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HIGH ENERGY PERFORMANCE, LOW ENVIRONMENTAL IMPACT, AFFORDABLE:

EXPLORING PASSIVE HOUSE IMPLEMENTATION FOR MULTI-APARTMENT BUILDINGS IN SERBIA

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CONTENTS

Autoclaved Aerated Concrete *a building material made from a mix of sand, lime, cement, water with aluminium powder as an expanding agent*	–	**AAC**
Cross-Laminated Timber *a timber construction material made by gluing multiple layers of solid-sawn umber*	–	**CLT**
Coefficient of Performance *the parameter that explains the heat pump's ratio of useful energy (either heating or cooling) to work required*	–	**COP**
Discount Rate *expresses the time value of money combined with uncertainty risk, and can make the difference between whether an investment project is financially viable or not*	–	**d**
Domestic Hot Water *a semi-independent or independent system for the preparation of domestic hot water*	–	**DHW**
Gross Domestic Product *the value of all goods and services made during a specific period, usually a year*	–	**GDP**
Heating, Ventilation and Air Conditioning *the system used for moving and treating the indoor air*	–	**HVAC**
Net Present Value *a method used to determine the current value of all future cash flows generated by a project*	–	**NPV**
Primary Energy Renewable *a future-proof methodology for evaluation and categorization of Passive Houses*	–	**PER**
Primary Energy *the methodology that preceded PER, still valid in the transition period*	–	**PE**
Passive House Institute *the research institute and leading authority for passive housing, founded by Dr Wolfgang Feist, co-originator of the Passive House concept*	–	**PHI**
Prefabricated Wood Composite Panelling *a wood-based building system adopted to the Passive House requirements*	–	**PWCP**
Pametnija Zgrada *the flagship development by the Belgrade-based civic association Ko Gradi Grad*	–	**PZ**
South-East Europe *geographical region of Europe, consisting primarily of the countries on the Balkan Peninsula, sometimes Turkey*	–	**SEE**

INTRODUCTION

Can *energy-efficient*, *low-impact* housing contribute to a more affordable and future-proof housing reality in Serbia, responding to the needs of its population? And does this demand rather different measures than conventionally explored in innovative housing approaches elsewhere?

It is this challenging set of questions that underlies the study in front of you.

The direct trigger for the study is the upcoming pilot project for a multi-apartment building Pametnija Zgrada (Eng. *Smarter Building*), abbreviated as PZ, to be developed in Belgrade by the civic association Ko Gradi Grad (Eng. *Who Builds the City*). Pametnija Zgrada is the first housing cooperative established in Belgrade in the last nearly twenty years, its construction is expected in the next two to three years. The study presented here aims to outline the viability of introducing such affordable, energy-efficient, low-impact construction for an affordable multi-apartment building in the Serbian context.

The housing sector in Serbia offers vast room for improvement: 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 their basic housing needs through purchase or lease. The situation for those seeking independence and a reliable housing situation is often unresolvable in the current environment. Only an estimated 15% of the population can buy an apartment on the market without institutional support, 69% of young people (18-34) still live with their parents (Eurostat, 2018), 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, Eurostat, 2018), resulting in a substantial number of them being under threat of disconnection from utilities (heating, electricity, etc.).

A novel approach to the housing sector in Serbia is necessary: one that is affordable as an investment, but also posing low long-term costs of living. With the real estate being one of the most proficient production sectors in Serbia, and the built environment a prominent contributor to climate change (the direct CO_2 impact of construction, as well as the long-term impact of the energy consumption of a building over its lifetime), it is immanent that any attempt at innovation in the housing sector at the same time requires a reduction of the environmental footprint.

Thus, this study brings together both ambitions: the search for affordable low-energy consumption housing with a reduced environmental footprint.

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WHY THE PASSIVE HOUSE APPROACH MAY BE RELEVANT?

When looking for an approach to low-energy construction, several rigorous, state-of-the-art construction standards (developed worldwide and implemented in numerous projects) are available for consideration: Leadership in Energy & Environmental Design (LEED), Nearly Zero Energy Building (NZEB), Zero Energy Building (ZE), Net Zero Carbon, Passive House – and more.

At the same time, it is important to consider the context in which such buildings are to perform. In the case of the Serbian market of general apartment construction, the availability of capital for construction is limited (due to a relatively weak economy) while construction work is undertaken by a largely low-skilled workforce. As an additional complicating factor, experience with ambitious low-energy construction is limited and, in the field of affordable multi-apartment construction, next to non-existent.

This points to the necessity to implement a construction standard that, while being rigorous, at the same time can be achieved with relatively straightforward and proven technical measures available in the local market.

The Passive House standard offers a combination of energy efficiency, the possibility to achieve this efficiency standard with modest capital investment, a verified calculation methodology using the Passive House Planning Package (PHPP) and decades of experience in the implementation of thousands of projects worldwide. It has, therefore, been pre-selected by Ko Gradi Grad as the most likely candidate for its upcoming pilot project.

The difference between the modelling results for final energy consumption of the Passive House (*Autoclaved aerated concrete low-energy blocks 20 cm, rock wool 15 cm wall insulation, 30 cm roof rockwool insulation, geothermal heat pump*) and C energy class, according to [1] (*AAC low energy blocks 30 cm, without wall insulation, 15 cm roof rockwool insulation equipped with individual natural gas boilers and individual split air-conditioning units*), for the heating temperature 20 °C and the cooling temperature 26 °C in both cases are shown in Figure 0.1 (and explained later in Chapter 9).

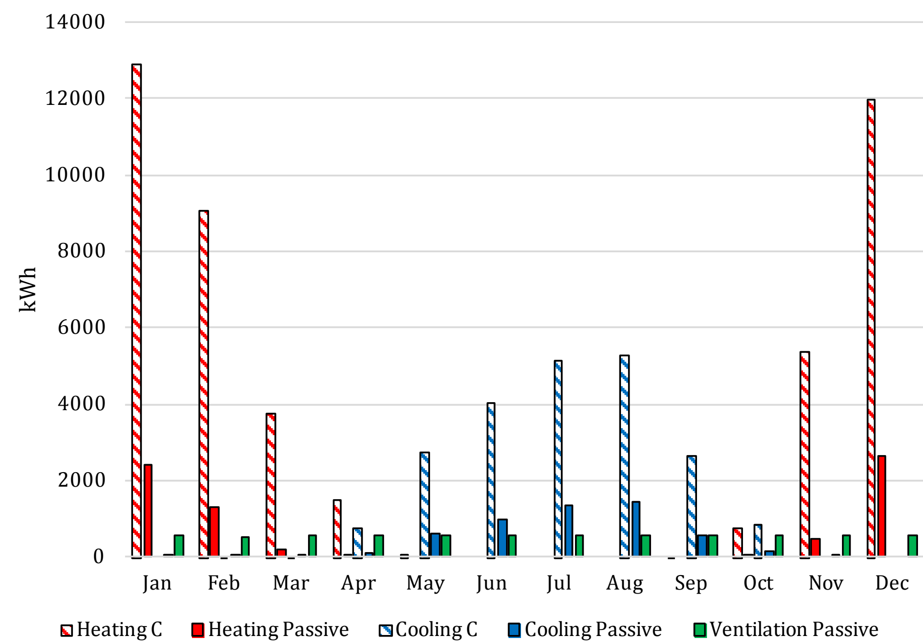


Figure 0.1. *Comparison of modelling results for cooling and heating energy demands for C Energy Class (minimum requirement for new residential buildings in Serbia since 2012, limiting heating demand to a maximum of 60 kWh/m² per year) and the Passive House implementation*

However, with limited implementation of the Passive House construction in Serbia's wider geographical region (including Croatia, Slovenia...) and next to no evident application of Passive House multi-apartment construction to date, the assumption of settling on this specific standard for the ambition to be fulfilled by the Pametnija Zgrada pilot project is the subject of verification in this study.

STUDY OVERVIEW

In order to provide a response to the key challenges, the study is divided into several sections. The Introduction to the study underlines the fact that the passive construction standard is characterized by a set of simple, but rigorously applied measures that ensure very low energy consumption. Like any other highly efficient system, Passive Houses are also sensitive to various circumstances, identified through the implemented analysis at several levels:

- The climate in Belgrade and Serbia is more demanding that the climate conditions in Central Europe where this construction standard has been well established;
- Electricity in Serbia is significantly cheaper than in the rest of Europe, which demotivates investments in energy efficiency;
    - Simultaneously, the production of electricity is characterized by a significantly higher environmental footprint per kWh compared to other countries;
- The low price of constructing the energy class C building in accordance with [1], leaves little manoeuvring room for the Passive House concept, i.e. for investments in energy efficiency measures;
- The market is underdeveloped, with a relatively poor supply of construction materials favourable for this type of construction, particularly regarding the supply of materials with low environmental impact.

The first chapter of the study presents the Passive House concept, with a more detailed review of this concept in the context of South-East Europe in Chapter 1.3. Chapter 2 presents the Ko Gradi Grad association and their pioneering project Pametnija Zgrada, designed as the first multi-storey Passive House in Serbia. The building is simultaneously striving toward low environmental footprint and an affordable price of construction.

The building envelope and the relevant materials for its construction are covered in Chapter 3, while the heating, cooling and ventilation installation are the topics of Chapter 4. The following paragraph presents a brief overview of the content of these two chapters.

Implementing the Pametnija Zgrada pilot project requires an analysis of technical aspects such as: choice of envelope materials, choice of appropriate installations for heating, ventilation and air-conditioning, and system for preparing sanitary hot water. Numerous products were found to exist on the Serbian market that, applied correctly, meet the requirements of Passive House standards, but when the emphasis in these requirements is placed on a low environmental footprint, the choice becomes considerably narrower. Using the provided set of requirements, recommendations were issued for several specific methods/materials for construction. Thus, regarding glazed surfaces as a key component of the building envelope, under the current conditions in Serbia, the analysis shows that double-glazed windows with fixed shades fit the pilot project under consideration. As for the heating, ventilation and air-conditioning system, the analysis shows that the best combination of efficiency, cost-effectiveness and simple implementation is provided by a decentralized ventilation system with a centralized heat source (geothermal heat pump or, alternatively, air-water heat pump). A centralized system integrated into the heating, ventilation and air-conditioning system is recommended for preparing sanitary hot water.

Chapter 5 studies the potential of generating renewable energy on the building itself. The integration of a solar photovoltaic power plant is a common measure and an integral part of the updated Passive House standard. The results presented here show that the integration of a solar photovoltaic plant (capacity 15-25 kWp) can provide for between approximately 25 and 45% of the primary energy needs. However, the specific nature of the market being reviewed, reflected in the lack of stimulative tariffs, lack of net metering and low price of electricity, makes it considerably more difficult to decide on the implementation of a photovoltaic plant. Fortunately, the expected price of photovoltaic plants of only 0.7 €/kWp in 2021 leaves sufficient room to recommend the use of this technology.

Furthermore, improvements to the energy efficiency of the Passive House are possible through the integration of various equipment available on the market, described under Chapter 6. The conclusion of this chapter is that circumstances favour cheap, technologically less demanding solutions. Thus a solar chimney is recommended as the only potentially acceptable option for this pilot project (decisively) rejecting solutions that could certainly be interesting under different market conditions.

An analysis of the environmental footprint of Pametnija Zgrada is found in Chapter 7. It is divided into the section resulting from the construction phase and the section resulting from usage of the building. The conclusion is that the environmental footprint resulting from usage of the building is dominant, therefore advising investments into energy-efficient equipment and the production of renewable sources on the spot, rather than into construction materials with a low environmental footprint.

Thereafter, Chapter 8 deals with certain specifics regarding the situation in Serbia, among other things, the challenge presented by the low price of electricity for the financial sustainability of energy-efficient buildings, but also the impact that the behaviour, i.e. habits of residents would have on the use of the building.

Chapter 9 first presents the methodology used, followed by the systematized results of this study. The end result of the analysis of the technical, social and other factors on the construction and use of Pametnija Zgrada is the methodology used to produce a spreadsheet tool that aims to enable future members of Pametnija Zgrada to understand the consequences of specific technological choices on construction price and use of the building, as well as life in it. Chapter 10 presents the space that has been opened for future studies. The conclusion is presented in Chapter 11, followed by the observation that under current conditions there is a small, economically positive margin that makes it possible to implement the project of Pametnija Zgrada in Serbia, using the Passive House principles. However, the implementation of this type of pilot project is not measurable by economic factors only but can be expected to play an important role in opening up accessible, energy-efficient and environmentally sustainable housing in Serbia.

CHAPTER 1

THE PASSIVE HOUSE PRINCIPLE

The Passive House standard originated in Germany in the late 1980s as an effort to completely rethink the housing sector of that era (under the pressure imposed by the first and second oil crisis). To date, that approach resulted in 60,000 certified[1] buildings, ranging from small detached houses to commercial buildings such as supermarkets, or public buildings such as schools. Buildings have been built predominantly in western and northern Europe (Figure 1.1), with a clear trend of spreading to the US, Canada, Japan, China and other, most developed and/or thriving economies. We should also mention that there is a significant lack of these types of buildings in the Balkans.

Figure 1.1. *Map of certified Passive Houses in Europe[2] (October 2019)*

1 Certification of Passive Houses is done through a rigorous procedure by the Passive House Institute located in Darmstadt, Germany
2 https://database.passivehouse.com/buildings/map/

The Passive House (principle summarized in Figure 1.2 and Figure 1.3) does not need additional heating in colder climate due to excellent thermal performance, in contrast to the conventional approach where additional heating is required to compensate for heat losses.

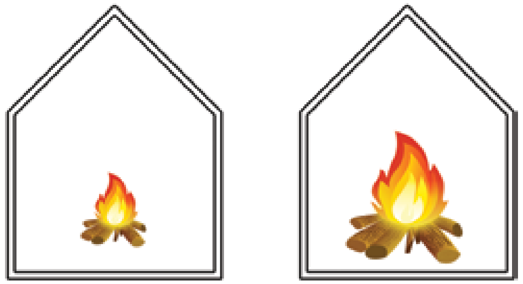


Figure 1.2. *Conventional approach (left – a temperate area; right – a cold climate)*

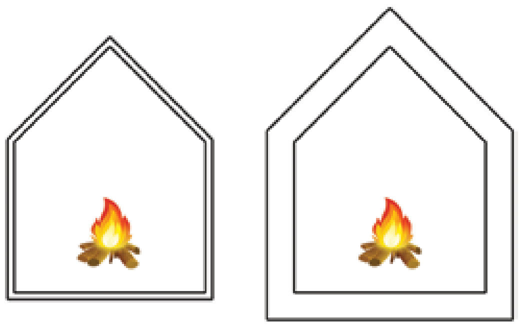


Figure 1.3. *Passive House approach (left – a temperate area; right – a cold climate)*

In practice, such results are achieved through a few steps, starting from planning and ending in carefully performed works and, as a rule, always keeping in mind the following **five** key points:

- Thermal insulation of walls: although not numerically specified for new buildings, the practice has shown that the envelope of a building should be very well insulated, with U-value ranging from 0.1 [W/(m^{2}K)] in cold to 0.3 [W/(m^{2}K)] in warm-temperate climate zones;
- Airtightness of the building envelope: a maximum of 0.6 volumes of the building is allowed to leak through the building envelope per hour with walls, windows, doors and other elements being under the pressure difference of 50 Pa. For the purposes of certification, this value is checked with a blower door test.
- Passive house windows: although U-value has not been specified, it is known that, depending on the climate conditions, the recommended value

should be around 0.8 [W/(m^{2}K)] for the entire window (frame + glazing). Special care should be taken about the thermal bridges and the airtightness of windows.

- Thermal bridge free construction: all connections, edges and penetrations must be executed with special care in order to avoid thermal bridges.
- Comfort ventilation with a high heat recovery rate: since the building is airtight, the necessary amount of fresh air is provided by mechanical ventilation. The role of that system is usually multiple – as a ventilation system, for heating, cooling and as the system for humidity control, while in multi-apartment buildings it can also work as a system for heat redistribution. Usually, these systems are equipped with automatically controlled bypasses, thus allowing the incoming air to bypass heat exchanger, for example, during the night in periods when days are warm and nights are cool. The efficiency of heat recovery is specified to be at least 75%.

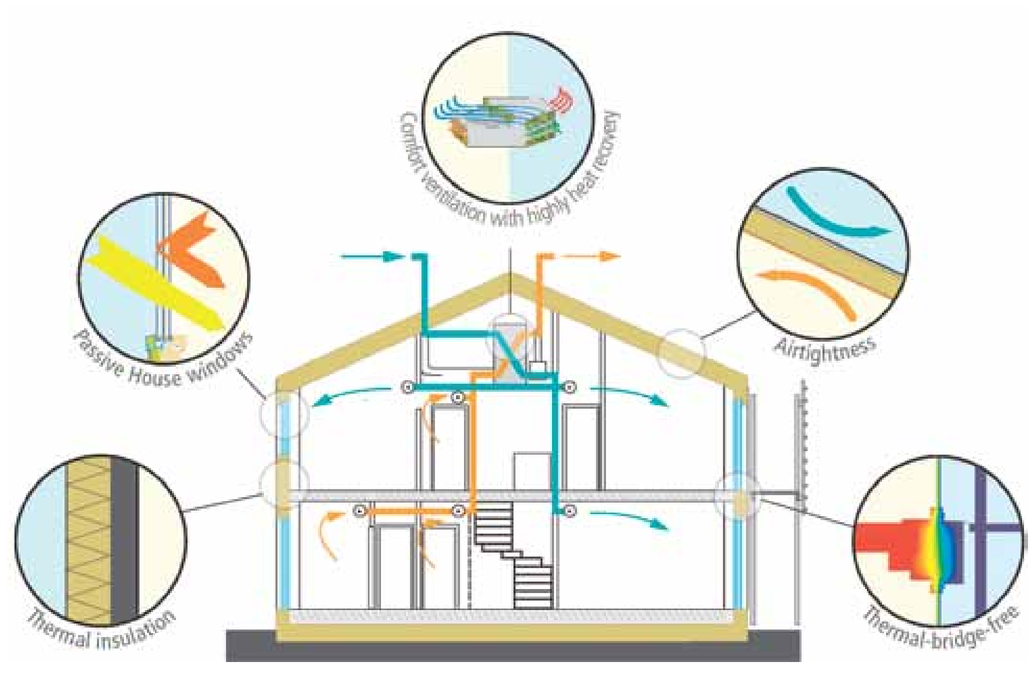


Figure 1.4. *Five Passive House principles that will help in achieving such low consumption of energy according to* [2]

Site-specific future-oriented sustainability criteria for achieving Passive House standard are given, according to [3], in Table 1.1.

			Criteria			Alternative Criteria
Heating						
Heating demand	[kWh/(m²a)]	≤	15			-
Heating load	[W/m²]	≤	-			10
Cooling						
Cooling + dehumidification demand	[kWh/(m²a)]	≤	15 + dehumidification contribution			variable limit value
Cooling load	[W/m²]	≤	-			10
Airtightness						
Pressurization test result n_{50}	[1/h]	≤	0.6			
Renewable Primary Energy (PER)			Classic	Plus	Premium	
PER demand	[kWh/(m²a)]	≤	60	45	30	±15 kWh/(m²a) deviation from criteria...
Renewable energy generation (with reference to projected building footprint)	[kWh/(m²a)]	≥	-	60	120	...with compensation of the above deviation by different amount of generation

Table 1.1. *Passive House Criteria* [3]

1.1. THE NEW PASSIVE HAUSE STANDARD: RENEWABLE PRIMARY ENERGY (PER) VERSUS PRIMARY ENERGY (PE)

As the worldwide energy supply structure is in transition and moves from fossil sources towards renewables, the old assessment systems for energy demand in buildings are not appropriate anymore. Therefore, a new Passive House evaluation system based on renewable primary energy (PER, Primary Energy Renewable) has been proposed. It introduces a novelty, in which buildings not only consume, but also start producing energy!

	Old (PE)	New (PER)
Space Heating Energy Demand	not to exceed 15 kWh/m² of net living space per year or 10 W/m² peak demand	not to exceed 15 kWh/m² of net living space per year or 10 W/m² peak demand
Space Cooling Energy Demand	roughly matches the heat demand with an additional, climate-dependent allowance for dehumidification	roughly matches the heat demand with an additional, climate-dependent allowance for dehumidification
Primary Energy Demand	PE - annually **not to exceed 120kWh/m²** for all domestic applications (heating, cooling, hot water, and domestic electricity)	PER - the total energy to be used for all domestic applications (heating, hot water, and domestic electricity) must **not annually exceed 60 kWh/m²** of treated floor area per year for Passive House Classic
Airtightness	maximum of 0.6 air changes per hour at 50 Pa pressure (ACH50), as verified with an onsite pressure test (in both pressurized and depressurized states)	maximum of 0.6 air changes per hour at 50 Pa pressure (ACH50), as verified with an onsite pressure test (in both pressurized and depressurized states)
Thermal Comfort	must be met for all living areas year-round with not more than 10% of the hours in any given year over 25°C	must be met for all living areas during winter as well as in summer, with not more than 10 % of the hours in a given year over 25 °C

Table 1.2. *Renewable primary energy (PER) versus primary energy (PE)*

The new evaluation system consists of three Passive House classes: Classic, Plus, and Premium. These classes can be achieved depending on the PER demand and the renewable energy generated. The Passive House Classic is the traditional Passive House. The Plus and Premium Passive House classes require on-site (in the building) generation of renewable energy: PV solar, wind (Table 1.1). The requirements for the PER demand and generation of renewable energy were first introduced in 2015. For the Passive House Classic Standard, the previous requirement for the non-renewable primary energy demand (PE) of QP ≤ 120 kWh/(m²a) can continue to be used in a transitional phase, as stated in [3]: the requirement for the PER demand replaces the previous requirement for the non-renewable primary energy demand (PE); however, the old method based on PE may continue to be used in parallel during a transitional phase (only for the Classic and PHI Low Energy Building categories). The difference between the old and new methods is presented in Table 1.2.

It is important to understand that the PER factors simply indicate how much more renewable primary electricity needs to be generated to cover the demand of the building. PERs represent the required resources for a given energy application, or more precisely, the renewable energy resources. The calculations conducted by the Passive House Institute (PHI) result in a PER factor[3] of approximately 1.3. (for systems with stored hot water from electrical sources). If buildings do not offer storage possibilities for this and grid-connected stores must be used instead, PER factor has a value of approximately 1.4 (also applicable for hot water from electric water heaters).

1.2. PASSIVE HOUSE SURCHARGE

A Passive House is considered worldwide to be more expensive to build than common building construction, and that difference in upfront costs is usually called premium or surcharge. According to a study [4], the surcharge ranges between 7% and 15%. The higher the surcharge, the more expensive electricity (energy) should be for a Passive House to be cost-effective.

3 According to [24]: Direct electricity consumption is assumed to the extent of supply and demand matching up. If the supply exceeds the demand, any excess electricity is fed into the storage facilities. Accordingly, any surplus energy demand during times of low RE availability is covered with the energy taken from the storage.

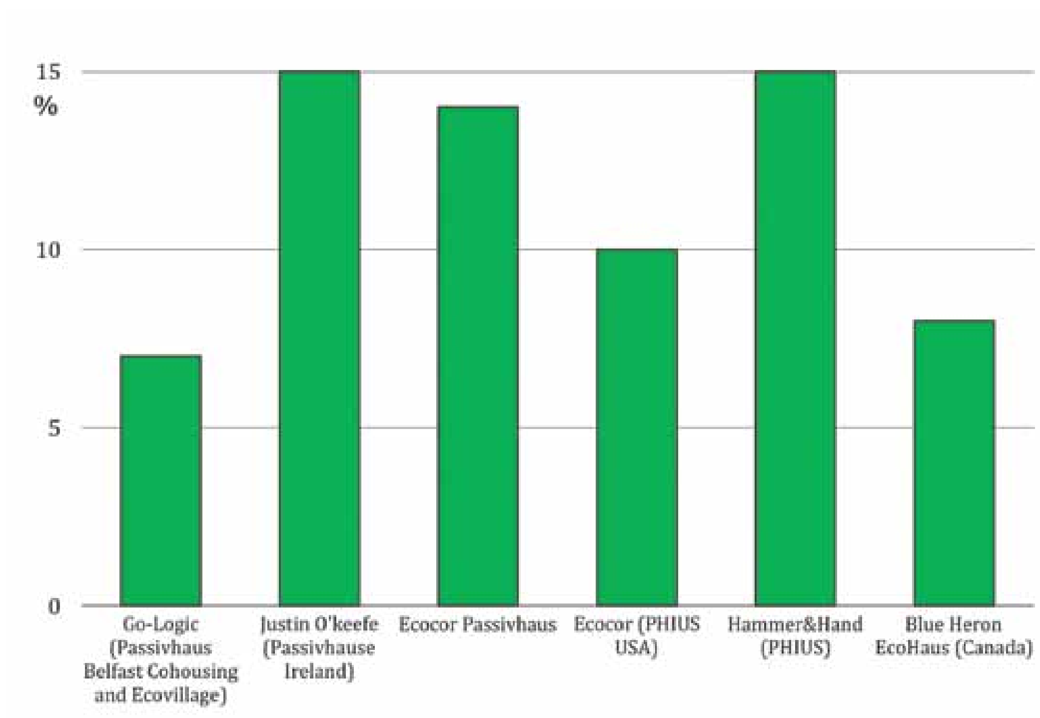


Figure 1.5. *Estimated additional cost (as % of construction cost) to be paid for a Passive House in different western European markets* [4]

To put the aforesaid 7–15% into perspective, we need to know the cost of building, shown in Figure 1.6.

