equipment is available, yet significant funds need to be invested in such equipment.
- The low price of electricity is undercutting investments in products which stand out for their efficiency.
- The observed chain of circumstances is, at least, challenging.

Additional challenges posed to the "Smarter Building" project are:

- The local climate is more demanding than the climatic conditions in Central Europe.
- The very low price of the *business as usual* building system (energy class C according to [39]), leaves little room for manoeuvre (or extra allocations) for Passive House requirements.

- The market is underdeveloped, with a relatively low supply of building materials suitable for this type of building (and even more underdeveloped if low impact materials are imperative).

However, if the guidelines outlined in this paper are followed, a thin (positive) margin for the implementation of the Passive House approach could remain.

Our main conclusion is that possible solutions under existing economic and climate conditions should be searched at the intersection of measure sets labelled as *clever* and *low-cost*. The *clever* is covering optimisation issues such as form-factor, building orientation, or windows-to-wall ratio, in short, *clever* takes advantage of meteorological conditions, solar insulation, *etc*. The *low-cost* tries to overcome economic shortcomings of the situation through *e.g*. using building materials that are cheap, well established, and available on the market, materials that are characterized by widespread know-how concerning the construction works while having an acceptable environmental footprint. The *low-cost* should also cover the benefits of the labour force which is less expensive than in most European countries, for example, labour-intensive envelope air-tightening is expected to be highly cost-effective. Also, *low-cost* is discarding expensive or high-end solutions such as seasonal or long-term thermal storage, CLT as the main building material, heat pump with integrated ground-to-air heat exchanger, thermodynamic solar systems, or even triple-paned glazing.

Our next conclusion is that, regardless of the mentioned recommendations, the fragility of the cost-efficiency of this project becomes visible when a range of future scenarios is exploring. Namely, after varying electricity price increase in the range between 3 and 10% per year, and the Discount Rate in NPV analysis in the range of 4 to 10% (or 20%), as seen in fig. 11, we can conclude that the combination of these two values has a more decisive impact on the project than any of the proposed technical or technological measures. Furthermore, that viability, achieved in a landscape of delicate cost-efficiency, under a clear, yet a very narrow set of technical/technological and market preconditions could easily become unreasonable if the capital is raised under unfavourable conditions.

Follow up research on questions that are opened during this research should answer:

- Possible arrangements, tax breaks, grants or subsidies that could allow this kind of buildings to penetrate the existing market.
- Questions related to the optimization issue such as:
  - Optimal thermal properties of main building material, which could be a practical and potentially cheap way to embed a short-term accumulation of heating/cooling energy.
  - Optimal size of the DHW buffer tank and/or heating buffer tank (for similar reasons as stated previously, the optimal size of the buffer reservoirs could further improve the performances of the building).
  - The optimal ratio of glazing and wall surfaces depending on the orientation of the walls, similarly as given in [43] for triple-glazed windows.
- Public relations issues on how to reach a wide audience and raise awareness on the importance of the issues explained here, and other similar questions.

Until those results arrive, the government and decision-makers should focus on three possible ways to improve the environment for this kind of investments:

- As lowering of the interest rate does not seem feasible (as interest rates are at an all-time low while in the EU reference interest rates are even negative) we stand at the view that the method of stimulating the construction of passive buildings should go in the direction of direct grants as a return on a certain percentage of investment after the completion of the project. As suggested by [3], those measures should be carefully tailored, otherwise, they could become counter-productive. Thus, as already stated, a necessity for future research on the type and amount of subsidies that could best fit current settings is opened.

- Raising the price of electricity.
- Lowering the emission factor (kgCO_2/kWh) of produced electricity.

While waiting for all this to take place, to make flagship projects similar to "Smarter Building" cost-effective, it is necessary to carefully balance the benefits of individual measures and to favour measures that are cost-effective, knowing that the vast array of measures which are applicable in *e.g.* Western Europe are simply inappropriate under conditions in developing countries.

It is needless to say, that, if successfully implemented, the "Smarter Building" pilot building could become the much-needed example of good practice, the point of dissemination of experiences and results, supporting all future (non-governmental) actions and helping in the creation of a smarter and more equal society.

Nomenclature

AAC – autoclaved aerated concrete
NPV – net present value
CLT – cross-laminated timber
d – discount rate
PHI – Passive House Institute
DHW – domestic hot water
PWCP – prefabricated wood composite panelling
MCDM – multi-criteria decision making

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