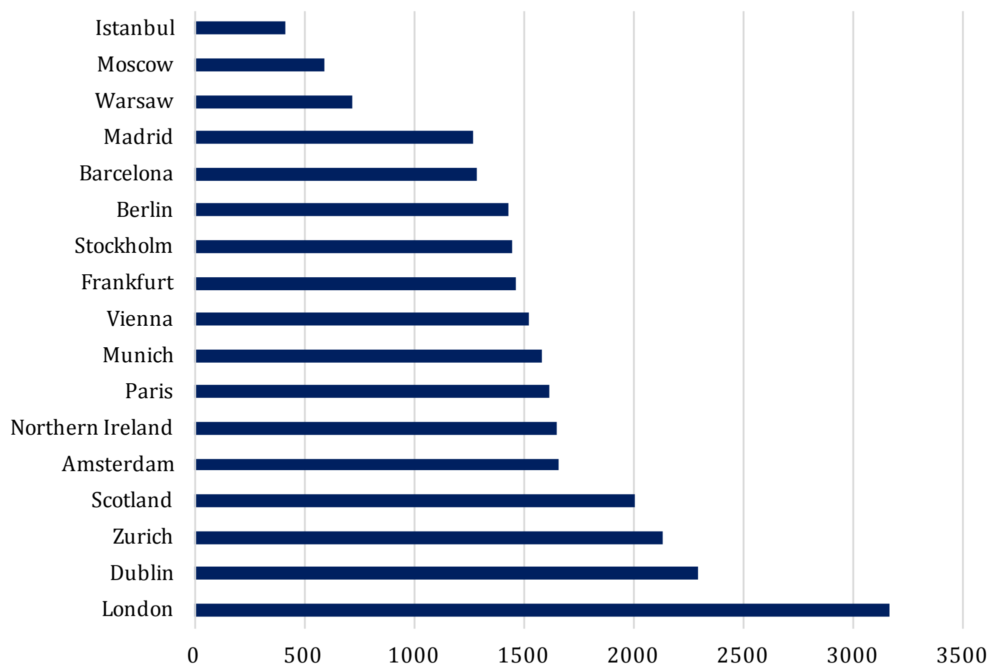


Figure 1.6. *Low-rise apartments building costs (€/m² of an internal area) in 2018 according to [5] (including materials, labour cost, equipment, HVAC equipment, contractor's margin, excluding site)*

Based on the Figure 1.5 and Figure 1.6, we can point to one of the crucial advantages (besides the price of energy) of the Passive House markets in the highly developed world: the high price of the usual (everyday) system of construction, resulting in good chances that the 7–15% premium (combined with the mentioned high price of energy) will be cost-effective. In other words: the relative surcharge in low-cost markets will be higher, making the cost-effectiveness more challenging.

1.3. PASSIVE HOUSE AND SERBIA(N MARKET CONDITIONS)

As indicated above, Passive House construction comes at a cost (additional investment, know-how, skills). In most contexts (like northern and western Europe) this pays off by delivering lower energy consumption and, thus, reducing the living costs for residents. However, in Serbia, we meet additional challenges. Identified weaknesses of conditions in Belgrade and/or Serbia and/or Southeast Europe in comparison to the usual market for this type of the buildings are:

- The significantly lower price of electricity/energy, which is always a determining factor for the projects that are related to energy efficiency – the lower the costs of energy are, the less attractive it is to invest in energy efficiency;
- Low diversity of local fuels/sources of energy (Serbian electricity is predominantly coming either from lignite (more than 70%) or hydro power, 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;
- Lack of completed projects and associated know-how, the underdeveloped knowledge-base on the technologies and possibilities that are available today;
- Lack of will among potential suppliers/producers of materials/equipment to engage in the projects that could result in the long-run savings of energy and environmental benefits, yet not generating immediate revenue;
- Climate, which is, in the case of Belgrade, demanding in terms of both heating and cooling.

Identified strengths of the conditions in Belgrade and/or Serbia and/or SEE in comparison with the usual market for this type of buildings are:

- The relatively low price of labour, potentially making some of the extra investments required in construction less expensive;
- Solar insolation (the quantity of solar energy received) is higher than in Western/Northern Europe, thus making it easier to achieve solar (energy) gains or produce renewables on-site from solar energy;
- Difference between day/night temperature on average higher than in Western/Northern Europe, making both night-time cooling in the summer as well as solar gain in the winter easier to achieve.

Possibilities for improvement of the design of Pametnija Zgrada are largely based on the aforementioned identified strengths.

1.4. CLIMATE AND PASSIVE HOUSE

The PH approach originated and was pioneered in the moderate and cool north-western European climate zones. Introducing it in other climate zones (Figure 1.7), like the south-east European climate zone (warm-temperate), requires adaptation of its implementation.

The PHI acknowledges the specific requirements for PH designs in the southern climates [6]. It is a novel terrain, and this study is, to the best knowledge of its authors, the first of its kind modelling the performance and requirements for the south-east European climate zone.

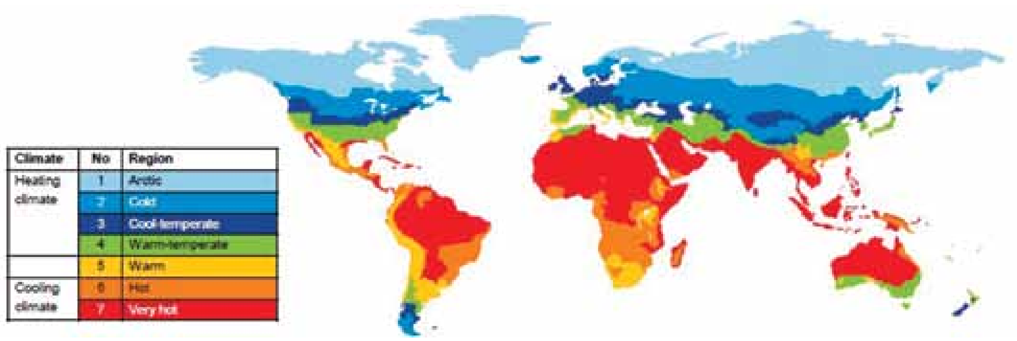


Figure 1.7. *Climate zones according to PHI (Serbia being categorized as a cool-temperate region)*

To provide deeper insights into the impact of location, the modelling results of simulations manipulating only the location/weather input data are given in Figure 1.8 under the following assumptions: *AAC Passive 3 (see* Table 3.1*), geothermal heat pump, double glazed windows, without shades, heating temperature 20 ˚C, cooling temperature 26 ˚C.*

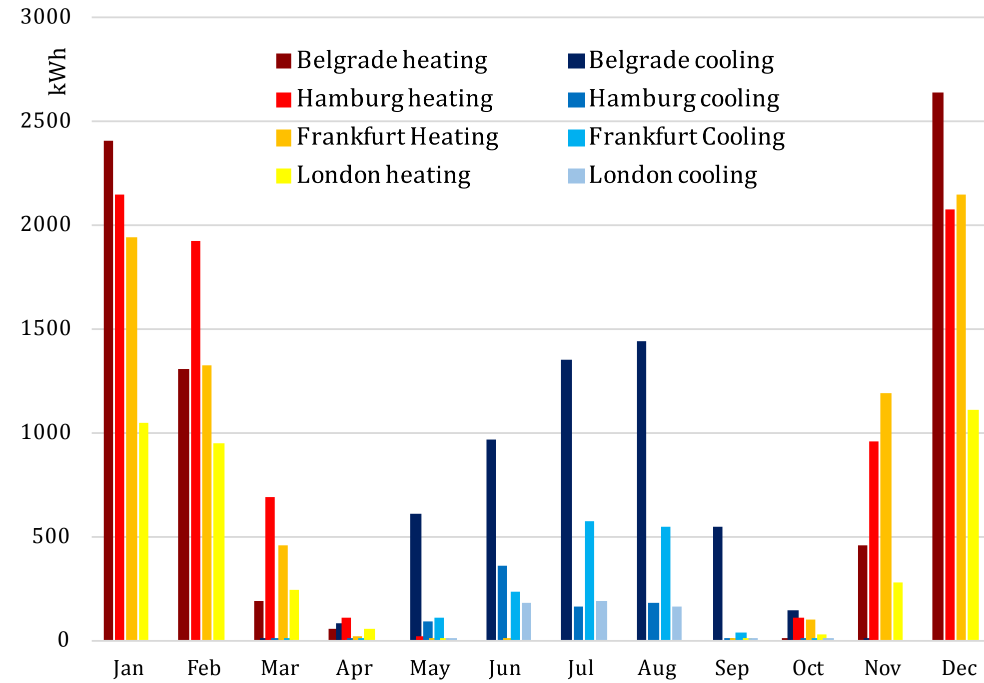


Figure 1.8. *Modelling results of the impact of weather data/location on energy consumption (kWh) of identical building Pametnija Zgrada in four hypothetical cases: Belgrade, London, Hamburg and birthplace of Passive House - Frankfurt*

The climate in Belgrade is demanding for both cooling and heating, additionally requiring air conditioning through e.g. humidifiers. When overlaid with solar irradiation data (the gains of the Sun in W/m^2), space opens for a different conception of building.

1.5. FORM FACTOR

Besides the five Passive House principles explained in this chapter, attention should be given to the so-called Form factor of the building: *the Heat Loss Form Factor is the ratio of thermal envelope surface area to the Treated Floor Area (TFA).* This is effectively the ratio of the surface area that can lose heat (the thermal envelope) to the floor area that gets heated [7].

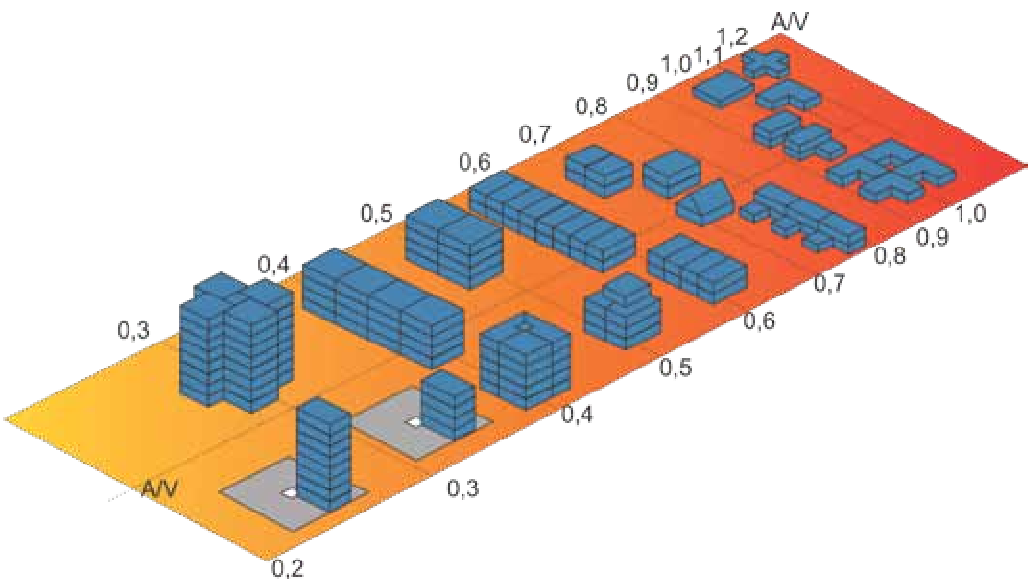


Figure 1.9. *Form-factor or compactness ratio* [8] *(smaller number is better)*

Improved Form-factor can have one of the following two results:

- Energy savings, or
- Lower initial investment, since it enables savings on e.g. insulating material.

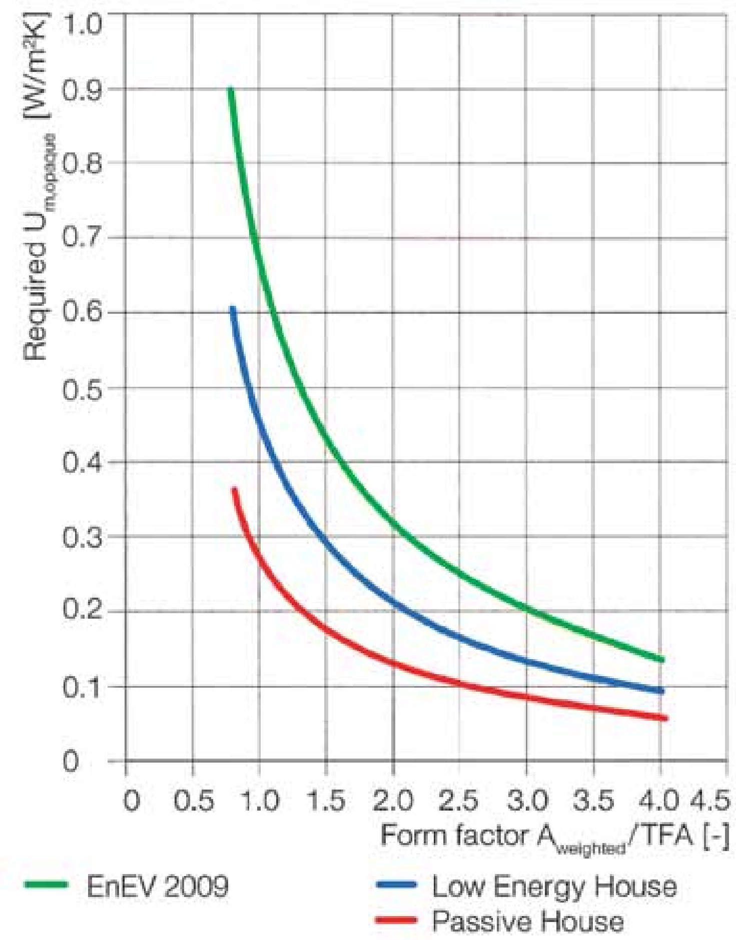


Figure 1.10. *Expected impact of the Form-factor on U-value necessary to fulfil certain requirements according to* [7]

SUMMARY OF CHAPTER 1

THE PASSIVE HOUSE PRINCIPLE

In its first chapter, the study introduces the Passive House concept, while in Chapter 1.3 it considers it in more detail and within the SEE context.

Passive Houses are characterized by a set of straightforward but rigorous thermal measures that enable an exceptionally low energy demand.

Like all high-performance systems, Passive Houses are sensitive to various impacts, among which the climate is one of decisive importance.

To counteract that sensitivity, detailed planning is necessary. In doing so, it is necessary to localise the Passive House implementation to the climate specifics of the SEE context.

CHAPTER 2

THE PAMETNIJA ZGRADA FLAGSHIP DEVELOPMENT BY KO GRADI GRAD

Ko Gradi Grad [9] formed in 2010 in Belgrade and is now one of the leading not-for-profit organizations in the field of citizen-led housing initiatives in Serbia. Its innovative Pametnija Zgrada approach has been under development since 2012, responding to the aforementioned issues of affordability and lack of access to housing in the Serbian context. It targets people who are currently not being served by finance institutions, nor can they afford the soaring market rental prices. According to Ko Gradi Grad's estimations, the Serviceable Available Market (SAM) for such housing in Serbia is 8% of the overall population, or 200,000 households.

For the upcoming years, Ko Gradi Grad has set out to implement the first "smarter building" flagship project in Belgrade. It is centred around a cooperative of inhabitants that collectively develops, finances, maintains and operates a multi-apartment building.

In Pametnija Zgrada, the homes and land are owned by the cooperative, rather than its individual members. The cost of building the homes owned by the cooperative is largely financed by a long-term mortgage loan (80% of the investment, covering the actual construction of the building). Under the terms of their lease, each member makes monthly payments to the cooperative, which will repay the loan and cover a deduction for service and utility costs.

Such a novel application of housing cooperatives provides advantageous and low-risk housing solutions for both users and investors. The special purpose vehicle (SPV) Housing cooperative Pametnija Zgrada has been incorporated (January 2019) as the developer, future owner and operator of the assets.

2.1. KEY DATA ABOUT THE PILOT PROJECT

Pametnija Zgrada, in its preliminary design, is a 19-unit, 4-story flagship development, with a heated floor area of 1,368 m^2 on an approx. 1,000 m^2 plot outside of the centre of Belgrade. It incorporates a range of apartments for different living requirements, including single users, families and co-housing arrangements.

Pametnija Zgrada will give access to housing to 50-55 people who are currently underserved by the housing market. It will create a robust community and includes approx. 10% of additional space (130 m^2) dedicated to shared resident facilities.

Capitalization is achieved through a joint investment by external lenders (80%) and cooperative members (20% of own equity).

The building will be constructed to the Passive House Classic energy efficiency standard (≤ 60 kWh/(m^2a) total energy demand), which is to cut utility costs, reduce environmental impact and minimize maintenance costs. The layout of the building incorporates a number of architectural measures to enhance energy efficiency: it has a relatively high compactness (ratio between the external surface area and the internal volume of a building), has large south-facing façade openings (allowing the Sun to penetrate deep during the winter period), offers extensive possibility for ventilation in the summer (by opening the atrium and the central communication space) and utilises a part of the shared resident facilities (atrium) as an isolating buffer in the winter. Finally, the roof terrace is oriented toward the north, to minimize overexposure to the Sun during summer periods.

Functional Program and m^2

- Apartments = 1,010 m^2 (total net apt area), 19 apartments:
  10 units x 40 m^2 (1-2p household)
  6 units x 55 m^2 (3p)
  2 units x 80 m^2 (4-5p)
  1 unit x 120 m^2 (4-6p co-housing)

- Community spaces (conditioned) = 130 m^2 (net)
  workshop = 11 m^2
  co-work / shop / cafe = 40 m^2
  multipurpose space with kitchen = 27 m^2
  laundry room = 13 m^2
  guestroom = 26 m^2
  rooftop kitchen + WC = 13 m^2

- Technical spaces and communication (non-conditioned) = 235 m^2
  atrium = 40m^2
  entrance = 20,5 m^2
  entrance roof terrace = 15 m^2
  technical space = 7,5 m^2
  corridor + stairs = 152 m^2

HEATED floor area = 1,368 m^2
TOTAL GROSS floor area = 1,582 m^2
External spaces = 375 m^2 (net)
Parking = 265 m^2
Roof terrace = 110 m^2
TOTAL area with external spaces = 1582 + 375 = 1,957 m^2

Figure 2.1. *The spatial setup of Pametnija Zgrada*

Figure 2.2. *Floor plan of Pametnija Zgrada*

SUMMARY OF CHAPTER 2

THE PAMETNIJA ZGRADA FLAGSHIP DEVELOPMENT BY KO GRADI GRAD

Pametnija Zgrada is the ground-breaking pilot project of the civic association Ko Gradi Grad. It is envisioned to be constructed during the next 2-3 years.

The goal of this flagship development is to build the first 19-unit multi-apartment Passive House in Serbia as the first housing cooperative in Belgrade in over twenty years and a producer of on-site generated renewable energy, all this while striving toward an affordable building with a low environmental footprint.

Its feasibility as an affordable, low-impact Passive House is subject to verification in this study.

CHAPTER 3

PAMETNIJA ZGRADA ENVELOPE

The building envelope (walls, windows, doors, roof and, as in the case of Pametnija Zgrada, parking lot ceiling) is crucial to achieving the Passive House standard since the majority of losses are happening through the interaction of the envelope with the environment, as shown by the example of the world's first Passive House (Kranichstein in Darmstadt, Germany) in Figure 3.1.

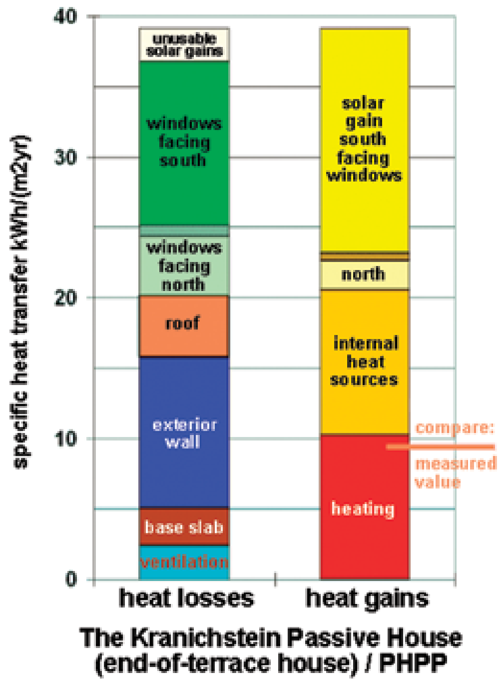


Figure 3.1. *The energy balance in the case of Kranichstein Passive House* [10]

3.1. MAIN BUILDING MATERIAL

The starting hypothesis of this study was that the main building material should be:

- Adequate for achieving the Passive House standard;
  - Low thermal conductivity, possible or cheap to achieve high air-tightness, adequate thermal mass for temperature extremes;
- Affordable;
- Adequate for a four-story building;
- Environmentally acceptable/friendly and;
- Locally sourced.

After an extended market survey, three main building materials are proposed (each implementation covering walls, floors, as well as the roof):

- Autoclaved Aerated Concrete (*AAC*);
- CLT (cross-laminated timber) provided by one company from Serbia (hereinafter: *CLT Supplier 1*) and one from Slovenia (hereinafter: *CLT Supplier 2*);
- Prefabricated wood composite panelling system (*PWCP*) supplied by a company from Serbia.

All these materials are compared with a declared baseline building material. The baseline building material is also AAC, built in order to achieve the C energy class standard according to the Serbian building certification guide [1].

All analyses and price estimations are covering only the aboveground part of the building, shown in Figure 3.2. The reasoning behind this decision is twofold:

- The ground floor and parking space will be the same (reinforced concrete column structure) regardless of the construction chosen;
- The ground floor/level has limited heated space.

Figure 3.2. *The aboveground part of the building that was the subject of the analysis*

3.1.1. PHYSICAL AND ECONOMIC ASPECTS OF PROPOSED MATERIALS

3.1.1.1. AUTOCLAVED AERATED CONCRETE

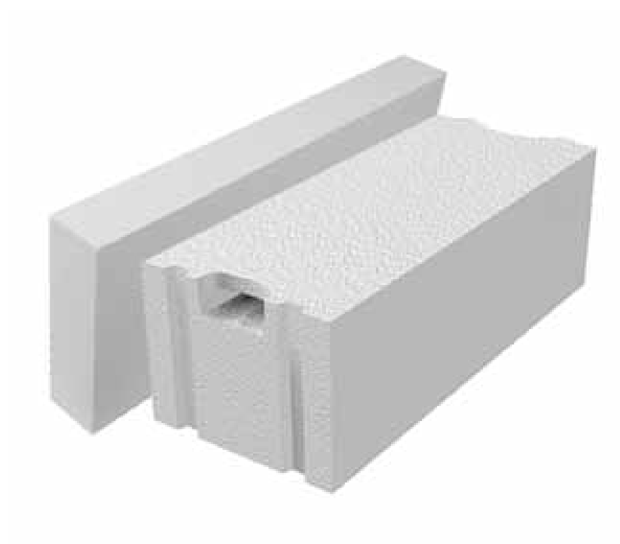


Figure 3.3. *AAC building block*

Autoclaved aerated concrete (AAC) is well known as a building material in the Passive House world. It is made from a mix of sand, lime, cement, water - with aluminium powder as an expanding agent. During production, the aluminium powder increases the volume and provides its typical porous structure when the material is "baked" in an autoclave. Its physical properties are very attractive (lightweight, low thermal conductivity, high fire resistivity and soundproofing properties), while environmental impact is among the best of concrete-based materials (yet not comparable with wood-based materials).

For the purposes of this study, four scenarios involving the autoclaved aerated concrete (AAC) were analysed with building construction costs data provided by Serbian companies (Table 3.1).

Type	Description of proposed construction	Material	The total cost of base construction for PZ [€/m² of Total Gross area] [€]
AAC C Class	Low energy AAC blocks (30 cm) without insulation, 15 cm roof rockwool insulation	AAC 30 cm	**83 €/m²** **€ 131,400**
AAC Passive 1	Low energy AAC blocks (37.5 cm) with 10 cm rockwool insulation, 30 cm roof rockwool insulation	AAC 37.5 cm + 10 cm mineral rockwool	**107 €/m²** **€ 167,800**
AAC Passive 2	Low energy AAC blocks (30 cm) with 10 cm rockwool insulation, 30 cm roof rockwool insulation	AAC 30 cm + 10 cm mineral rockwool	**101 €/m²** **€ 159,900**
AAC Passive 3	Low energy AAC blocks (20 cm) with 15 cm rockwool insulation, 30 cm roof rockwool insulation	AAC 20 cm + 15 cm mineral rockwool	**100 €/m²** **€ 158,300**

Table 3.1. *AAC based buildings costs (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)*

NOTE: Key drawback of AAC as the main building material is **airtightness** and how to achieve airtightness specified by PHI, the (non)existing know-how and the price of achieving this rigorous requirement.

3.1.1.2. CROSS-LAMINATED TIMBER

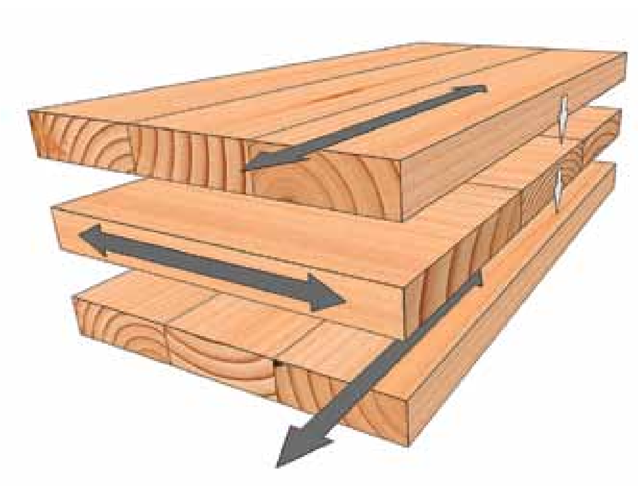


Figure 3.4. *Cross-laminated timber (CLT)*

Cross-laminated timber (CLT) finds increasing application in Passive House construction. A CLT panel consists of several layers of kiln-dried lumber boards stacked in alternating directions, bonded with adhesives and pressed to form a solid, straight, rectangular panel [11], pre-sized according to building needs. The resulting panel is lightweight, strong, with good seismic and adequate thermal performance. Once prefabricated, the installation of CLT panels is fast. In comparison with concrete-based materials, CLT is more suitable for markets with higher purchasing power.

Two options for CLT have been considered for Pametnija Zgrada as shown in Table 3.2.

Producer or supplier	Description of proposed construction	Prices for PZ	Note	The total cost of base construction for PZ [€/m2 of Total Gross area] [€]
CLT Supplier 1	10 cm internal walls 15 cm for building envelope walls 18 cm floor-boards of the building	438,200 € for 576 m^3 or 18 cm - 136 €/m^2 10 cm - 76 €/m^2	- Price covers only material; additional installation costs are +5% - Airtightness know-how could be an issue	**336 €/m^2** **531,552 €**
CLT Supplier 2	10 cm internal walls and building envelope 18 cm floor-boards of the building	18 cm - 86 €/m^2 10 cm - 60 €/m^2 Installation 20 €/m^2 of all board's surfaces (could be lower) Steel framework 10 – 12,000 € Transportation from Wien in 15 tow trucks with 2,500 € per truck is 37,500 € (could be lower)	- PHI supports possible - Airtightness know-how exists - Blower door test possible	**271 €/m^2** **428,722 € or slightly less**

Table 3.2. *CLT and its aspects (includes main building material, external wall treatment (insulation), ceilings, flat roof, workers' salary, with separation walls between apartments and without separation walls inside apartments, excluding VAT)*

Other available data regarding the price of CLT refer to a project developing in Barcelona [12] at the moment of writing this report:

- The total amount of CLT used 470-490 m³ (non-visible quality as a final finish);
- The total price of CLT (including assembly) – 365,000 €.

If this project (and its price of 760 €/m³ including assembly) is scaled to the Pametnija Zgrada, the expected price would be between 376,200 € and 437,800 € depending on the amount of CLT used (CLT Supplier 1 is suggesting 576 m³, while CLT Supplier 2 is suggesting 495 m³).

3.1.1.3. PREFABRICATED WOOD COMPOSITE PANELLING

Figure 3.5. *Composition of PWCP external walls*

The prefabricated wood composite panelling system (PWCP) is the third option available on the Serbian market and suitable for a Passive House. The panels are composed of a structure of load-bearing wooden studs, filled in with a thermal insulation of mineral wool and complemented with a solid board of pressed wood-fibre. They are produced by a certified Passive House builder according to PHI requirements (and if chosen, PHI support could be available).

Producer or supplier	Description of proposed construction	Prices for PZ	Note	The total cost of base construction for PZ [€/m2 of Total Gross area] [€]
PWCP	Prefabricated Wood-Based Panels	190 €/m² or less 300,000 € or less	- PHI supports possible - Airtightness know-how exist - Blower door test possible	**300,000 € or could be less in case wood wool is replaced with rock wool** **190 €/m²**

Table 3.3. *PWCP and its aspects (includes main building material, external wall treatment (insulation), ceilings, flat roof, workers' salary, with separation walls between apartments and without separation walls inside apartments, excluding VAT, includes montage)*

It is worth noting that airtightness of the construction suggested by the PHI can be achieved by the PWCP Supplier, as well as tested with a blower door.

3.1.2. IMPACT ON CONSTRUCTION TIME AND EFFECT ON RENTAL INCOME

Different building materials result in different construction times. At this point, it's not easy to estimate the potential gains of time or how much project could be hindered by different construction materials since there are variables that have not been examined, such as:

- The amount of time suppliers will have to prepare, develop documentation and produce/deliver materials;
- The ability of a supplier to deliver the building material within the stipulated time (e.g. if it has waiting lists) and how that fits with Pametnija Zgrada timeline;
- Planning logistics, e.g. how well a pilot project can be organized and by whom, and knowing that, if e.g. CLT is chosen, this project will be the first of its kind (carrying all the usual difficulties of a debut).

When the three aforementioned building systems and their corresponding estimated times they take to build the Pametnija Zgrada are compared (comparison covers only the building envelope, the time needed for installation of insulation, dividing walls etc.), the conclusion is as follows:

- AAC:
  - Immediately available in the market;
  - Know-how and consultancy if necessary/needed is available;
  - AAC is the slowest material to build with among the selected (above-ground part of the building could be built and insulated in between 40 and 100 days);
- CLT:
  - Requires advance ordering of material (not immediately available);
  - Lists for EU customers/buyers are long and it is unclear how quickly the construction could be delivered by *CLT Supplier 1* or *CLT Supplier 2*;
  - Existing know-how is debatable;
  - Once panels are prefabricated, the erection of the building could be very quick (in 2 weeks to one-month time);
- PWCP:
  - Similar to CLT, except for the know-how which is, according to data available to date, estimated as higher.

After all of the above is considered, the conclusion is that CLT and Prefabricated panels *could result* in faster building times, ranging from 2 to 3 months (with all the uncertainties mentioned).

Having in mind that the average rental income per flat is 250 €/month (rough estimates[4]), the advantage of choosing CLT or Prefabricated panels over AAC could result in savings ranging 9,000 – 14,000 €. Therefore, for the purposes of this analysis, AAC as a main building material will be penalized with 10,000 €.

3.1.3. RECOMMENDED BUILDING MATERIAL FOR PAMETNIJA ZGRADA

Considering all of the above, two materials will be proposed, with identified **advantages** listed in relation to each other:

- AAC Passive 3:
  - Lower investment;
- PWCP **with rock wool insulation**:
  - Lower environmental impact of the construction;
  - PHI support possible;
  - Airtightness easier to guarantee due to known factory contractor;
  - The "green innovation" factor, making it more attractive or more visible for a pilot project.

The price of the PWCP construction is higher, yet not unreasonably high to the extent that could undermine the Pametnija Zgrada project.

4 Made under optimistic assumption that all 19 units will be rented from the first month after building commissioning.

3.2. INSULATING MATERIALS

In order to achieve the appropriate (desirable) thermal properties of building envelopes, it is necessary to install thermal insulation materials. The available thermal insulation materials can be differentiated according to:

- Origin/type of the base material;
- Values of thermal conductivity λ [W/mK];
- Density;
- Place of application of thermal insulation materials and;
- Environmental impact.

Thermal insulation materials have a thermal conductivity below 0.3 W/mK. There are three[5] main categories of thermal insulation materials:

- Inorganic materials,
- Organic materials,
- New materials.

According to the structure, these materials are further divided into fibrous and cellular.

Numerous different thermal insulation materials are available in the Serbian market. In order to select the appropriate one, it is necessary to analyse their properties. The thermal conductivity of a material is the most important property. A lower value of thermal conductivity contributes to the higher thermal resistance *R* [m^{2}K/W] of the entire building envelope structure. In addition, density, water vapour diffusion resistance μ [-], carbon footprint, as well as the resistance to fire, are also important properties of thermal insulation materials. In Table 3.5, the characteristics of thermal insulation materials that can be found in the Serbian market are shown.

The thermal conductivities of insulating materials available in the domestic market slightly differ. Organic petrochemical cellular materials (PU) and new materials (aerogel) have the lowest values (very good insulation properties). On the other hand, high-density wood wool has the highest value (sufficient insulation properties).

5 An additional main category called "combined materials" is found in several literature sources. This group includes materials produced using different base materials from the other three groups.

Figure 3.6 shows that carbon footprints per kilogram of insulating materials are quite different. Organic petrochemical cellular materials emit the highest amounts of CO_2 per kilogram, while the production of organic renewable fibrous materials emits the lowest amounts.

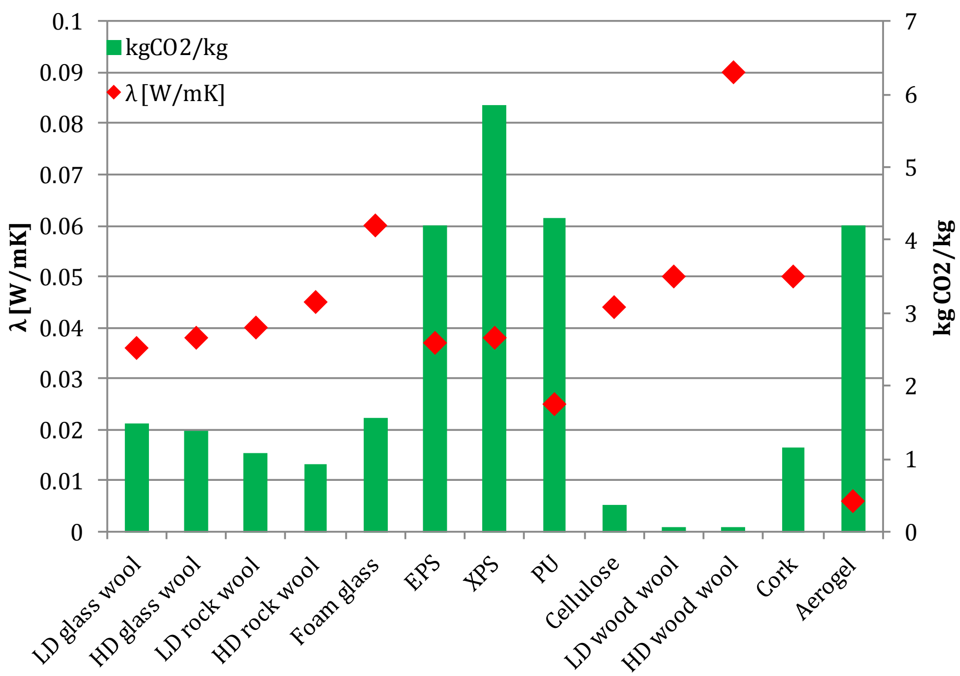


Figure 3.6. *Thermal conductivity and carbon footprint (per kilogram of insulating materials).* [13] [14]

Different values of thermal conductivities require different thicknesses of insulation in order to obtain the same R-value on the building envelope as shown in Figure 3.7. Based on the thickness of materials it is possible to determine the carbon footprint per unit area of the envelope, as shown in Figure 3.7. The foam glass has the maximum environmental impact, while the impact of wood wool and cellulose is the lowest. Commonly used thermal insulation materials, such as EPS, glass wool and rock wool, have a relatively low carbon footprint per unit area of the envelope.

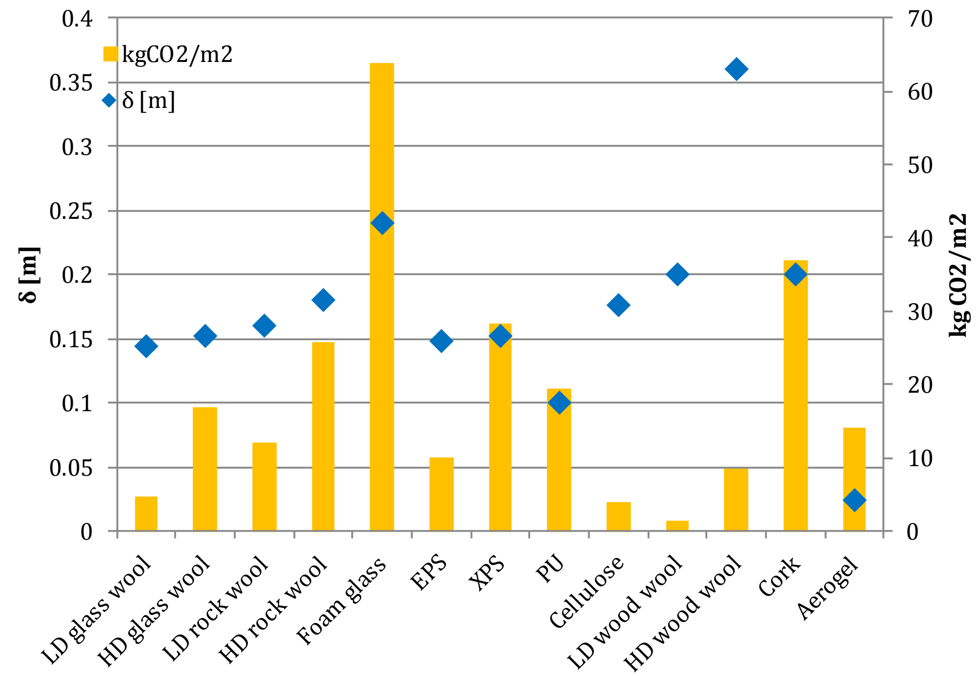


Figure 3.7. *The required thickness and carbon footprint (per m² of insulating materials) for the same R-value* [14] [13]

The average price of commonly used thermal insulation materials available in the Serbian market (EPS 15 cm equivalent) is shown in Table 3.4.

Material	**Price [€/m²]** *including VAT, excluding montage*
EPS	6.10
XPS	17.80
Rock wool	11.02
Glass wool	6.36
Wood fibre wool**	29.66

** Price for the EU market

Table 3.4. *Average prices of commonly used insulating materials in the Serbian market (EPS 15 cm equivalent)*

RECOMMENDATION: Having in mind that the price of wood-based insulation materials is high, EPS and rock-wool are selected as alternatives with acceptable environmental impacts. Since EPS' fire resistance is low, **HD rock wool should be considered as the main insulation material for Pametnija Zgrada.**

Material group	Material		Material composition	Density [kg/m³]	λ [W/mK]	Carbon footprint [kg CO_2/kg]	Fire resistance class	Water vapour resistance factor μ [-]
Inorganic materials - fibrous	Glass wool	LD*	Cullet, quartz sand dolomite	15-40 (22)	0.034-0.04 (0.036)	1.494	A1	>1
		HD*		40-150 (80)	0.03-0.045 (0.038)	1.380		
	Rock wool	LD	Diabase, basalt	20-120 (70)	0.033-0.042 (0.04)	1.082	A1	1 - 5
		HD		120-200 (155)	0.035-0.048 (0.045)	0.920		
Inorganic materials - cellular	Calcium silicate		Chalk, sand cellulose fibres	121	0.04-0.065 (0.045)	-	A1	6 - 20
	Foam glass		Cullet, feldspar, dolomite	90-200 (170)	0.038-0.08 (0.06)	1.565	A1	-
Organic petrochemical materials - cellular	EPS		Expanded polystyrene – Benzene, ethylene, pentane	10-30 (16)	0.034-0.045 (0.037)	4.205	E-F	20 - 100
	XPS		Extruded polystyrene – Benzene, ethylene, pentane	28-45 (32)	0.031-0.044 (0.038)	5.840	E-F	80 -300
	PUR		Polyurethane – Isocyanate, polyol	28-100 (45)	0.022-0.03 (0.025)	4.307	D-F	50-100
Organic renewable materials - fibrous	Cellulose		Recycled paper, wood fibre	30-80 (60)	0.04-0.05 (0.044)	0.367	E	2-3
	Wood wool	LD	Wood	50-270 (120)	0.038-0.06 (0.05)	0.062	E	5
		HD		350-600 (380)	0.075-0.11 (0.09)	0.062		
Organic renewable materials - fibrous	Cork		Cork	100-220 (160)	0.045-0.07 (0.05)	1.156	E	5-30
New technology materials – cellular	Aerogel		Silicon alkoxide	60-160 (140)	0.013-0.024 (0.017)	4.2	A1	2-5.5

Table 3.5. *Characteristics of insulating materials available in the Serbian market [13] [14]*

* LD – LOW DENSITY; HD – HIGH DENSITY

3.3. WINDOWS

One of the five key points in Passive House design are windows. This is easy to understand, as the thermal performance of the envelope is of crucial importance and windows are the "weakest link" of that envelope, thus requiring detailed attention. Furthermore, windows are a potential source of both heat losses and heat gains, so the emphasis is usually put on two things:

- Their thermal transmittance or U-value and;
- Their airtightness.

Windows that are available in today's market are very well engineered, characterized by almost every U-value imaginable (Passive House database [15] lists windows with U-values ranging from 0.6 W/m²K for triple glazed to a maximum value of 1.2 W/m²K for double glazed windows). Materials range from wood to aluminium, PVC or fibreglass, or a combination of some of these materials.

A key choice to be made is the application of double- or triple-pane glazing, as they come at a significant price difference. Results of the modelling and the difference between double and triple glazing in the case of Pametnija Zgrada are shown in Figure 3.8 under the following presumptions: *AAC Passive 3, heating temperature 20 °C, cooling temperature 26 °C, no overhangs, no blinds, air sourced heat pump*. The value *Total* corresponds to the gross energy consumption of the building including lighting, appliances, ventilation etc. All other values show the consumption of electricity. The shown results are pointing to one of the differences of the Southeast European climate (in comparison to northern Europe where triple glazing is the standard) - "our" climate context isn't favouring triple glazing as one could expect. Things are even clearer when we consider the surplus price that should be paid for triple glazing (Figure 3.9, Figure 3.10).

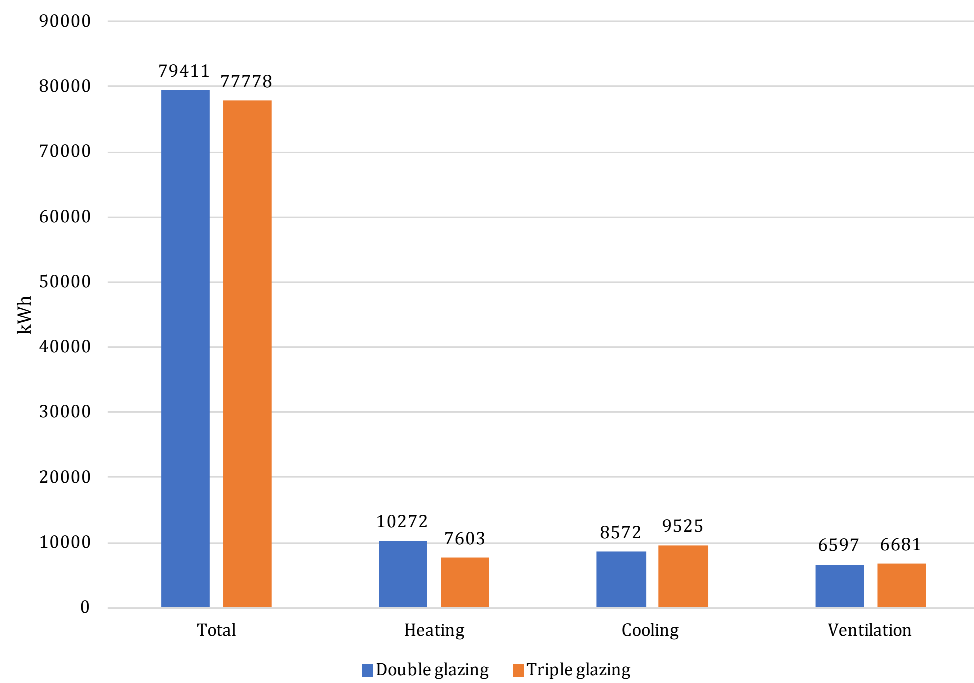


Figure 3.8. *Triple* (U-value 0.785 W/m²K) *vs. double* (U-value 1.341 W/m²K) *glazing*

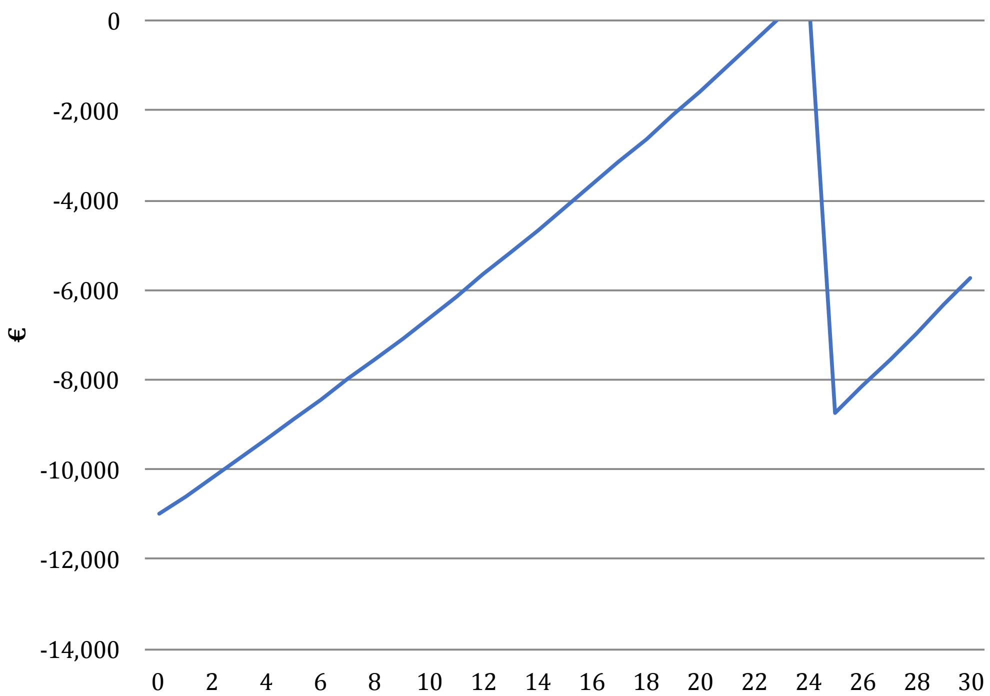


Figure 3.9. *NPV analysis of the profitability of investing in triple glazed PVC windows in comparison with double glazed PVC windows*

NPV analysis for investment in triple glazing is given in Figure 3.9 under the following assumptions: *42,000 € investment for all windows triple glazed, 31,000 € for double glazed (both including montage, including VAT), 25 years expected lifetime, main envelope AAC Passive 3, heat pump air to air, 6% annual rise of the price of electricity, d=**4.5%** (optimistic).*

A variance of Figure 3.9 is shown in Figure 3.10, where all parameters are the same, except d=8% (risk-free value).

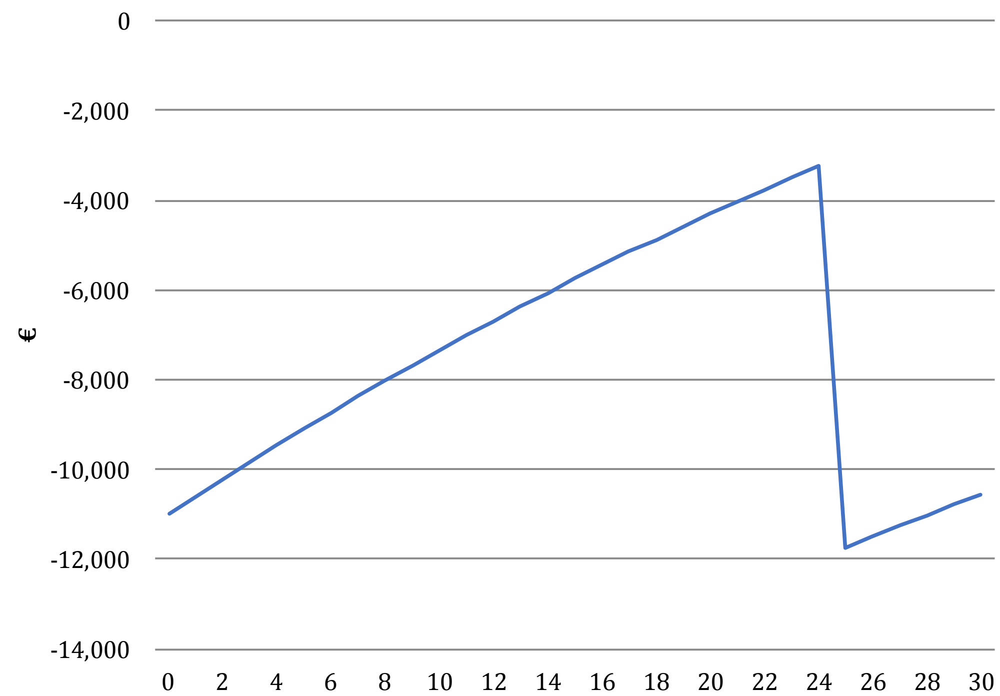


Figure 3.10. *NPV analysis of the profitability of investing in triple glazed PVC windows in comparison with double glazed PVC windows*

NPV analysis of double (31,000 € for Pametnija Zgrada, U-value 1.341 W/m^2K) and triple glazing (42,000 € for Pametnija Zgrada, U-value 0.785 W/m^2K) is a great showcase to accentuate the impact that the low price of energy (electricity) can have on measures that could, in other cases, be profitable.

Triple glazed windows: **Should not be considered under the circumstances in Serbia.**

3.3.1 SHADES

Large-sized glazed surfaces are one of the characteristics of modern architecture and very often a mark of a Passive House. When we are talking about energy losses, windows and skylights are usually the weakest parts of the building envelope, meaning that thermal transmittance is higher than through walls or ceilings and the amount of unwanted heat gains during the summer can be anything but negligible. On the other hand, they can be a source of much-needed energy gains during the winter and late autumn, or in early spring. Finding a balance between these wanted and unwanted gains is not easy, and it is hard to achieve through the optimization of orientation and/or size of glazed surfaces, so shades are an (almost obligatory) way to balance that.

In this study, the impact of two ways (between an infinite number of options) to shade glazed surfaces were analysed:

- Fixed shades on:
  - South façade and;
  - South, East and West façade and;
- Motorized venetian blinds on:
  - South façade and;
  - South, East and West façade.

Figure 3.11. *Fixed shades on Belfield Townhomes Philadelphia Passive House (left) and motorized venetian blinds (right)*

The approximate cost of fixed shades with steel substructure per meter is estimated at 80 €. The approximate cost of Warema motorized venetian blinds is ranging from 150–450 €/m^2, mainly depending on window size, resulting in the following cost (including VAT, including montage):

- West: 8,000 €;
- East: 9,760 €;
- South: 26,700 €.

The impact of the installation of venetian blinds on energy consumption is shown in Figure 3.12, under the following assumptions: *AAC Passive 3, heating temperature 20 ˚C, cooling temperature 26 ˚C, double glazing, air sourced heat pump.*

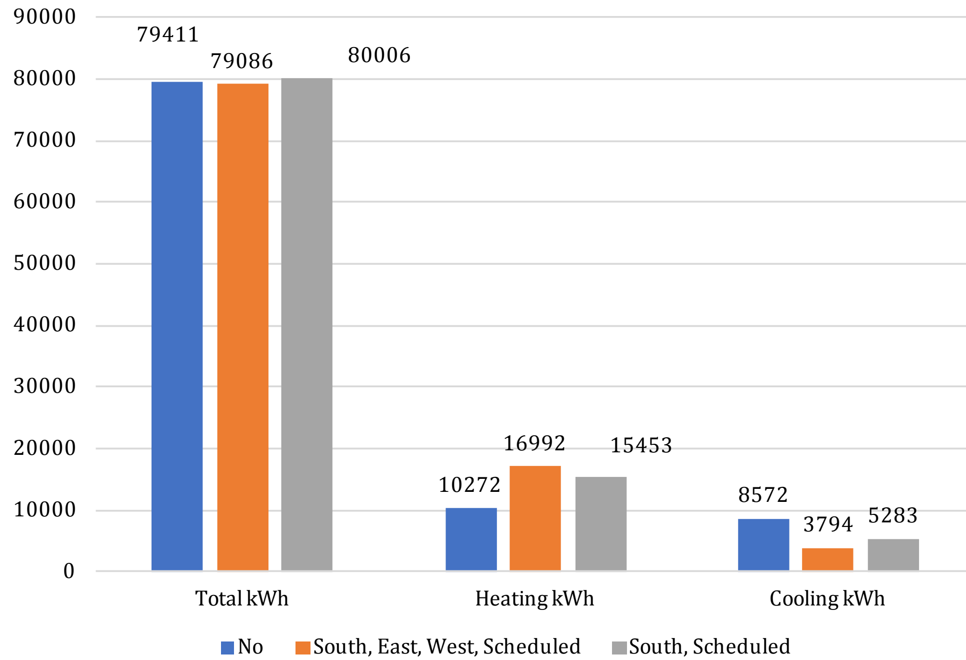
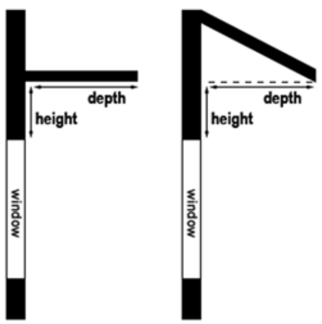


Figure 3.12. *Impact of venetian blinds on the consumption of energy (kWh)*

The conclusion is that the installation of venetian blinds will have more effect on comfort than on energy savings and, since the price of the equipment is relatively high: **Venetian blinds should not be considered under the circumstances in Serbia.**

Figure 3.13. *Low-tech low-price fixed shades and the way they are mounted, taking into account thermal bridges (Passivehouse Canada)*

Overhangs will be considered according to three scenarios [16]:



- depth: 2.0 height: 0.3;
- depth: 1.7 height: 0.8;
- depth: 1.1 height: 0.8;

mounted on:

- South façade and;
- South, East and West façade.

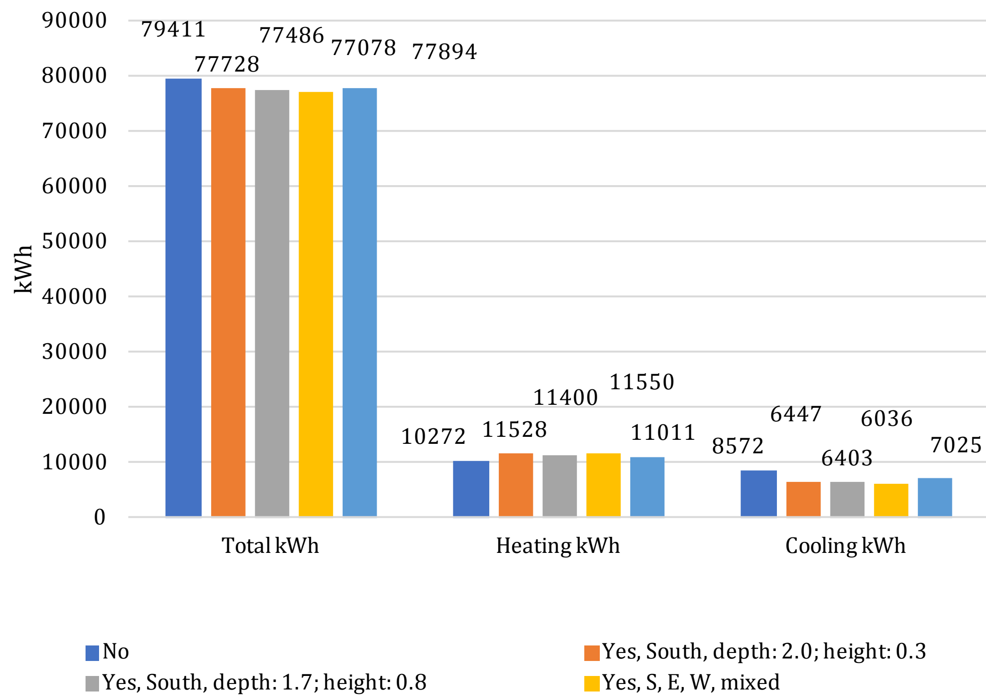


Figure 3.14. *Impact of fixed shades on the consumption of energy*

The impact of shades is shown in Figure 3.14, under the following assumptions: AAC Passive 3, heating temperature 20 °C, cooling temperature 26 °C, double glazing, air sourced heat pump.

NOTE: Before the implementation, the redesign of the south façade (height of the windows, to allow for the required space above windows) should be reconsidered. There is also a possibility to install PV panels as shades on the south façade.

Figure 3.15. *PV panels as shades on the south façade*

Low-tech fixed shades: **Should be considered under the circumstances in Serbia only on the south façade, predominantly as a measure for improvement of comfort rather than as significant improvement of energy efficiency.**

SUMMARY OF CHAPTER 3

PAMETNIJA ZGRADA ENVELOPE

Chapter 3 analyses the building envelope as a cause of most of the heat losses.

To counteract that, special care should be put to the choice of main construction method/material, insulation material, windows and airtightness.

In the Serbian market, multiple products that meet the requirements of the Passive House standard are available. If requirements emphasize a low footprint, the choice is somewhat more complex.

Based on this combined set of requirements, a number of specific construction methods/materials are recommended, as specified in this chapter.

Differentiating from the anticipated Passive House implementation in most of the North-Western Europe, the analysis for the SEE region shows that the pilot project benefits from double glazing and fixed shades, rather than triple glazing and movable shades.

CHAPTER 4

HVAC AND DOMESTIC HOT WATER SYSTEM

The Heating Ventilation and Air Conditioning (HVAC) system is a crucial part of a Passive House: it provides space heating/cooling, as well as the necessary exchange of fresh air (ventilation) required for a healthy indoor climate. The number of possible configurations for HVAC and the installation for Domestic Hot Water (DHW) is endless and limited only with the creativity of designers, so the authors of this study relied on solutions already addressed in the literature (which, to some extent, reduced the number of solutions considered).

Guidelines used for the development of the system proposed here are:

- Low impact;
- Affordable;
- Simple – appropriate;
- Reliable;
- Locally sourced & serviceable;
- Comfortable & needs-based (to compensate for the impact of the climate zone (as per Figure 1.8, which requires extra attention to the need for heating (winter) and cooling (summer));
- Flexible & future-proof and;
- Encouraging behavioural change.

Since Pametnija Zgrada is a Pilot project to be built at a location that is unknown at the time of writing this report, special care is given to the universality of the proposed conceptual solution.

The specificity of passive construction, which is primarily reflected in the airtightness of the building, implies that some form of ventilation must be incorporated. Balanced mechanical ventilation (introduces fresh outdoor air into the building at the same rate at which the stale indoor air is exhausted from the building) with heat recovery is the standard solution for this demand.

The considered solutions could be divided into three main groups:

- Centralized;
- Partly (de)centralized or semi-centralized and;
- Fully decentralized or individual.

All these solutions are based on the energy provided by (one or more) heat pumps. This is a mechanical device that is highly efficient in transferring heat energy from a source of heat (the air or the ground) with the use of electricity. Using a heat pump is many times more efficient than using conventional electric heating. It is, therefore, becoming a standard application to provide for the base demand for heating in energy-efficient buildings. The efficiency of a heat pump is expressed by the Coefficient of Performance (COP) – the higher the COP, the better its performance.

Peak demands for heating energy will be covered with auxiliary heating elements either integrated into the HVAC system, or as standalone devices. Backup heating systems will be considered.

The following sub-chapters will outline the advantages and disadvantages of the systems under consideration.

4.1.1. OTHER ASSUMPTIONS

Offers obtained from the relevant companies, data obtained through market research, values specified by standards, as well as estimations based on conducted research have been used as input data in the spreadsheet tool for the assessment of Pametnija Zgrada (see Chapter 9.2).

Technical equipment maintenance costs and estimated life span (according to EN 15459-1:2017) are given in Table 4.1.

Equipment	Estimated life span [year]	Annual maintenance costs [% of investment cost]
Air conditioning units	15	4
Boiler - condensing	20	1.5
Control equipment	20	4
Duct system for filtered air	30	2
Fans	20	4
Fans with a variable flow	15	6
Heat pumps	15	3
Tank storage for DHW	20	1
Heat recovery units	20	4
PV panels	25	0.5
Invertor	10	-
Pipes plastic (floor heating)	50	1

Table 4.1. *Equipment maintenance costs and estimated life span according to EN 15459-1:2017*

4.2. AIR BASED VS. WATER-BASED HVAC

When designing an HVAC, a choice has to be made between water and air as the transport medium of the heat produced by the heat pump. The following considerations are mostly about the amount of air needed to achieve the designed temperatures. This difference is coming from two main factors:

- The specific heat capacity of water is approx. 4186 J/kg·K, while the specific heat capacity of air is 1005 J/kg·K, and;
- The density of water is 1000 kg/m^3, while the density of air is 1,2 kg/m^3.

The difference in the amount of heat that can be carried per m^3 of the working medium is, therefore, enormous – water is a far more efficient transport medium.

As a result:

- If air is the heat carrier, under the assumption that the temperature of the room is 22 ˚C, and the heating air temperature is 38 ˚C, to deliver 30 kW of heating energy (Pametnija Zgrada peak consumption) 5600 m^3/h of air is necessary;
- At the same time, according to DIN1946, between 1000 m^3/h and 3000 m^3/h of air will be needed for 50 tenants, depending on the circumstances (lower value during night time when the ventilation is set to “low”, and higher value when the ventilation is set to “boost”) i.e. 2–5 times less air with various side effects:
  - In the first case, the main duct size in case of square ducts and for speeds of 5 m/s will be 0.62 m^2, while in the second case the ductwork cross-section will be 0.25 m^2;
  - Loss of energy on the heat recovery unit will be, in accordance with the flow, 2–5 times higher.

4.2.1. AIR AS A HEAT CARRIER

Pros:

- Air quality can be completely controlled (although adjusting all parameters could be expensive);
- High rates of air entering/exiting the building with adequate filtration could result in the comfort that feels like the best one;
- Redistribution of energy between flats results in energy savings;

Cons:

- The air flow rate is significantly higher than in case when water/refrigerant is the heat carrier (where airflow in ventilation system covers only ventilation) meaning:
  - All ducts have a larger diameter resulting in expensive and space-consuming distribution network (especially important for vertical shafts connected to the loss of floor space);
  - Fan(s) energy consumption is higher (Passive House electricity demand for ventilation is limited to 0.45 W/(m^3/h)), and even higher if the system is centralized;
  - Heat loss on the heat recuperator is, for the same efficiency of the recuperator, higher;
  - Penetration of ducts through ceilings/walls requires additional fire-rated components;
- Noise spreads between flats;
- Impossible simultaneous heating and cooling;
- Very little control over temperature and/or flow rate in individual apartments;
- Balancing of the distribution network is challenging;
- Lack of know-how, since this type of multifamily buildings doesn’t exist in the Serbian market.

RECOMMENDATION: Should not be considered for Pametnija Zgrada.

4.2.2. WATER AS A HEAT CARRIER

Pros:

- Very efficient, especially when paired with a geothermal heat source;
- Per flat controls of temperature easily implemented;
- Without significant penetrations through floors/ceilings/walls;
- Ventilation needed only to provide air for occupants - minimized ductwork, fans are consuming 2–5 times less energy in comparison with the air-based system;
- Simultaneous heating and cooling possible (although this requires a four-pipe system that could be expensive);
- Know-how exists;
- Balancing of the distribution network is easily achievable.

Cons:

- Additional piping required (still cheaper than ductwork).

RECOMMENDATION: Should be considered for Pametnija Zgrada.

4.3. CENTRALIZED VS. DECENTRALIZED SUPPLY OF HEATING/COOLING ENERGY

When planning a multi-apartment building HVAC, there is always a choice between the centralized and decentralized HVAC. The “business as usual” scenario in Serbia is the choice of a highly decentralized system, usually encouraged by an approach that is seen as “independence” or “disconnection” from neighbours (taught by the problems related to the maintenance of shared equipment) and, since the Pametnija Zgrada is conceptualized differently, the cons and pros of possible system configurations will be listed in the following subchapters.

4.3.1. CENTRALIZED SUPPLY OF HEATING/COOLING ENERGY

In a centralized system, one large unit provides the heating/cooling energy for the entire building.

Pros:

- One unit is sufficient, resulting in lower initial investment, lower maintenance costs, easier access etc.;
- If the heat pump compressor is placed on the ground floor, noise won’t be an issue;
- Backup system (electric heater) easy to integrate;
- Centralized hot water preparation possible;
- In the case of air to air heating, only two penetrations of the building’s envelope are necessary.

Cons:

- Charging for heating per consumption is significantly more complicated.

RECOMMENDATION: Should be considered for Pametnija Zgrada.

4.3.2. DECENTRALIZED SUPPLY OF HEATING/COOLING ENERGY

In a decentralized system, multiple smaller units (one per floor, or one per apartment) are used to provide the heating/cooling energy.

Pros:

- Each apartment can easily adjust temperature;
- Charging per consumption is possible.

Cons:

- More units mean more investment;
- Maintenance is more complex;
- An electric preheater is necessary for Belgrade to allow the recuperator to operate during a prolonged period with below-freezing outdoor temperature (the condensate turns into ice and blocks the recuperator);
- Geothermal energy is practically out of reach, so air to water or air to air systems are possible;
- Could be more expensive;
- Filter replacement more challenging than in the case of a centralized system.

RECOMMENDATION: **Should not be considered for Pametnija Zgrada.**

4.4. CENTRALIZED VS. DECENTRALIZED MECHANICAL VENTILATION WITH HEAT RECOVERY

Similarly to the previous Chapter (4.3), the pros and cons of the two approaches are listed in the following subchapters.

4.4.1. CENTRALIZED MECHANICAL VENTILATION WITH HEAT RECOVERY

In a centralized system, one large unit provides mechanical ventilation for the entire building.

Pros:

- Air quality can be completely controlled (although adjusting all parameters could be expensive);
- Redistribution of energy between flats results in energy savings.

Cons:

- The air flow rate is significantly higher than in the case when water/refrigerant is the heat carrier (where airflow in ventilation system covers only ventilation), meaning:
    - All ducts have a larger diameter resulting in expensive and space-consuming distribution network (especially important for vertical shafts connected to the loss of floor space);
    - Fan(s) energy consumption is higher;
    - Heat recuperator heat loss is, for the same efficiency, higher;
    - Penetration of ducts through ceilings/floors/walls requires additional fire-rated components;
- Noise spreads between flats;
- Impossible simultaneous heating and cooling;
- Very little control over temperature and/or flow rate in individual apartments;
- Balancing of the distribution network is challenging.

RECOMMENDATION: **Should not be considered for Pametnija Zgrada.**

4.4.2. DECENTRALIZED OR INDIVIDUAL MECHANICAL VENTILATION WITH HEAT RECOVERY

In a decentralized system, multiple smaller units (one per floor, or one per apartment) are used to provide the mechanical ventilation.

Pros:

- Air quality can be completely controlled (although adjusting all parameters could be even more expensive than in the case of a centralized system);
- Each apartment can easily boost flow when necessary.

Cons:

- Individual mechanical ventilation could be more expensive;
- Two penetrations of the building's envelope per flat/per floor that should be properly sealed and insulated;
- Filter replacement more challenging than in the case of a centralized system.

RECOMMENDATION: **Should be considered for Pametnija Zgrada.**

4.5. RECOMMENDED HVAC

The proposed solution is a balance between investment and achievable comfort: **Decentralized (per floor or per flat) mechanical ventilation with heat recovery coupled with a centralized ground-source heat pump as the heating/cooling source with heat exchanger integrated into ventilation ducts. For the reasons of thermal comfort, floor heating should be considered for the first floor.**

Pros:

- High(est) COP of all systems considered;
- Low price per installed kW;
- Air quality comparable with air source heat pump with heat recovery ventilation, while the price of the distribution network is significantly lower since:
  - It is easier to carry any amount of heat with water than with air;
  - Air conditioning is possible to the extent that is acceptable to the investor;
- Individual controls of flow and temperature for each apartment is possible (even remote control);
- Network balancing is easy;
- The backup heating system is cheap and easy to integrate;
- Centralized preparation of hot water is possible;
- Integration with a PV plant is easy, with the possibility of integration of a heat accumulator/buffer tank, as well.

Cons:

- In comparison with an air source heat pump, additional costs are necessary for drilling and auxiliary equipment for heat source/sink, estimated at 4,000 € (two wells, each 15 m deep);
- Decentralized ventilation means more penetrations through the building envelope, which complicates the sealing and insulation of the building envelope (and possibly its aesthetics);
- Significantly more complex to charge tenants according to the consumption of energy (which in the case of a cooperative housing should not be a problem).

The estimated price for the compressor is 5,500 €, pipework and heat exchangers 38,000 €, in case of per flat decentralized ventilation, HRV price is estimated at 1500 €/flat, in case of per floor semi-centralized ventilation HRV, the price is estimated at 3200 €/floor i.e. 12,000 €/building.

The price of two wells and auxiliary equipment is estimated at 4,000 €.

The total price should not exceed 74,000 €, excluding VAT and excluding montage.

NOTE: Air to water heat pump could be an alternative in case geothermal energy isn't (for any reason) obtainable on site. The difference between the consumption of energy of air sourced and geothermal heat pump is shown in Figure 4.1 under the following assumptions: *AAC Passive 3, heating temperature 20 ˚C, cooling temperature 26 ˚C, double glazing.*

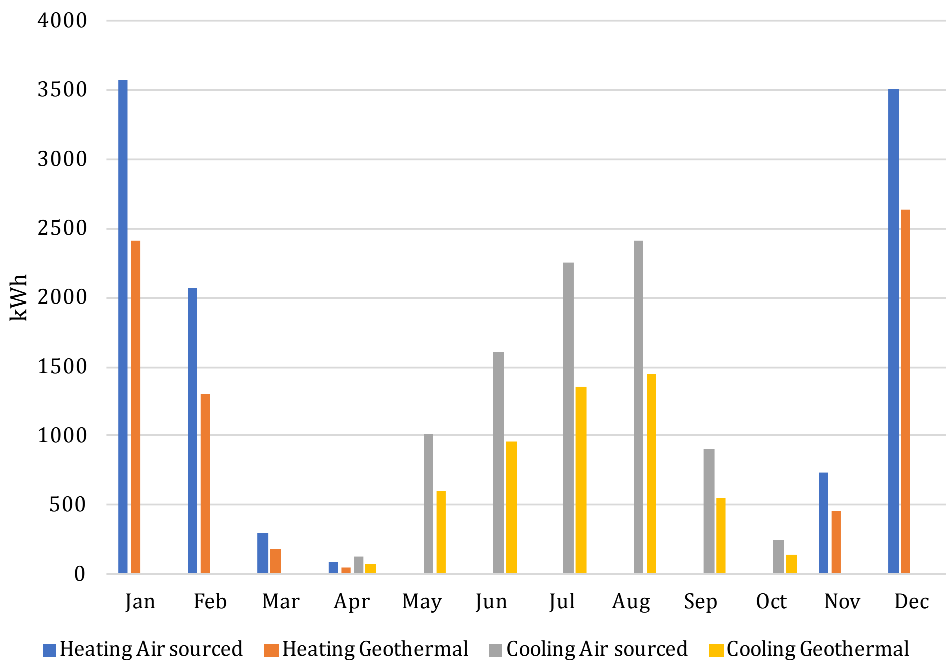


Figure 4.1. *Difference between the consumption of energy (kWh) for ground source and air source heat pump*

NOTE: To avoid dry air during winter (and moist air during summer), a so-called enthalpy exchanger or total heat exchanger (THEX) can be used in the energy recovery unit. These recover energy both from temperature (sensible heat) and hygrometry (latent heat) and, while doing so, allow moisture to be transferred. This could retain 80% of moisture, leading to a better inner indoor climate. A cheaper alternative could be the installation of humidifiers inside ductworks, to be used only during the winter.

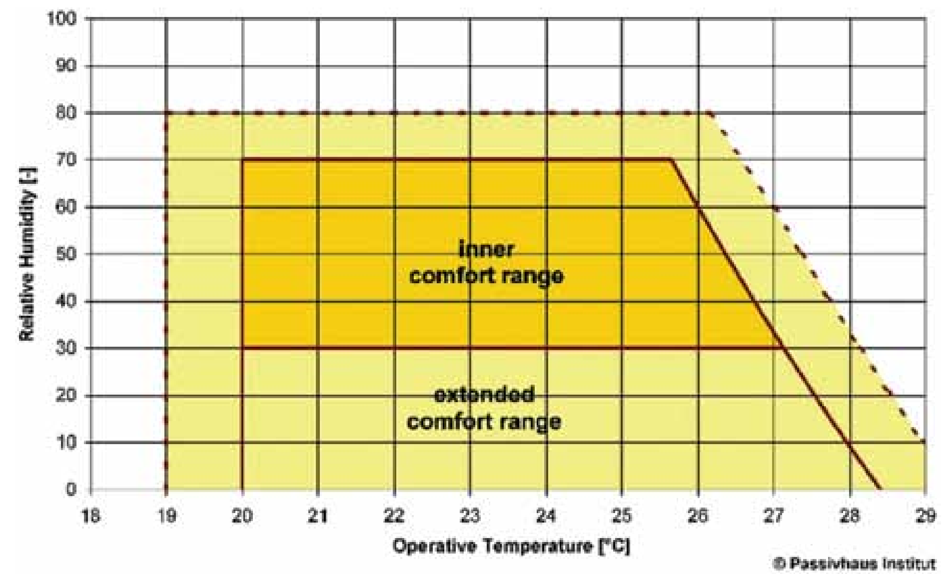


Figure 4.2. *Comfort range according to PHI*

NOTE: *Accurate price estimate of heat recovery systems is possible after the development of detailed HVAC project documentation.*

4.6. DOMESTIC HOT WATER SUPPLY SYSTEM

Once the centralized heating and cooling system has been proposed or designed, a centralized hot water distribution system conceived as an addition to HVAC is imposed by itself. In that case, the heat pump is a shared resource, requiring a negligibly higher investment in a slightly larger heat source; investment in a relatively large isolated vessel is also required, but this vessel is necessary as a buffer tank whose role is to ensure the integration of the PV power plant. Considering all of the above, the heat pump powered centralized sealed domestic hot water supply system is proposed for Pametnija Zgrada. Integration of the proposed system will result in:

- Large storage tank resulting in high comfort and cheap preparation of hot water, especially if the PV power plant is integrated into the system (or another renewable energy source);
- It requires less space and less maintenance than units in each apartment.

Main disadvantages of the centralized hot water supply system are:

- Long lengths of the pipework can lead to heat losses e.g. heat gains, which shouldn't be an issue during the winter, yet it could be a problem during the summer since these losses are unwanted heat gains for the building;
- Price of a centralized system could be higher than the price of a decentralized system; the whole system (piping) should be well insulated, and a detailed project should be developed to estimate the price;
- Charging per consumption could significantly increase the investment;
- Prevention of the development of bacteria legionella could be energy-demanding;
- Energy consumption of the pump used to circulate water could be significant; to minimize that loss, some form of control strategy should be implemented, e.g. the pump should be controlled according to the return temperature of the water.

NOTE: Buffer tank for domestic hot water **should be installed**. The volume of the buffer vessel is dependent on the system and the way energy is used:

- According to BS EN 14511:2011 "*should be based on approximately 25 litres per kW output of the heat pump*",
- According to BS EN 15450:2007 "*A guidance value for sizing the buffer storage volume is 12 to 35 l per kW maximum heat pump capacity*"

Clyde Technical Guide 788/1 (2006):
"*V (intermittent use) = heating load (kW) x 25 l,*
V (continuous use) = heating load (kW) x 80 l"

In the case of Pametnija Zgrada, the capacity should be up to 1500 litres. In case there is no net-metering for e.g. 20 kW PV plant, the buffer tank capacity should be divided into two, one for heating and one for hot water, with the total volume of 3,000 l (as explained in Chapter 10, this could be the subject of further research). If 60 °C is not achievable via heat pump, an electric heater should be installed in the buffer tank and periodically run to prevent the development of legionella pneumophila.

SUMMARY OF CHAPTER 4

HVAC AND DOMESTIC HOT WATER SYSTEM

Chapter 4 covers the choice of the necessary technical installations for heating, ventilation and cooling (HVAC), as well as for the provision of Domestic Hot Water (DHW).

The HVAC system is a crucial element in the case of Passive House:

- **It substitutes the missing part of the heating energy during the winter (heat is predominantly coming from appliances, lighting and human bodies);**
- **It helps get rid of excess heat during the summer;**
- **It takes care of air quality.**

The analysis of the pilot project shows that a decentralised HVAC system with a centralised heat source (a ground-source heat pump) using water as the transport medium provides the best combination of efficiency, cost-efficiency and ease of implementation. For DHW, a centralised system is recommended.

To fulfil these requirements, high integration of all subsystems is welcome. The recommended systems are all-electric, preferably using on-site produced renewable (PV solar) energy.

CHAPTER 5

PV POWER PLANT

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. As mentioned earlier, the new Primary Energy Renewable standard (PER) for Passive Houses foresees building-integrated production of renewable energy. Observing the situation in the Serbian market, besides geothermal, the only applicable renewable energy source is the integration of a PV solar plant. A PV solar plant consists of an array of solar panels and (one or more) inverter, delivering electricity. At the moment of writing this report, the price of PV plants is 0.8 €/kW_p for complete plant including installation. The price of the plant is estimated to be 0.7 €/kW_p including VAT in 2021, according to the estimation made by U.S. PV Price Brief (Figure 5.1) by GTM Research.

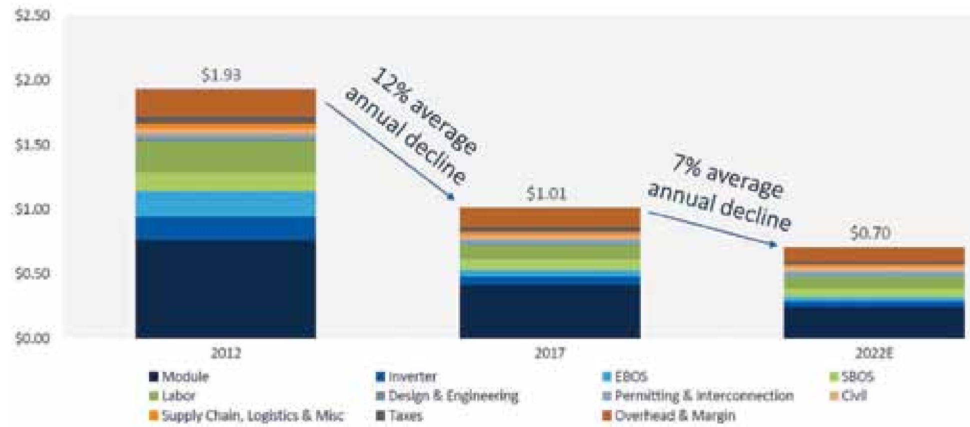


Figure 5.1. *GTM Research U.S. PV Price Brief as the basis for estimation of the price of a PV power plant on 0.7 €/kW_p in 2021*

Three different sized roof-mounted PV solar plants have been examined for this study. Using the PV GIS [17] (based on location Belgrade, orientation south, optimised panel angle 35°, total system losses 14%) the following PV electricity production can be expected:

15 kW_p – > 18,600 kWh/year
20 kW_p – > 24,800 kWh/year
25 kW_p – > 31,050 kWh/year

If the pilot building has a PER <= 60 kWh/(m^2anually) and a heated floor surface of 1,368 m^2, the yearly consumption is +/- 79400 kWh. Thus, the plant can cover **between +/- 23 % and 39 % of Primary Energy Demand with PV energy generated on-site.**

After numerous scenarios of PV plant integration have been analysed, not a single one was identified with a payback time below 10 years (Figure 5.2). The most preferable scenario implies the largest observed PV plant capacity (25 kW_p), predicted increase of the price of electricity of 10% per annum, and d = 4.5% (both the discount rate and the increase of the electricity price being optimistic). Results in Figure 5.2, Figure 5.3 and Figure 5.4 are given under the following assumptions: *inverter price in cca. 2030 is assumed to be 3500 €, inverter lifetime 10 years, maintenance costs 0.1 €/kW_p/year.*

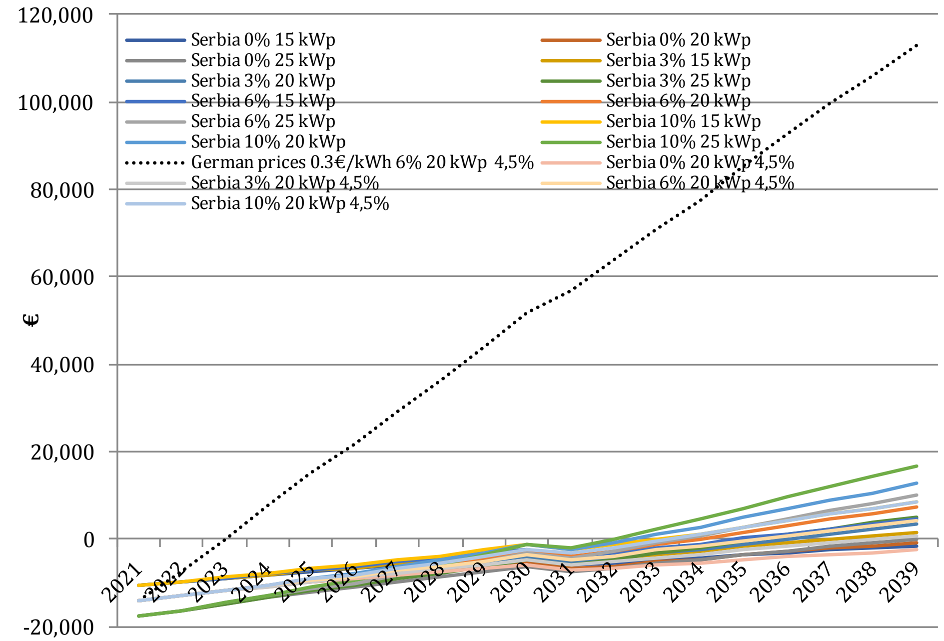


Figure 5.2. *NPV analysis of different installed capacities, rates of electricity price increase and different discount rate values; one scenario is covering the German price of electricity, to emphasize the importance of the price of electricity*

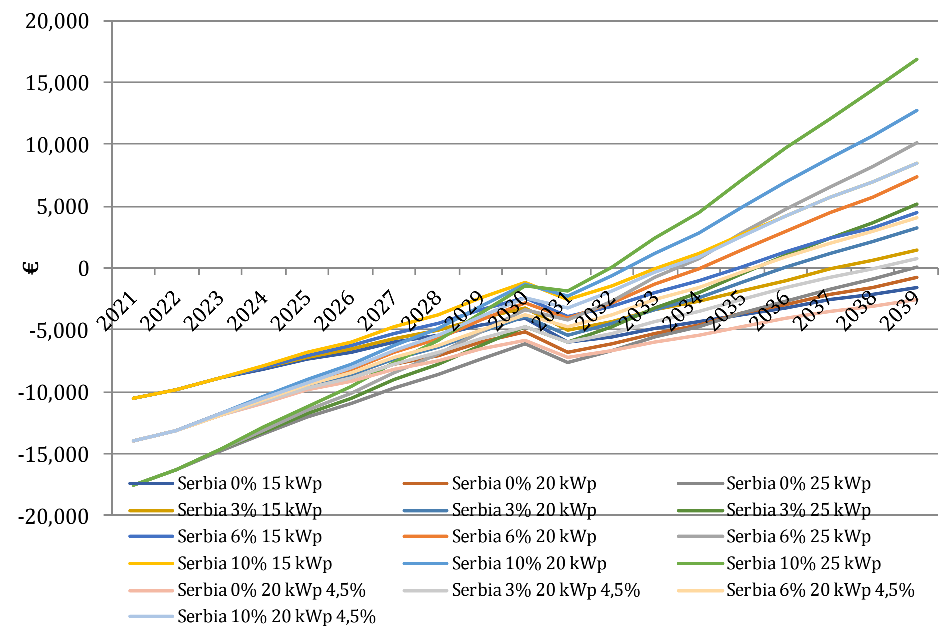


Figure 5.3. *NPV analysis of different installed capacities, rates of electricity price increase and different discount rate values*

More realistic scenarios are shown in Figure 5.4, from which we can conclude that the expected payback period is close to 15 years. It is worth mentioning that there are scenarios in which PV plant will never pay off (plant capacity of 15 kW_p, slow increase of the price of electricity (3% per annum), the discount rate of 10%).

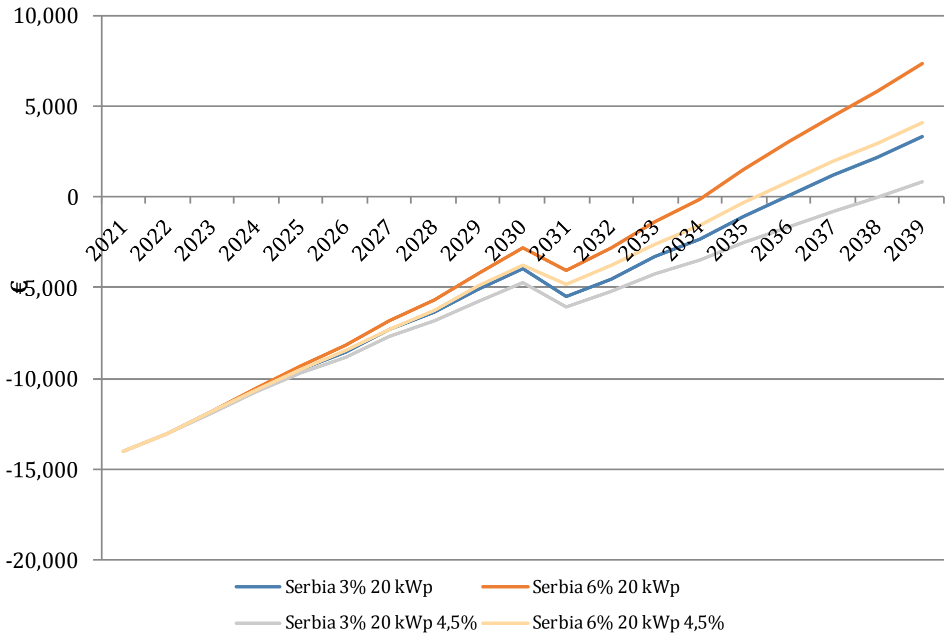


Figure 5.4. *NPV analysis of 20 kWp installed capacity, rates of electricity price increase and different discount rate values*

Figure 5.5. *15 kWp PV power plant on the roof of Pametnija Zgrada*

RECOMMENDATION: PV plant should be considered for Pametnija Zgrada

SUMMARY OF CHAPTER 5

PV POWER PLANT

Chapter 5 explores the potential of low-impact or renewable energy generation at the site of the building.

The integration of renewables in Passive Houses is more than common and an integral part of the updated Passive House standard (PER demand).

Analyses show that integration of a PV solar plant (in the range of 15-25 kWp) can cover between +/- 25 and 45 % of Primary Energy Demand with electricity generated on-site.

However, the specifics of the Serbian market are a complicating factor: there are no feed-in tariffs, there is no net-metering and the price of electricity is among the lowest in Europe (see chapter 8.3). It is fortunate that the price of PV power plants per peak of installed kW is at the all-time-minimum, thus leaving the thin margin required for a recommendation of this technology for the Pametnija Zgrada flagship building.

CHAPTER 6

AUXILIARY SYSTEMS

In the following few subchapters, auxiliary equipment designed to improve the performance of the Passive House will be discussed:

- Ground to air heat exchanger and thermodynamic solar panels as a way to improve the heat pump's COP, based around the idea of minimising the difference between the evaporator and condenser temperature;
- Solar thermal panels, as a way to produce domestic hot water;
- Solar chimney, as a way to deal with heat accumulated during summer heats and;
- Seasonal thermal storage as a way to store energy and/or to deal with peak loads in any period of the year.

6.1. GROUND TO AIR HEAT EXCHANGER

Air source heat pumps often use the ground to air heat exchanger (also called Earth Tubes or a Climate Battery – uses pipes placed in the soil under or next to a building) for preheating and/or precooling air, which relies on the much smaller fluctuation of the ground temperature compared to air temperature during the year.

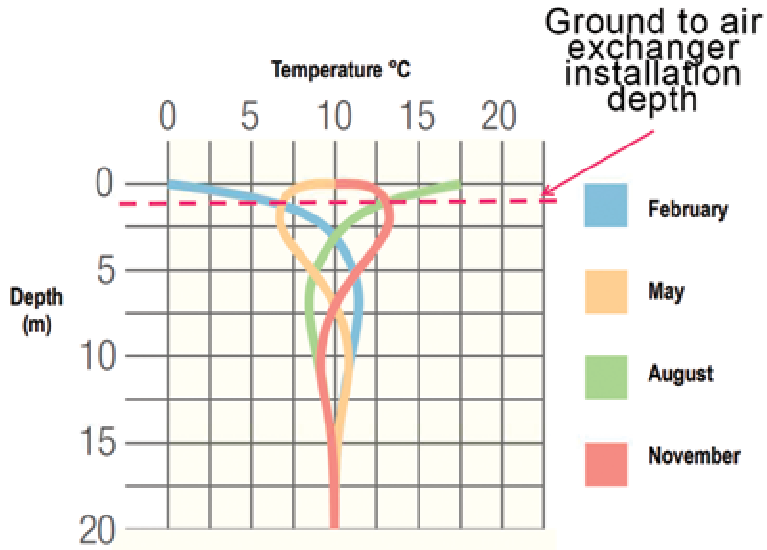


Figure 6.1. *Ground to air heat exchanger (REHAU)*

Some indisputable benefits can be identified:

- The solution can provide a higher COP of the heat pump, improving the overall performance of the system;
- It will result in improved ventilation during a much longer period of the year than without this addition;
- The solution is future proof;
- Maintenance costs could be low and;
- Complete installations are hidden from view.

On the other hand, identified drawbacks are at least equally significant:

- If air is the heat carrier, to transfer approximately 30 kW of heat at least 5,500 m^3/h flow rate is necessary, resulting in approximately 600–800 mm main pipe and an adequate number of side pipes (parallel, self-balancing layout) (to ensure heat transfer from ground to air, low speed (1–2 m/s) and low diameter side pipes are needed – cca. 200 mm) all resulting in high investment;
    - To grasp the size of installation, a good example is the Carclaze School in Cornwall, England, where for the flow rate of 3,457 m^3/h the main duct installed was 500 mm with 16 side pipes, each with 200 mm diameter and 30 m long (meaning that in the case of Pametnija Zgrada the placement of pipes could be difficult);
- To ensure adequate air flow through the pipes, a fan is necessary, adding to the consumption of electricity (and possibly increasing the noise);
- Drainage of the pipes is necessary; if installed correctly the possibility of water entering is low, but condensation is impossible to avoid, especially during the summer. Water could result in:
    - Mouldy smell;
    - Growth of bacteria, especially the dangerous *Legionella pneumophila*,
    - Costs for cleaning at least once a year (while it is unknown who has the know-how in the Serbian market for this very specific cleaning job).
- Pipes installed should be made of a material with good heat conductivity, rigid enough to prevent tree roots to tear them, and resistant to the growth of bacteria, resulting in a higher price of the system.

RECOMMENDATION: Should not be considered under circumstances in Serbia.

6.2. SOLAR THERMAL PANELS

Solar thermal panels capture heat by absorbing sunlight and use this heat to warm up the water (in contrast to PV solar panels, which produce electricity). They are used to save energy, predominantly for domestic hot water heating, and not exclusively in Passive Houses. After considering thermal solar panels (Figure 6.2), it is concluded that, per kWh of produced hot water, a similar investment is needed as in the case of a PV plant in combination with a heat pump.

Figure 6.2. *Solar thermal panels*

Solar thermal panels are not recommender as technology for Pametnija Zgrada on the following grounds: if included as a part of the installation, the heat from the surplus electricity generated by PV couldn't be managed and stored into hot water buffer tank, thus undercutting PV's payback time, especially in the case in which the net-metering is not introduced in Serbia. In other words, since investment in the heat pump will happen in every scenario, it is wiser to manage electricity (PV) and divert according to needs, than to manage heat energy (thermal solar).

RECOMMENDATION: Should not be considered in the case of Pametnija Zgrada, except in the case of abandoning the PV power plant as an idea for any reason. In that case, the use of solar thermal panels should be reconsidered.

6.3. THERMODYNAMIC SOLAR PANEL SYSTEM

Similarly to the previously mentioned ground to air exchanger, this addition to the heat pump aims to raise its COP, but rather than geothermal energy, it uses solar energy by exposing the refrigerant fluid to the Sun's irradiation in the panels mounted on the roof, or on a vertical wall.

Figure 6.3. *Thermodynamic Solar Panel*

This system could be especially effective in cases when a large amount of water is heated with a heat pump. The disadvantage of thermodynamic solar panels is their usefulness only during the winter (if the addition is not used exclusively to heat water with a dedicated heat pump), so it is estimated that expected gains will not justify the necessary investment.

RECOMMENDATION: Should not be considered under the circumstances in Serbia.

6.4. SOLAR CHIMNEY

One of the expected problems of the implementation of the Passive House concept in Serbia is the accumulation of heat during the summer, characterized by multi-day periods with very high day-time temperatures. Solar chimneys are passive solar elements that can help with object heating or cooling. In their simplest form, they are just an addition on the top of the building, chimney-shaped and painted in black. Heat accumulated in the chimney induces the draft necessary to get rid of the accumulated heat in common spaces, thus lowering the cooling bills.

It is hard to make an exact estimation of effects, so the recommendation for this measure is based solely on the presumption that solar chimney is an inexpensive addition to a building.

Figure 6.4. *A solar chimney(s) as a way to increase draft needed for passive cooling*

RECOMMENDATION: Should be considered for Pametnija Zgrada.

6.5. SEASONAL THERMAL STORAGE

Seasonal thermal energy storage is the storage of heating or cooling energy that can be used for prolonged periods of time, sometimes up to several months. The energy can be stored when it is cheap to produce and used when needed or when it is expensive to produce.

In contrast to the aforementioned short-term storage, seasonal thermal storage is either more expensive, or has a low heat recovery rate. The main energy storage principles and their characteristics are shown below [18]:

- Hot Water Energy Storage (HWES):
  - High cost due to manufacturing costs;
  - Energy recovery high (~90–98%);
  - Storage capacity compared to 1 m^3 water: 1 m^3;
- Gravel-Water Thermal Energy Storage:
  - High cost due to manufacturing costs;
  - Energy recovery lower than HWES because of greater thermal conductivity;
  - Storage capacity compared to 1 m^3 water: 1.5 m^3;
- Aquifer Thermal Energy Storage:
  - Low initial costs of drilling and equipment, with high maintenance costs;
  - Energy recovery rate – medium (65–95%);
  - Storage capacity compared to 1 m^3 water: 1.5–2.5 m^3;
- Borehole Thermal Energy Storage:
  - High drilling cost, low maintenance and manufacturing costs, modular construction, harder rock may increase drilling costs;
  - Energy recovery rate - low (~70–90% efficiency);
  - Storage capacity compared to 1 m^3 water: 2–4 m^3.

Taking all of this into consideration, if we want to save energy produced by e.g. 20 kW_p PV plant during 1 month in the summer (approximately 3 MWh) with the starting temperature of e.g. Gravel-Water Thermal Energy Storage of 15 °C and end temperature of 50 °C, the volume of the reservoir should be at least 65 m^3, i.e. we would need a reservoir 9 meters in diameter and 1 meter deep, resulting in very high investment.

RECOMMENDATION: Should not be considered under circumstances in Serbia.

SUMMARY OF CHAPTER 6

AUXILIARY SYSTEMS

Further improvement of the energy efficiency of a Passive House is possible through the integration of a diverse range of equipment available in the market.

Having in mind the recommended (aforementioned) HVAC and DHW solution, several of these systems have been analysed for their cost-efficiency.

According to this analysis, only solar chimneys prove to be a viable option for the pilot project.

CHAPTER 7

ENVIRONMENTAL FOOTPRINT

Following the (recent) global trends, and knowing that the construction industry is one of the main sources of greenhouse gases[6], one of the main demands of Pametnija Zgrada is the requirement that its environmental footprint should be reasonably low. Footprints of the main building materials are calculated for the Pametnija Zgrada pilot building according to different literature sources and expressed in tonnes of carbon dioxide.

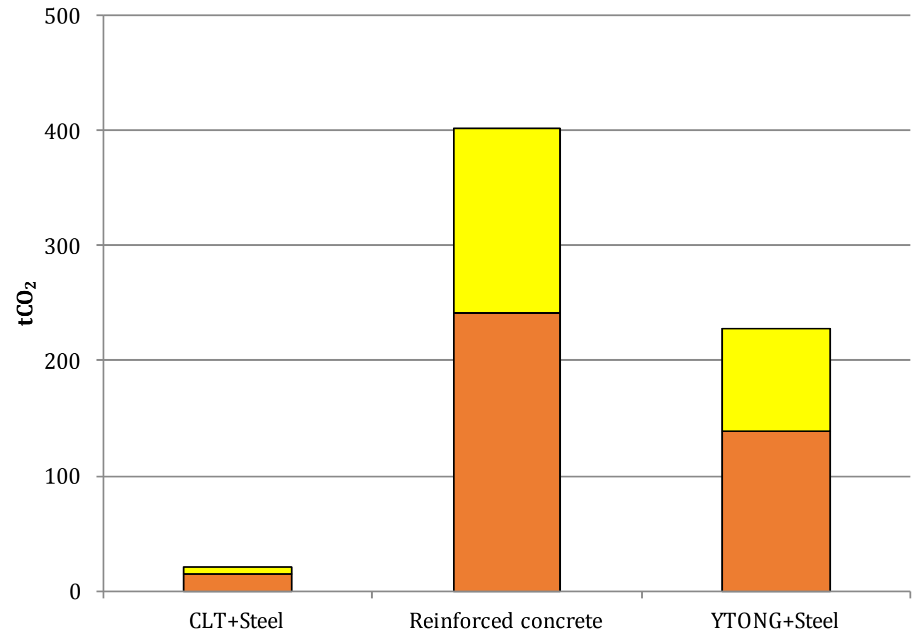


Figure 7.1. *The estimated amount of CO_2 (t) emitted for AAC and CLT construction as the main building materials (reinforced concrete is given as a hypothetical building material), in all three cases the yellow colour indicates the footprint of the steel*

6 Production of cement results in over 4.1 billion tons per year globally as of 2017, and alone accounts for around 5 percent of worldwide CO_2 emissions, of which 50% from the chemical process and 40% from burning fuel for its manufacturing.

After that, the values are compared with the value of CO_2 generated during the assumed lifetime of the building (50 years, *although the lifetime of buildings could be much longer than 50 years*) with presumed emission of 1.055 $kgCO_2/kWh$ (UNDP) of produced electricity in Serbia (70% lignite) (Figure 7.2).

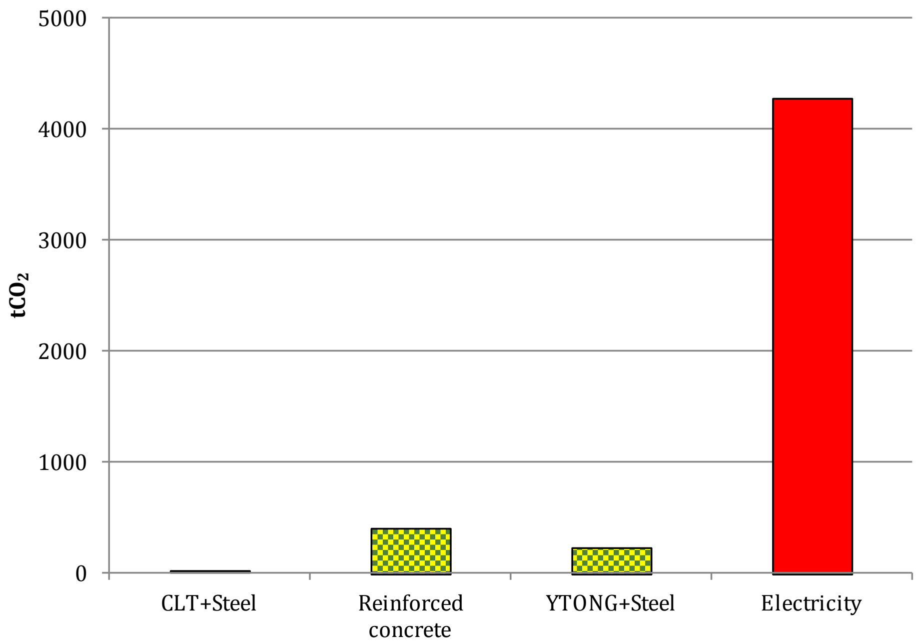


Figure 7.2. *Previous figures put in perspective or compared with the amount of CO_2 generated during 50 years of assumed building lifetime on a 60 kWh/m² annual rate*

The first conclusion is that the main part of the emission will come from electricity consumed rather than from the chosen building material.

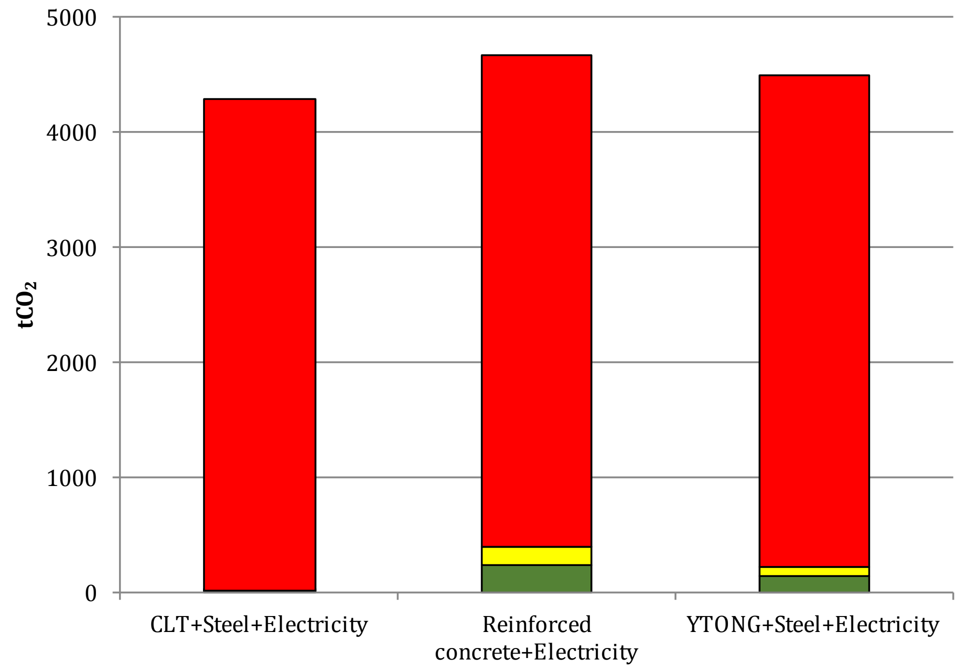


Figure 7.3. *Previous numbers "stacked" together (tCO_2)*

Even after considering the possible (and very optimistic) scenario in which Serbia is phasing-out coal at the rate of 2% per year (with new average of 0.66 $kgCO_2/kWh$), these values are firmly on the side of the electricity, suggesting that the best way to lower the impact of Pametnija Zgrada is to invest into its energy efficiency[7] or on-site generation of renewables, rather than investing large assets into construction materials.

7 On the other hand, as it has been shown already, investment in energy-saving technologies isn't always cost-effective.

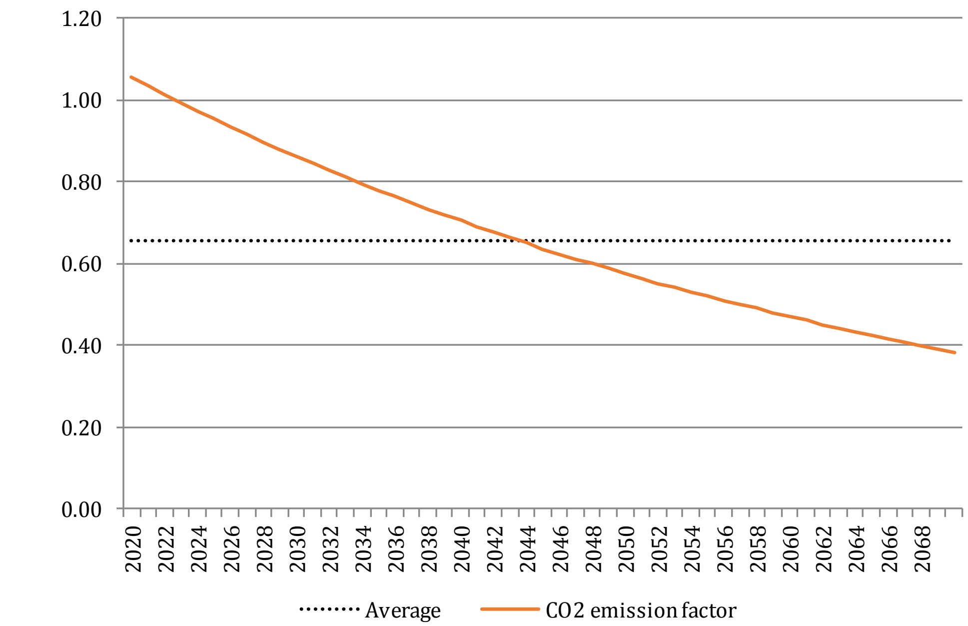


Figure 7.4. *CO_2 emission factor projections for the next 50 years for coal-based electricity phase-out at the rate of 2% per year (fairly optimistic)*

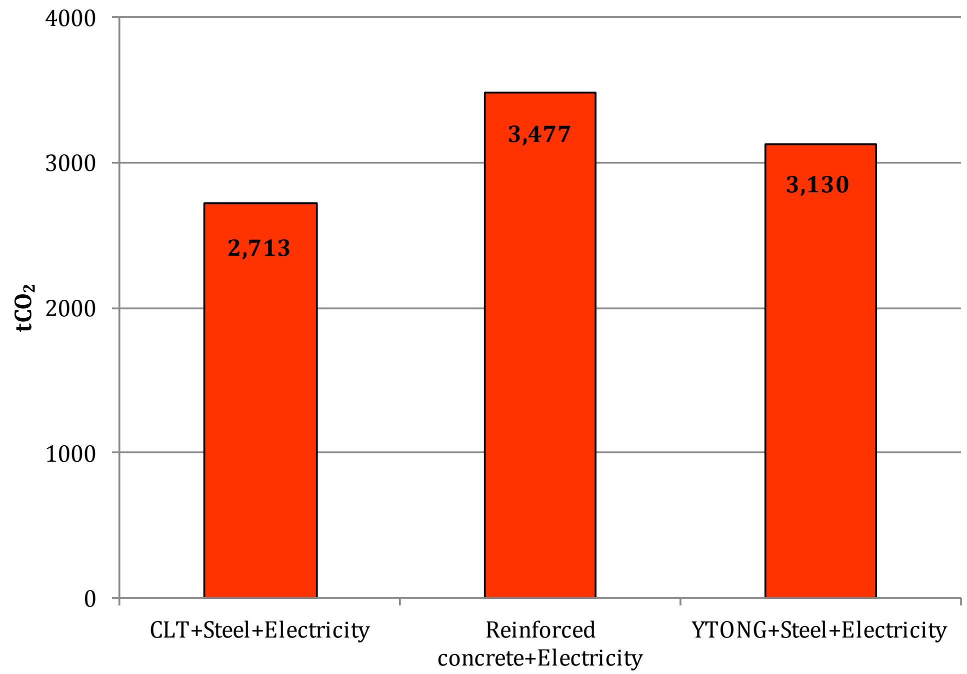


Figure 7.5. *All previous numbers after taking into consideration the assumed coal phase-out and the average emission factor of 0.66 kgCO_2/kWh for the next 50 years*

Approximately 13% difference between AAC and CLT over the 50 years project lifetime (under very optimistic assumptions) can be achieved, so since the majority of CO_2 emissions come from the consumption of electricity, we can conclude that, in order to lower emissions, it is more important to invest in building insulation, envelope airtightening and energy-saving technologies (and on-site produced electricity from renewable energy sources) than in the building materials.

7.1 EMISSIONS REDUCTION AS A RESULT OF THE PV POWER PLANT

One part of the emission of CO_2 will be reduced thanks to the installation of the PV power plant. Estimates of that reduction are given in Table 7.1 under the following assumptions:

- The emission of CO_2 per kWh of electricity replaced is 1.055 kgCO_2/kWh (UNDP) according to the analysis given in Chapter 8.3;
- The projected lifetime of the PV plant is 25 years;
- In the case without net-metering, only 30% of the electricity potentially produced by PV panels is used (self-consumption, this share can be improved with large(r) buffer tanks).

		kWh	tCO_2/year	tCO_2/25 years
With net-metering	15 kWp	18600	19.6	490.5
	20 kWp	24800	26.2	654.1
	25 kWp	31050	32.8	818.9
Without net-metering	15 kWp	5580	5.9	147.2
	20 kWp	7440	7.9	196.2
	25 kWp	9315	9.8	245.7

Table 7.1. *Reduction of CO_2 as a result of the PV power plant*

Please note that the values *tCO_2/25 years* are approximately corresponding to 5% - 20% of emissions of CO_2 showed in Figure 7.5.

SUMMARY OF CHAPTER 7

ENVIRONMENTAL FOOTPRINT

Chapter 7 touches the environmental footprint of the building. One of the requirements placed in front of Pametnija Zgrada is a low environmental footprint, i.e. low carbon emissions. To analyse footprint, the total footprint is divided into that arising from the construction and from the exploitation phase of the objects, leading to the conclusion that exploitation footprint is very dominant, thus suggesting investing in energy-efficient equipment and on-site generation of renewables (PV solar) rather than in building materials.

CHAPTER 8

ENVIRONMENTAL FOOTPRINT

8.1 HABITS

Habits and the way users are using energy are relevant factors in a Passive House or any other type of housing. The extent of variation in the consumption of energy from (the same) house to (the same) house is shown in Figure 8.1 (we could agree that the main reason for the differences shown are habits and the way users are consuming energy) [19].

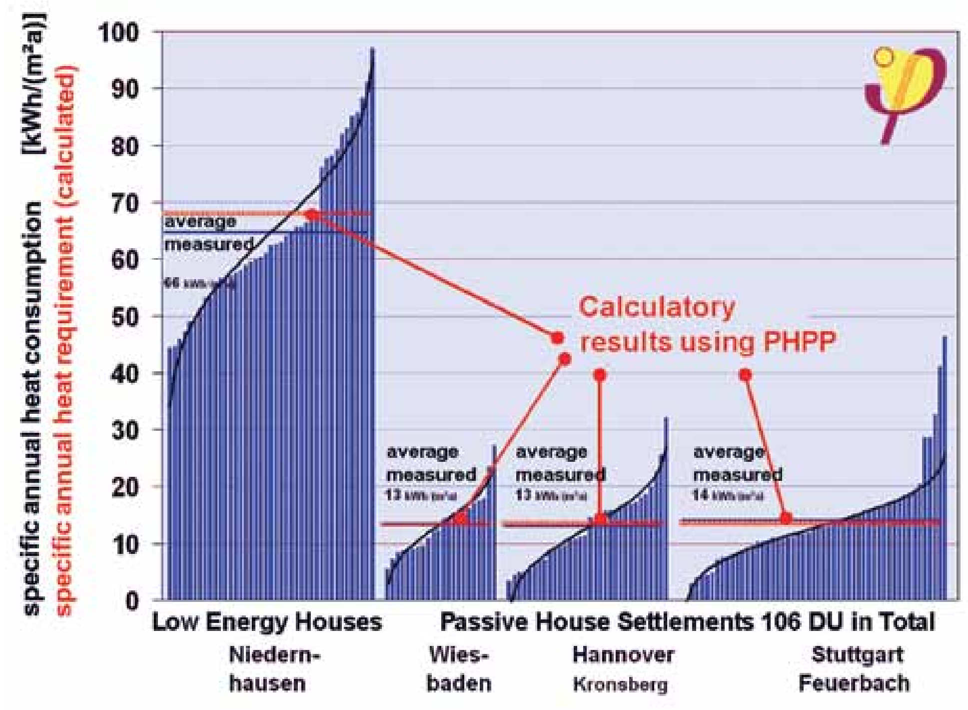


Figure 8.1. *Consumption of energy varying from 45 kWh/m² annually to 97 kWh/m² annually (double) for Niedern low energy houses and from 3 kWh/m² annually to 46 kWh/m² annually (11 times) for Passive Houses in the Stuttgart Feuerbach settlement*

Figure 8.2. *Stuttgart Feuerbach settlement (note that this is row housing for reasons explained in 0)*

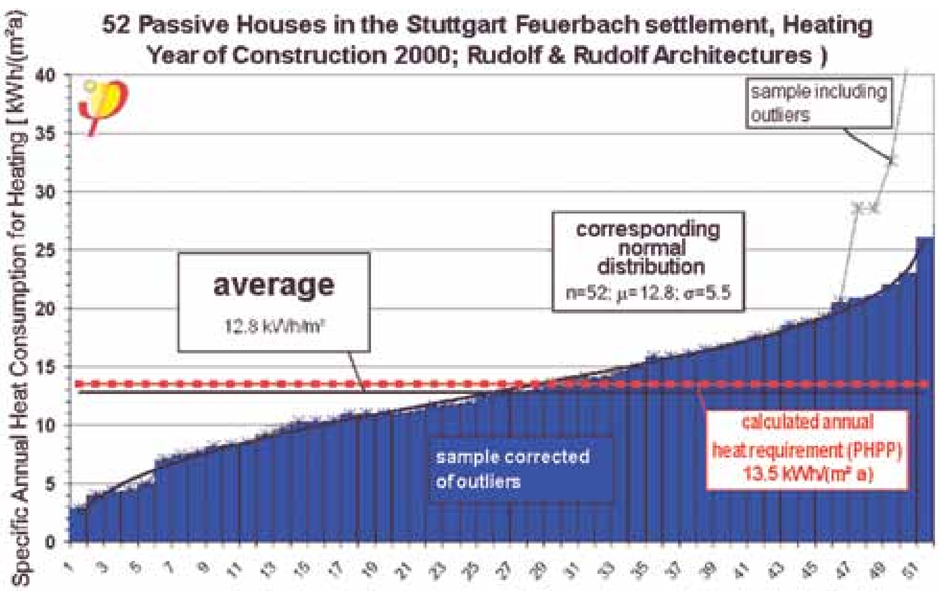


Figure 8.3. *Results of Passive House development in Stuttgart/Feuerbach with a total of 52 terraced and detached houses (note that the error between the average and calculated consumption is 5%)* [19]

Several simulations have been produced of the possible impact of the tenant's behaviour, with 19 families, and the effects of the potential impact on their behaviour were assessed. The assumed use of electricity per person per month ranges from 40 kWh to 120 kWh, with a 75 kWh average, and the consumption of energy contained in hot water is assumed to range from 20 kWh to 52 kWh per person per month, with a 35 kWh average.

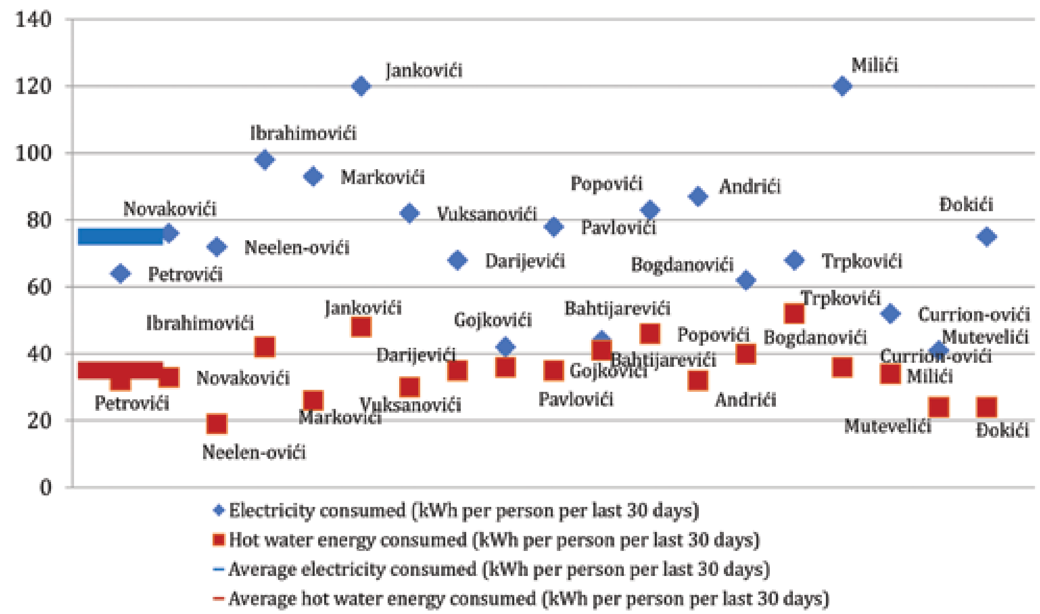


Figure 8.4. *The situation "before influencing" the behaviour of tenants*

The assumed scatter of the results is taken from the literature, with the average electricity consumed "before" at 75 kWh/person/month and average hot water energy consumed at 35 kWh/person/month.

The situation "after" influencing the behaviour of tenants is shown in Figure 8.5. The assumption is that we only affected families whose consumption was higher than average and that we have succeeded in reducing their usage to the average value.

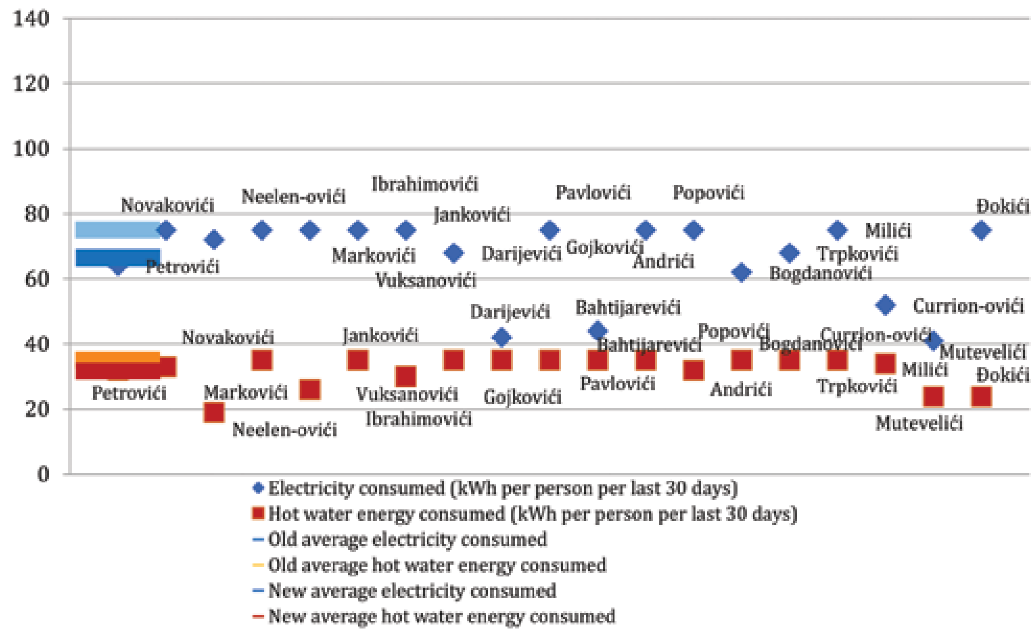


Figure 8.5. *The situation "after influencing" the behaviour of tenants*

The "after" value for average electricity consumed is 66.4 kWh/person/month, while the "after" average hot water energy consumed is 31.8 kWh/person/month. The difference is 8.6 kWh/person/month for electricity and 3.2 kWh/person/month for hot water.

If the whole procedure were to be repeated one more time, the tenants could save 4.5 kWh/person/month for electricity and 2 kWh/person/month for hot water resulting in approximate savings of 10 kWh/m^2/year for Pametnija Zgrada, or 500 € per year.

At least two approaches should be introduced to make all that possible:

- Energy use monitoring should be introduced for each flat;
- Some forms of awareness-raising programs should be delivered to tenants at regular intervals e.g. semi-annually.

In regards to this subject, it would be important/necessary to develop a User Manual for cooperatives and future tenants, as shown in Figure 8.6.

LIVING IN THE PASSIVE HOUSE – AT A GLANCE

WHAT YOU SHOULD DO ON A REGULAR BASIS:

- The windows should be closed from November to the end of March (according to the weather), and the ventilation system should be operated with the Bypass-gate set.
- Normal window ventilation during the summer and venting of the bathroom and toilet by switching to "summer ventilation". During the warm summer period, take out the Bypass-gate and place it on the system, so it is easy to find again.
- Filter change: Inspection of the ventilation system every 3 months (both filters), inspection of the kitchen filter every 3 months.
- Monthly visual inspection of the building services and solar thermal system.
- To avoid over-heating during the summer use night ventilation and shades, use the most energy efficient household equipment possible.

WHAT YOU SHOULD REGULARLY DO OVER LONGER PERIODS OF TIME:

- Wash the ventilation system's heat exchanger every two years.
- Adjust the windows, check the seals and grease the fittings.

WHAT YOU SHOULD BE AWARE OF:

- Even during long periods of absence during the winter, do not turn off the heating system. e.g. set the thermostat at 18 ˚C.
- Only open windows during the heating period if absolutely necessary (ventilation system failure, party, etc.), close entrance doors and balcony

doors after use as quickly and snuggly as possible! The main door only closes air-tight when the key is turned fully twice.

- Avoid placing indoor items and bright or reflective surfaces in front of the window (minimum distance 20 cm), local heating could lead to the breaking of glass.
- Puncturing of the air-tight envelope due to dowels, nails, screws, etc.: After removal, carefully spackle the remaining holes in the plaster with caulking mortar!
- Always keep inflow, overflow and outflow openings free and do not change the settings!
- Do not use exhaust-air drying machines to dry clothes (mold formation due to too much condensed water)!
- Empty the garden water pipe before the first frost.
- If possible, avoid shading the windows during the cold season (solar gains).

HOW YOU CAN SAVE ENERGY:

- Avoid window ventilation during the hot season.
- Set the room temperature only as high as necessary (don't overheat rooms!)
- As a rule, keep the bathroom heater switched-off, or at least avoid using it to heat continuously.
- To dry clothes, use an airing cupboard **without** an electrical heater or dry the clothes on a clotheshorse in the hallway or the bathroom so that the humidity can better dissipate.
- Use high-efficiency household equipment and energy-saving (CFL) lightbulbs, turn off systems with stand-by functions completely when not in use.

Figure 8.6. *Example of a User manual for Passive House tenants* [20]

8.1.1. EFFECT OF ROOM TEMPERATURE ON ENERGY CONSUMPTION

When considering habits, the main mechanism to lower energy consumption are the temperature settings in rooms, i.e. it is possible to save energy by lowering the heating temperatures during winter and setting higher cooling temperatures during summer. Therefore, the following scenarios are discussed:

- The cooling temperature set at 25, 26 and 27 °C;
- The heating temperature set at 20, 22 and 24 °C.

The impact of the above temperatures on energy consumption in the case of *AAC Passive 3, no blinds, no overhangs, double glazing, air sourced heat pump* is shown in Figure 8.7 and Figure 8.8.

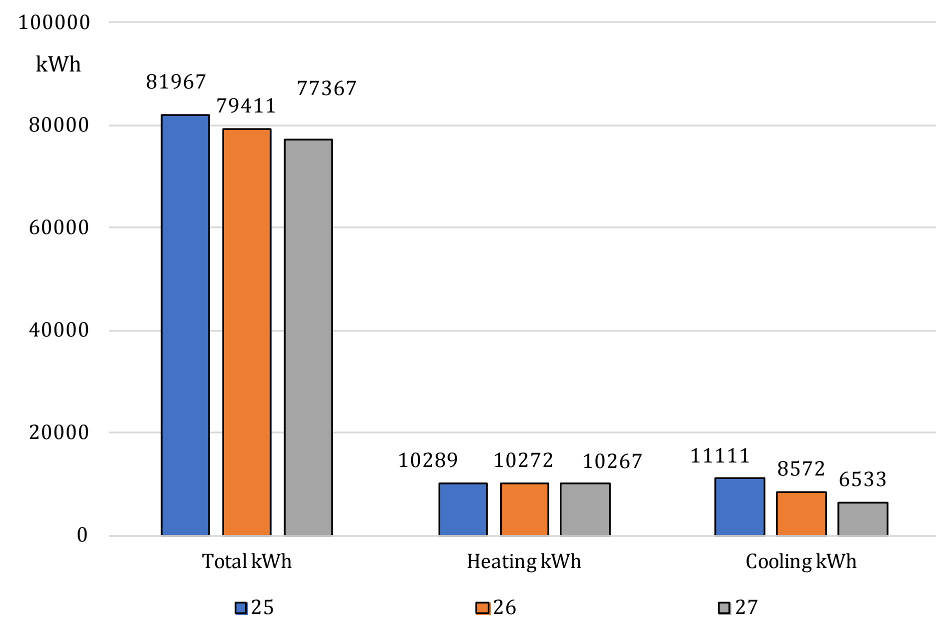


Figure 8.7. *The difference in energy consumption (kWh) for different cooling temperatures (25, 26 and 27 °C)*

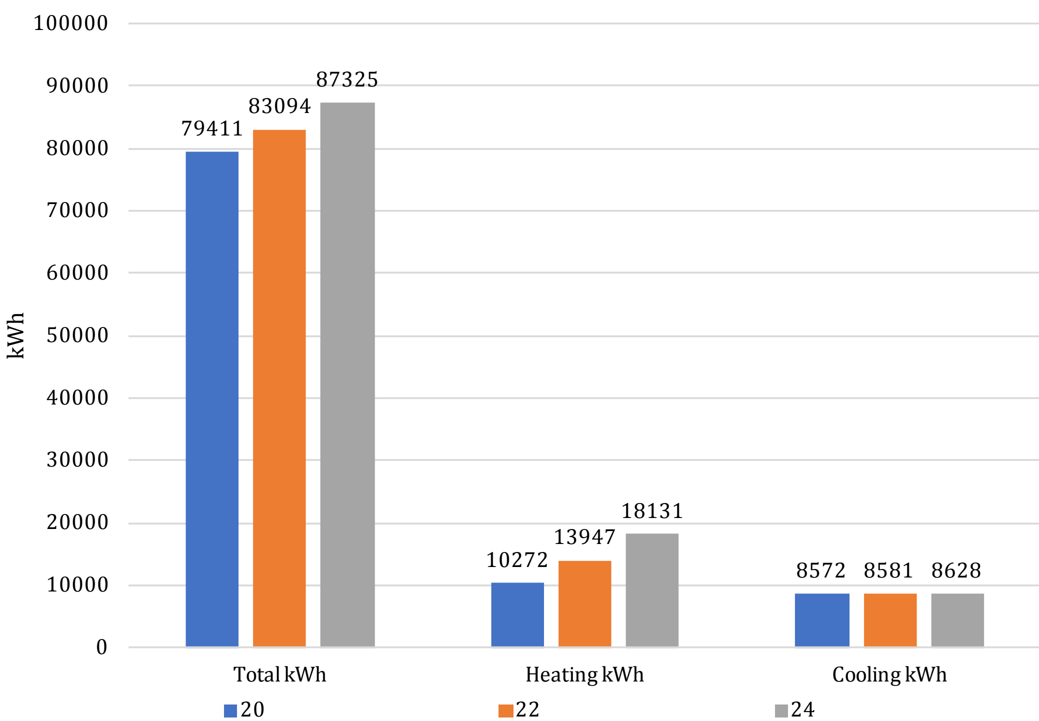


Figure 8.8. *The difference in energy consumption (kWh) for different heating temperatures (20, 22 and 24 ˚C)*

The worst-case and best-case scenarios have been extracted from Figure 8.7 and Figure 8.8 and, under the same assumptions, combined into Figure 8.9.

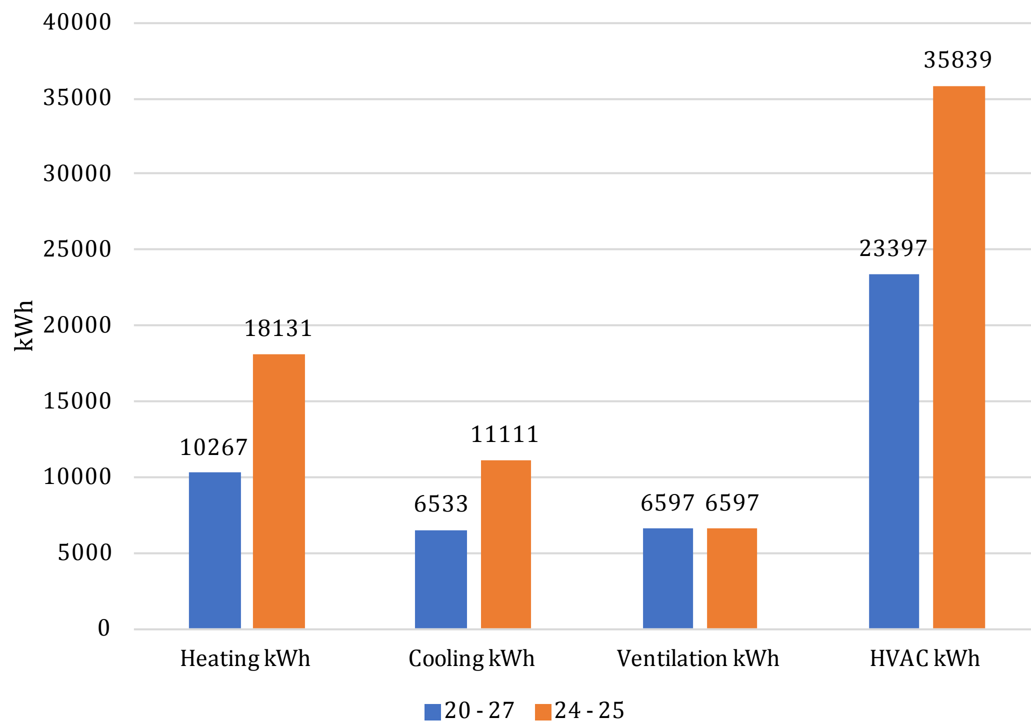


Figure 8.9. *Two extreme cases (heating 20 ˚C and cooling 27 ˚C vs. heating 24 ˚C and cooling 25 ˚C) and the possibilities for energy savings (HVAC is a sum of heating, cooling, and ventilation)*

The differences shown are very significant (estimated at 35%, or at least 800 € per building per year), yet the possibilities for the introduction of this measure by setting fixed temperatures are debatable and part of a wider picture of what is and what isn't acceptable within the community of a co-operative housing project.

8.2. FORM FACTOR

As explained in Chapter 1.5, form-factor is the ratio of surface area that can lose heat (the thermal envelope) and the floor area that gets heated. To improve the form-factor or compactness ratio of Pametnija Zgrada (the starting premise will be that is not possible to change the treated floor area):

- Ground floor parking space should be displaced to eliminate cca. 300 m^2 of building envelope exposed to external influences (this measure could raise additional questions);
- The building should lean against nearby buildings i.e. be a part of row housing, and;
- In theory, to save energy, the building should have more stories.

8.3. PRICE AND OTHER ISSUES CONCERNING ELECTRICITY IN SERBIA

This study suggests all-electric HVAC as a principle that should be fostered in cases pursuing low energy consumption and a low footprint in accordance with the requirements of Pametnija Zgrada, for the following reasons:

- Low upfront costs of equipment, no costs of connection to any other energy source e.g. natural gas, low cost of the electric backup heating system;
- All necessary technologies for achieving high(est) comfort levels are available, whereas e.g. natural gas or biomass-based cooling is technically demanding and expensive;
- A lot of possibilities for integration and pairing of different technologies, including renewables, such as e.g. PV power plants;
- Inexpensive and precise monitoring equipment available, the implementation of remote monitoring possible and also inexpensive, the possibility for monitoring energy use in individual flats and lowering consumption through education of tenants;
- Relatively easy upgrade/update with compatible equipment;
- Future integration with electric cars will be more effective (providing resilience (protection) in the case of disturbances to the grid – with growing consumption due to climate change potentially being an important factor);

- Although electricity isn't the cheapest source of energy, the price of electricity, combined with highly efficient equipment is very attractive (unfortunately);
- When properly installed, used and maintained, electricity is a safe source of energy;
- Energy is produced in Serbia (versus e.g. natural gas):
  - Makes it possible to build an energy-independent society;
  - The tenants of the Pametnija Zgrada will have an interest and the opportunity to participate in building up consciousness on the reduction of the environmental footprint of electricity produced in Serbia;
- Since this study is focused on a pilot building, to be erected at an unknown location, the possibility for connections to other sources of energy could be non-existent/hard to achieve.

The shortcomings of the all-electric approach are:

- High footprint with current forms of electricity generation in Serbia (70% lignite) (both in global terms e.g. tCO_2/kWh, and in pollution concerning local communities);
- Some sources of energy could be cheaper/lower impact per kWh of energy produced (usually undermined on versatility issues);
- The integration of a non-electric backup system could be very expensive, so the all-electric approach will result in the building being dependent only on one source of energy. On the other hand, the amount of energy accumulated in the building, combined with low energy consumption, will allow short power cuts (that could happen quite often in Serbia).

Furthermore, choosing "all-electric" has to cope with electricity prices that are out-of-bounds in the wider European context, making it difficult to rely on conventional assumptions and approaches, especially since there is no publicly available long-term strategy on that topic.

	2016S2	2017S2	2018S2
EU-28	0.2038	0.2042	0.2113
Euro area	0.2179	0.2175	0.2242
Belgium	0.2745	0.2877	0.2937
Bulgaria	0.0938	0.0983	0.1005
Czechia	0.1421	0.1488	0.1586
Denmark	0.3084	0.3010	0.3123
Germany	0.2977	0.3048	0.3000
Estonia	0.1238	0.1319	0.1418
Ireland	0.2338	0.2355	0.2539
Greece	0.1723	0.1620	0.1646
Spain	0.2284	0.2177	0.2477
France	0.1711	0.1756	0.1799
Croatia	0.1331	0.1236	0.1321
Italy	0.2261	0.2080	0.2161
Cyprus	0.1621	0.1826	0.2183
Latvia	0.1624	0.1582	0.1511
Lithuania	0.1171	0.1107	0.1097
Luxembourg	0.1698	0.1618	0.1691
Hungary	0.1125	0.1134	0.1118
Malta	0.1274	0.1298	0.1306
Netherlands	0.1592	0.1556	0.1707
Austria	0.2010	0.1978	0.2012
Poland	0.1352	0.1451	0.1396
Portugal	0.2298	0.2230	0.2293
Romania	0.1233	0.1289	0.1317
Slovenia	0.1629	0.1613	0.1638
Slovakia	0.1537	0.1442	0.1462
Finland	0.1545	0.1599	0.1698
Sweden	0.1962	0.1993	0.1990
United Kingdom	0.1831	0.1856	0.2024
Iceland	0.1478	0.1518	0.1457
Liechtenstein	0.1747	0.1618	:
Norway	0.1631	0.1605	0.1907
Montenegro	0.0970	0.1003	0.1030
North Macedonia	0.0828	0.0811	0.0787
Albania	0.0835	0.0856	0.0910
Serbia	0.0654	0.0695	0.0709
Turkey	0.1205	0.0959	0.0857

Figure 8.10. *The average price of electricity in European households in 2016, 2017 and 2018* [21]

When the price of electricity is observed on a global level, there is no clear evidence that the average price can be easily related to any other indicator (Figure 8.11 shows the relationship between the price of electricity and GDP per capita). The dark red dotted line on Figure 8.11 is a polynomial trendline, while the R^2 value indicates how many points fall on the regression line. For example, the R^2=0.2691 shown here means that 27% of the variation of the price of electricity fits the trendline. If data are correlated

to each other, the R^2 value shown in Figure 8.11 should be 0.8 or more, so the R^2 value of 0.27 is showing that the data aren't linked to the economic development of observed countries. Therefore, the conclusion is that the price of electricity is not only an economic or technical decision, which makes it difficult to predict its future trends accurately.

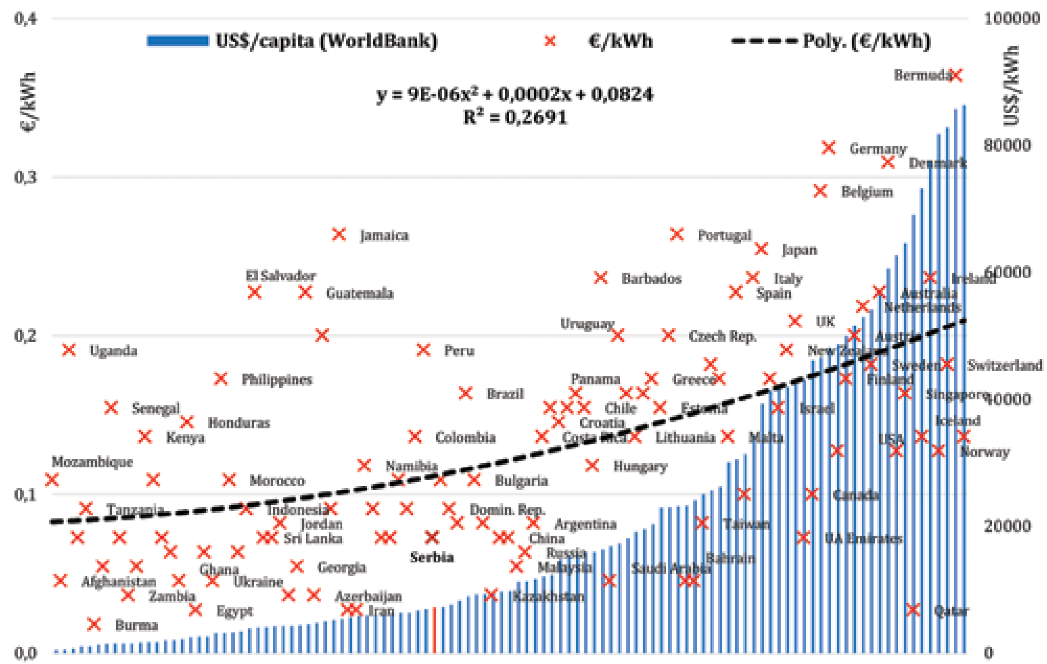


Figure 8.11. *Price of electricity €/kWh (left axis) and GDP per capita of corresponding countries in US$ per capita (right axis) according to World Bank*

Another way of predicting future price is by looking at data from the past (shown in Figure 8.12) which was the basis for scenarios developed for the spreadsheet tool explained in Chapter 9.2 where the increase in electricity price per year ranges from 3% to 10%.

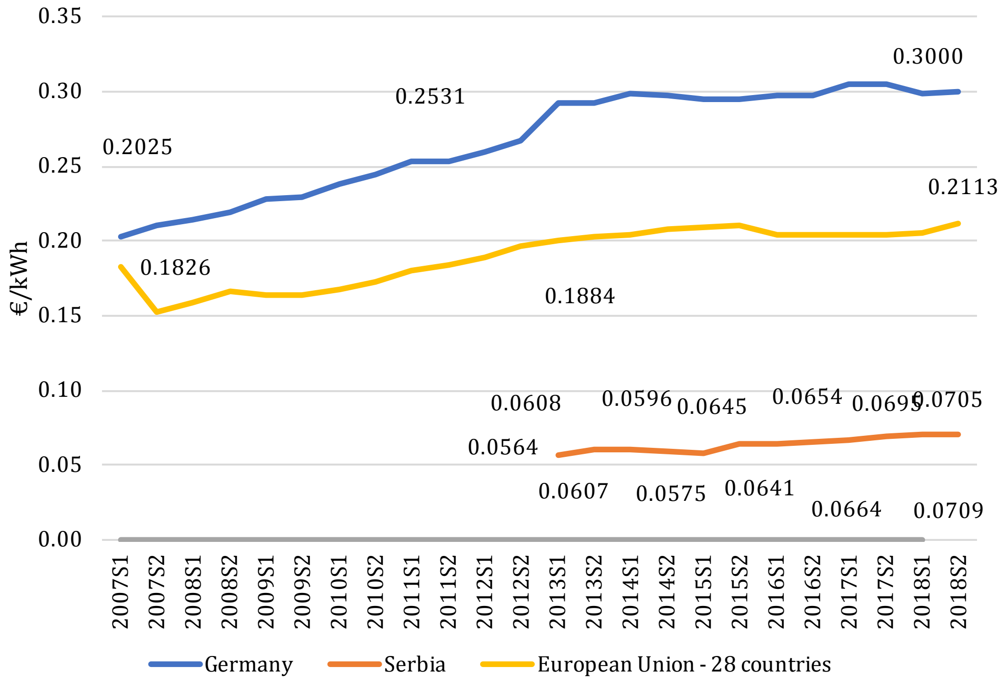


Figure 8.12. *Semiannual electricity price trend [€/kWh] in EU28, Germany, and Serbia according to EUROSTAT - all taxes and levies included. Note: Eurostat data for Serbia is available as of 2013.*

Country specific emissions of CO_2 according to three different sources will be shown in Figure 8.13, Figure 8.14 and Figure 8.15.

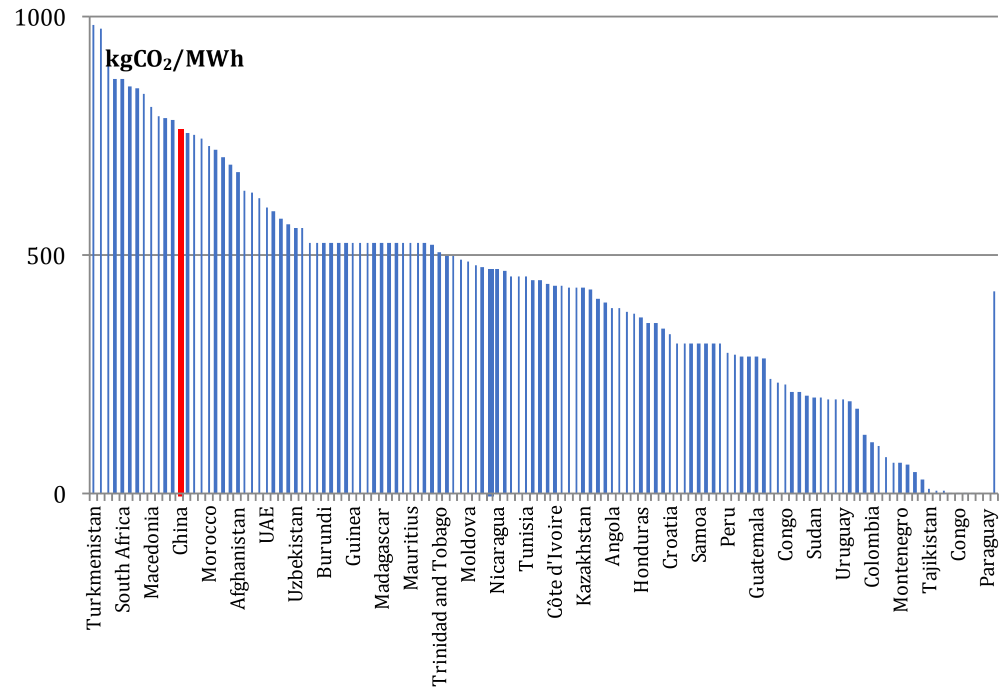


Figure 8.13. *2014 figures for emission ($kgCO_2/MWh$) according to the World Bank (Serbia is shown as a red column, the average value is shown in the far-right column)*

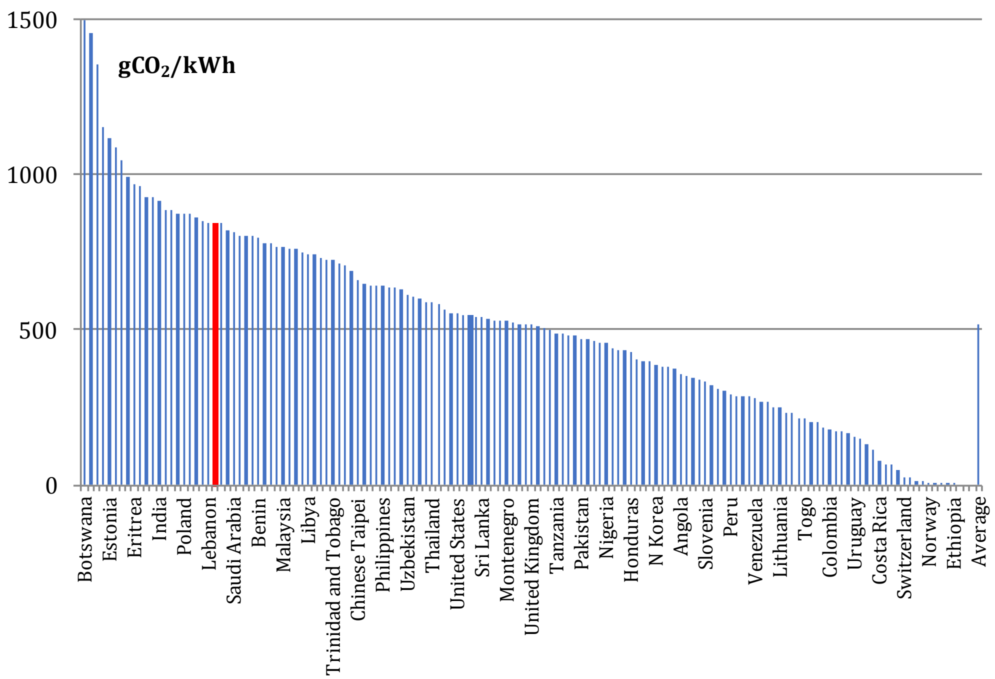


Figure 8.14. *2018 global emissions factor figures for the low voltage network (gCO_2/kWh) (Serbia is shown as a red column, the average value is shown in the far-right column)*

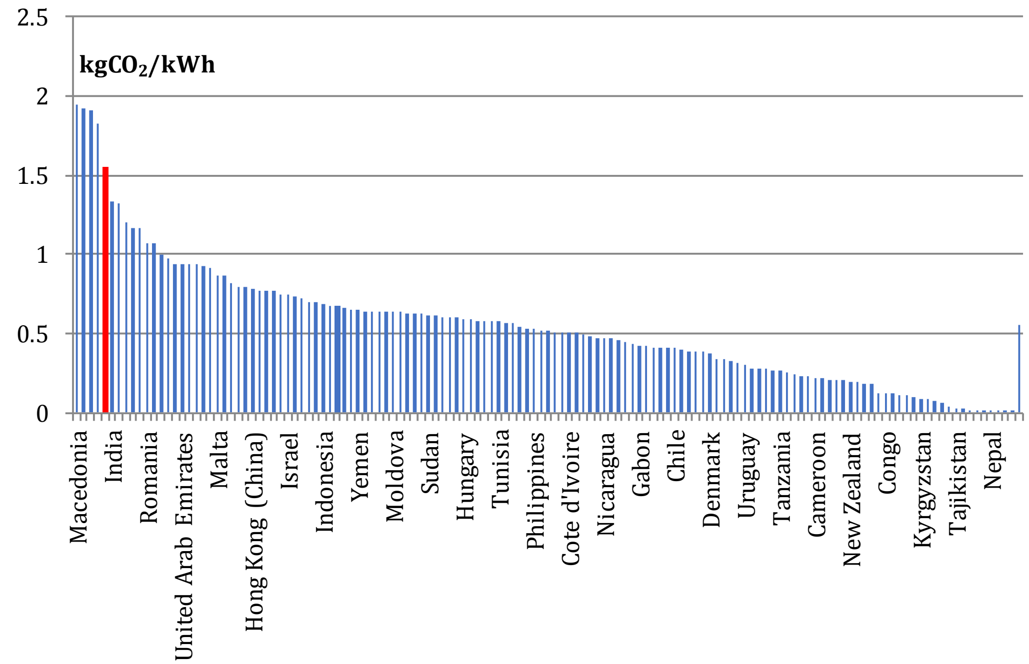


Figure 8.15. *2011 global electricity specific factors ($kgCO_2$/kWh) by Ecometrica (Serbia is shown as a red column, the average value is shown in the far-right column)* [22]

All of the above sources indicate Serbian electricity is at the top of the list of CO2 emissions, and while there is no clear evidence that the price of electricity should be either higher or lower, there are indicators that the production of electricity could/should have a lesser environmental impact.

For the purposes of this study, the authors have used the value proposed by UNDP in 2012 (1,055 tons of CO_2eq/MWh).

SUMMARY OF CHAPTER 8

OTHER THINGS TO CONSIDER

There are many other factors that affect Pametnija Zgrada, some of which are analysed in this chapter.

One issue that can have a substantial influence on the actual performance of a Passive House (and thus the consumption of energy) is the impact of the residents' behaviour, like the set heating/cooling temperature.

The situation in Serbia regarding the footprint and price-point of electricity is discussed as a crucial factor when considering investment related to energy-efficiency; while publicly available energy policy (regarding the energy mix, future pricing, etc.) would very much contribute to the viability of such investments.

CHAPTER 9

METHODOLOGY AND RESULTS

This chapter features and discusses the results of OpenStudio simulations, paired with the economic part of the analysis. Up to this point software simulations have been a very powerful tool to plan and improve the design of Passive (or any other) Housing, within the restrictions characteristic for any simulation, best visible in a study conducted by PHI:

- The difference between the calculated (11.8 kWh/m^2 annually) and monitored value (16 kWh/m^2 annually) is 26% on a sample of 32 buildings (this larger sample will result in a smaller difference between the measured and calculated value);
- The highest value measured (33 kWh/m^2 annually) is 2.8 times higher than the calculated value (11.8 kWh/m^2 annually) and;
- The lowest value measured (4 kWh/m^2 annually) is 3 times lower than the calculated value (11.8 kWh/m^2 annually).

This example serves to illustrate that values derived from the modelled performance can differ significantly from actual monitored values, and thus have to be treated with a degree of caution.

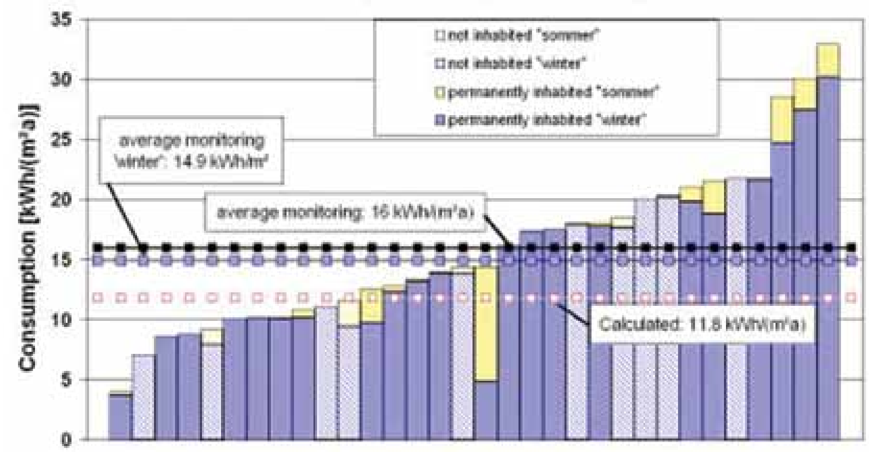


Figure 9.1. *Differences between the calculated (11.8 kWh/m^2 annually) and monitored value (16 kWh/m^2 annually), i.e. 26% on a relatively large sample in the case of the Passive House settlement in Hannover-Kronsberg* [23]

9.1 OPENSTUDIO MODEL

Energy modelling is the process of developing mathematical models of energy systems in order to analyse them. If we consider a building as an energy system, we are talking about a complex thermodynamic object with constantly changing energy flows between the different thermal zones within the building and the external environment. And if we want to analyse the effects of different energy conservation and energy efficiency measures and their complex interactions more efficiently, comprehensively and accurately, then computer simulations are the best available method.

The most common approach is to use some of the existing open-source or commercial software applications. A number of software tools exist to model and simulate individual buildings. An open-source platform called OpenStudio and its underlying EnergyPlus simulation engine are used for the purposes of this study. OpenStudio is intended for energy use simulation to enable decision-making by diverse stakeholders at each stage of a building's lifecycle. The platform contains a number of attributes unique to energy modelling, including an object-oriented data model, extensible scripting, and an analytical framework that scales from individual buildings up to portfolios (Figure 9.2).

Figure 9.2. *Screenshot of the OpenStudio graphical user interface – plugin for SketchUp*

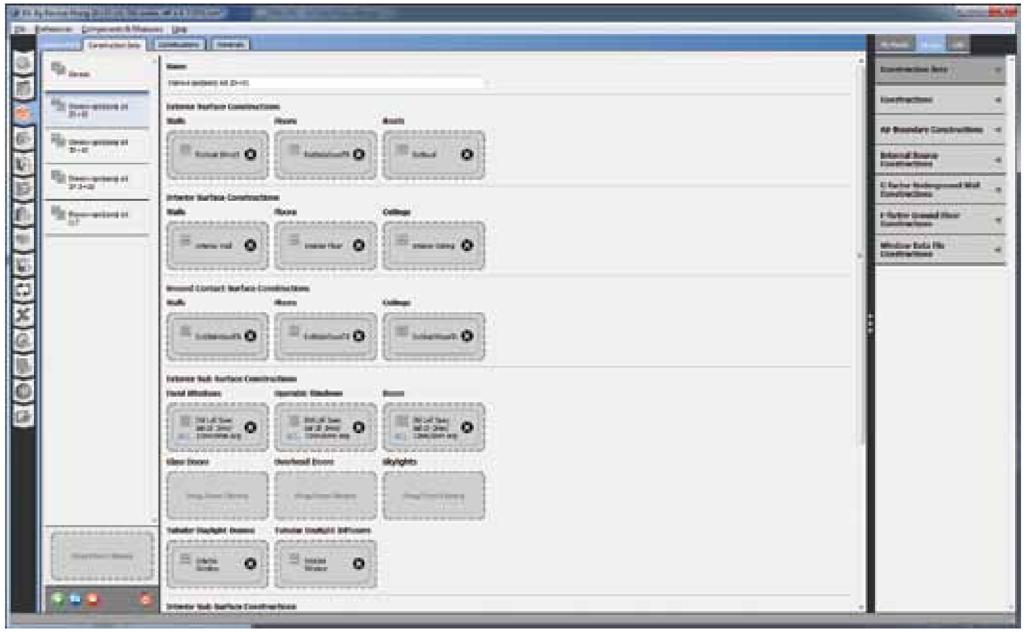


Figure 9.3. *Screenshot of the OpenStudio application programming interface – envelope construction parameters*

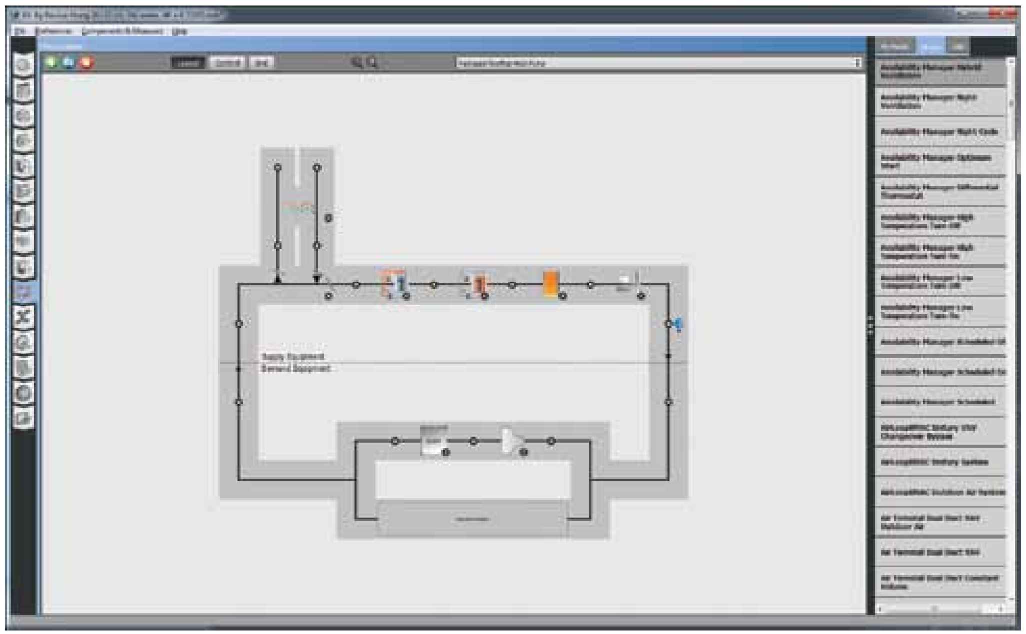


Figure 9.4. *Screenshot of OpenStudio – HVAC layout*

Two main components of the building energy simulation model are the building components (envelope: walls, floors, ceilings, and loads: occupants and equipment) as shown in Figure 9.3, and plant components (HVAC equipment and other environmental control systems) as shown in Figure 9.4.

When using software for simulating energy flows the most reliable approach is to use the baseline scenario. Varying the input parameters of the energy system and benchmarking the results to the baseline scenario results shows the impact of the changes through comparative analyses. This approach has been used for this study.

Figure 9.5 shows an example of the modelling results of the simulation made in OpenStudio based on pilot project design, given under the following assumptions: *AAC Passive 3, double glazing, geothermal heat pump, without overhangs, without blinds*.

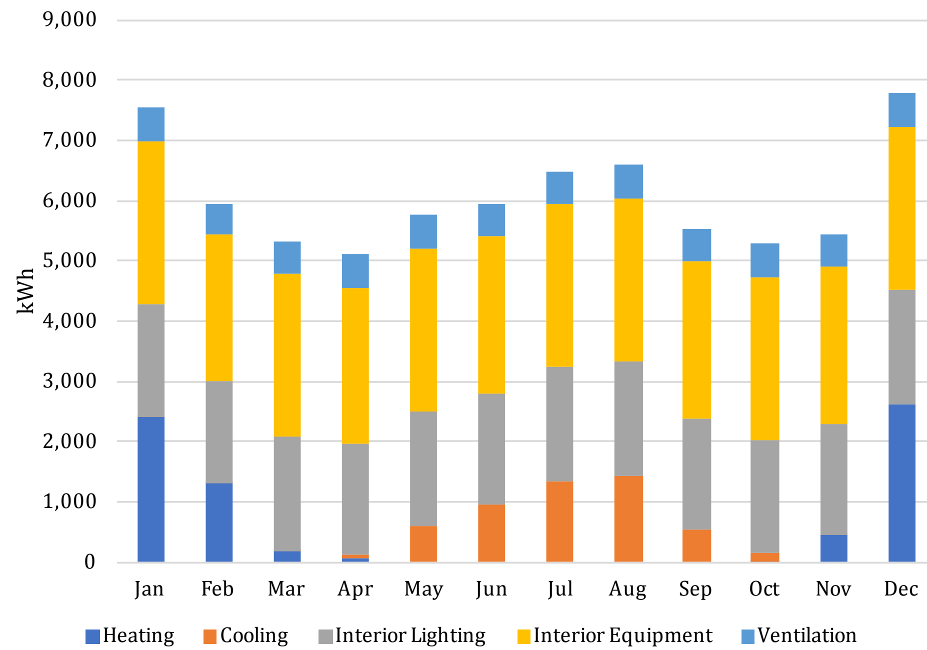


Figure 9.5. *Energy consumption structure for one of the most reasonable/cost-effective scenarios for a highly efficient building*

A few things should be noted regarding Figure 9.5:

- The consumption of electricity for heating/cooling is relatively low, thanks to the very high airtightness factor used in the model, the favourable form-factor of the building, very high efficiency of the HVAC system, etc.;
- The consumption of electricity used for lighting and for interior equipment (appliances) could be lower. These values should be interpreted as just one scenario that could be affected by habits or higher efficiency devices;
    - Please note that change of energy consumption for lighting or appliances will also impact the amount of energy used for heating/cooling;
- The model suggests that energy consumption for ventilation could be more precise if detailed documentation for HVAC is developed. Special attention should be paid to that part of Pametnija Zgrada, since that equipment is engaged 24/7 and therefore every watt of installed fan power is important, as is every pascal of pressure drop.

9.2. SPREADSHEET TOOL FOR THE ASSESSMENT OF PAMETNIJA ZGRADA

Since the authors of this study believe that members of the cooperative should be precisely informed, they have developed an easy to understand, custom-tailored spreadsheet tool aimed at helping future members of the Pametnija Zgrada understand the consequences of specific technological choices on their lives in the cooperative.

The tool consists of three tabs, the first being an introductory tab with some general references (Figure 9.6), while the second is an interactive tab (Figure 9.7) where the impact of different choices on 35-year cache flow could be examined.

Figure 9.6. *Printscreen of the first tab of the developed spreadsheet tool*

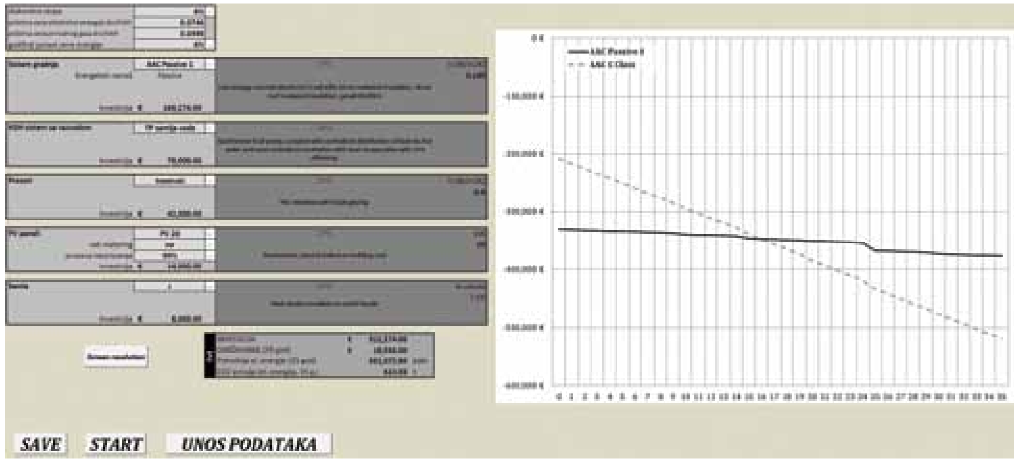


Figure 9.7. *Printscreen of the second tab of the developed spreadsheet tool*

The third tab (Figure 9.8) allows the user to keep the tool updated by changing the main input parameters. Part of main input parameters is economic in nature, such as the price of building materials, while another part are the results from OpenStudio (if necessary, these data could be replaced with data from a simpler modelling software). In addition to learning, the tool could be used as a planning tool for the future estimation of the cost-effectiveness of specific measures.

Figure 9.8. *Printscreen of the third tab of the developed spreadsheet tool*

9.3. RESULTS

Comments will be given for all results from OpenStudio and the developed spreadsheet tool in the following figures. Where appropriate, results will be compared with the baseline scenario (the building that meets the legal minimum in Serbia), corresponding to energy class C according to [1] with an annual amount of energy required for heating of 65 kWh/m^2.

The impact of the main building material on cash flow is shown in Figure 9.9 under the following assumptions: *geothermal heat pump, double glazed windows, fixed shades on the south side, 20 kWp PV plant without net-metering, d = 8%, starting price of electricity 0.088 €, increase in the price of electricity 6% per year, heating temperature 20 ˚C, cooling temperature 26 ˚C.*

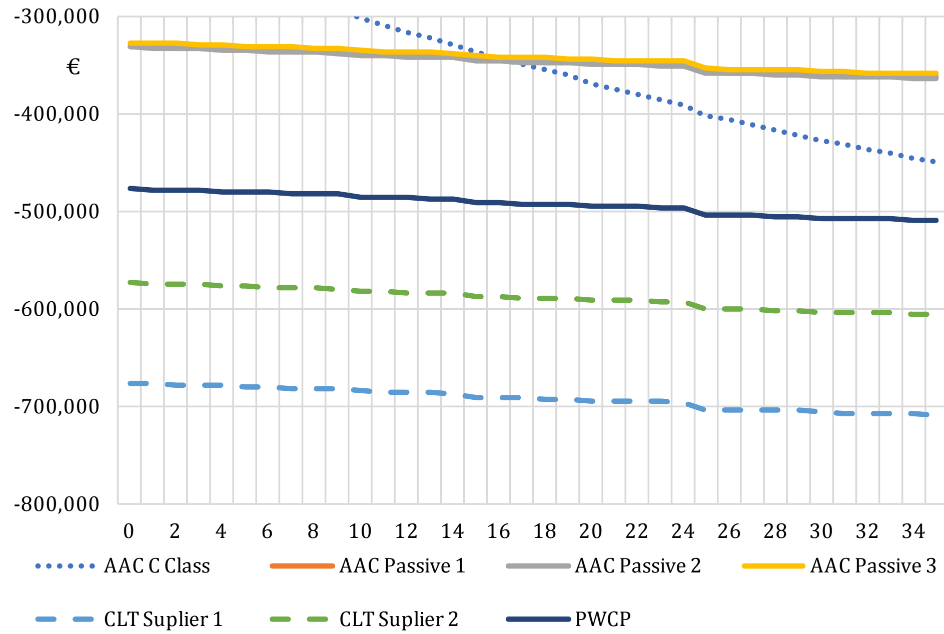


Figure 9.9. *Impact of the main building material on the cash flow of Pametnija Zgrada*

The impact of the chosen HVAC on cash flow is shown in Figure 9.10 under following assumptions: *AAC Passive 3, double glazed windows, fixed shades on the south side, 20 kWp PV plant without net-metering, d = 8%, starting price of electricity 0.088 €, increase in the price of electricity 6% per year, heating temperature 20 ˚C, cooling temperature 26 ˚C.* First, note that all lines are close to parallel (except AAC C) since the energy consumption of all buildings is very similar. The high initial investment eliminates both CLT suppliers. PWCP is also not cost-effective under these conditions (with wood wool insulation), leaving AAC as the only viable solution.

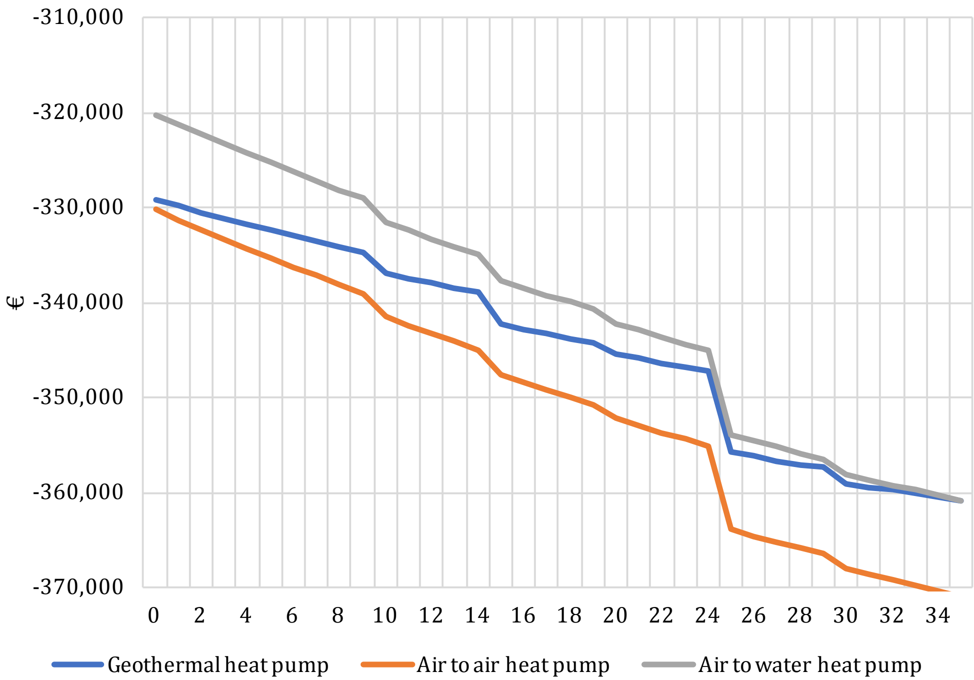


Figure 9.10. *Impact of the HVAC system on the cash flow on Pametnija Zgrada*

The results of the modelling for the impact of the PV plant are shown in Figure 9.11 under the following assumptions: *AAC Passive 3, geothermal heat pump, double glazed windows, fixed shades on the south side, d = 8%, starting price of electricity 0.088 €, increase in the price of electricity 6% per year, heating temperature 20 ˚C, cooling temperature 26 ˚C*. These results show a slightly different initial investment, while the future high discount rate (d=8%) discourages investment into more expensive equipment (a geothermal heat pump is significantly more efficient than an air-to-water heat pump, yet the lines seem parallel).

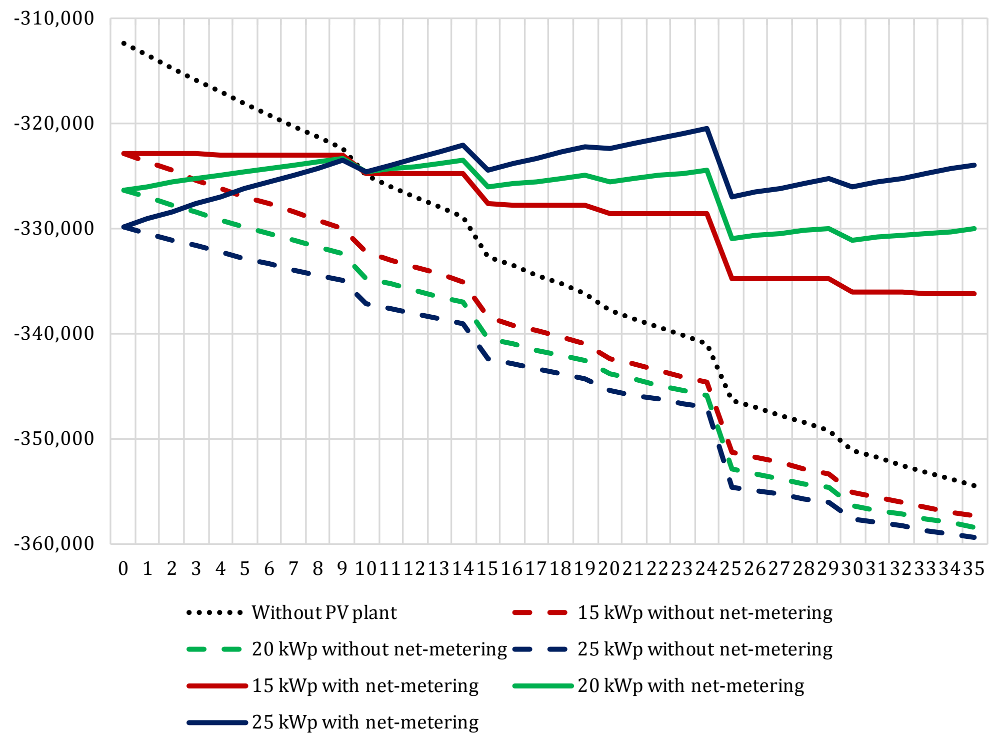


Figure 9.11. *Impact of the PV power plant on the cash flow on Pametnija Zgrada*

The percentage increase of the price of electricity according to the model will affect Pametnija Zgrada as shown in Figure 9.12, under the following assumptions: *AAC Passive 3, geothermal heat pump, double glazed windows, fixed shades on the south side, d = 8%, starting price of electricity 0.088 €, heating temperature 20 ˚C, cooling temperature 26 ˚C*.

There are many possible conclusions to be drawn from Figure 9.11. Firstly, net-metering could have a decisive impact on this project, secondly, higher capacity is wise only if all produced electricity is used, in any other case an investment in higher capacity is unwise (note the differences between 15, 20 and 25 kWp after 35 years in both cases, with and without net-metering).

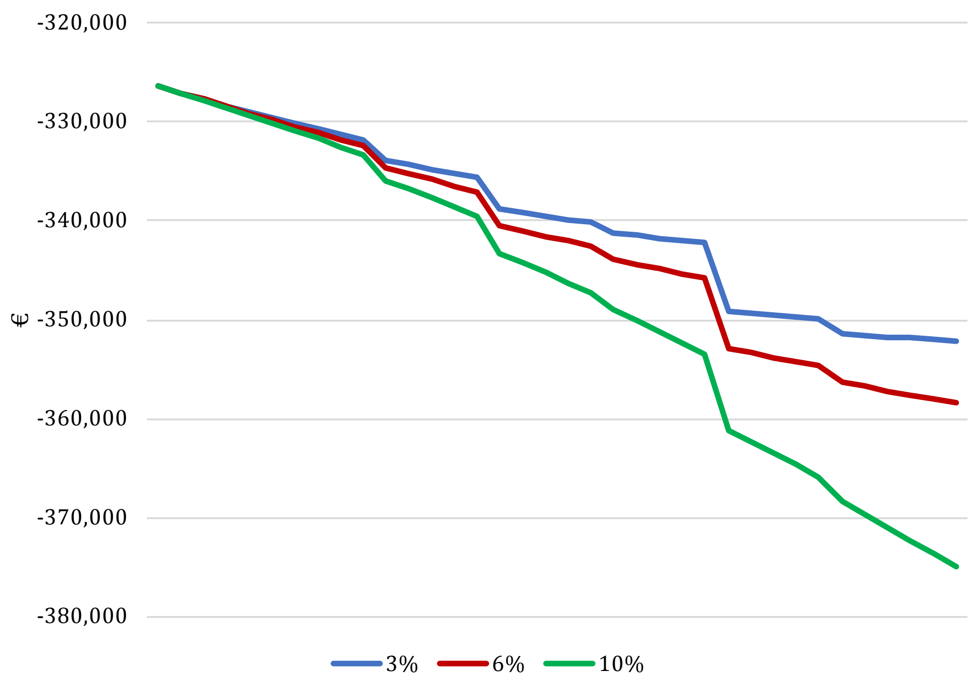


Figure 9.12. *Impact of an increase in the price of electricity on the cash flow of Pametnija Zgrada*

The impact of the discount rate is shown in Figure 9.13 under the assumptions: *AAC Passive 3, geothermal heat pump, double glazed windows, fixed shades on the south side, starting price of electricity 0.088 €, increase in the price of electricity 6% per year, heating temperature 20 ˚C, cooling temperature 26 ˚C*. The differences between scenarios are clearly visible. It may be counterintuitive that the owner of a passive house is least affected by the price increase, while in the case of AAC C this is significantly more dramatic.

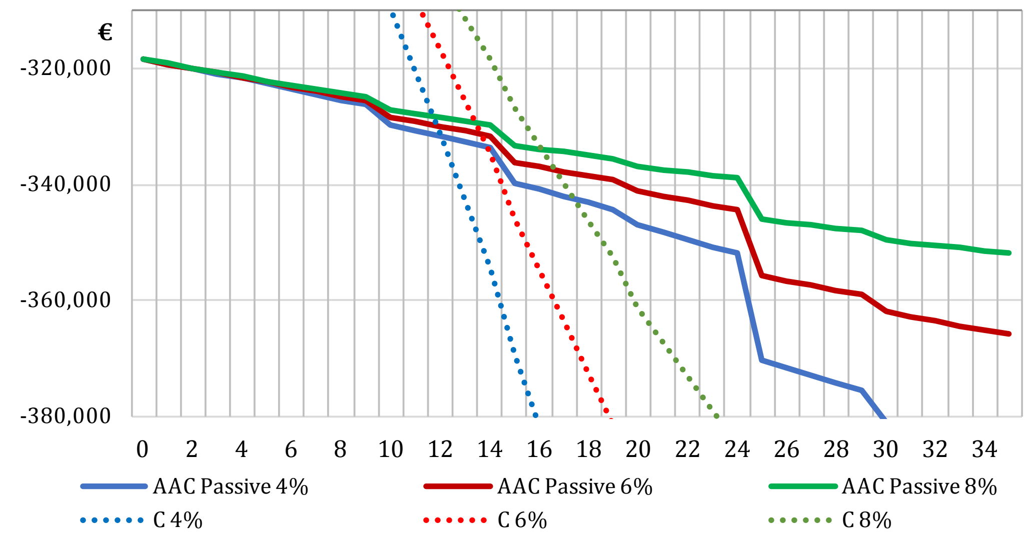


Figure 9.13. *Impact of the discount rate on the cash flow of Pametnija Zgrada*

Once defined, the model permits an exploration of the impact of a wide variety of variables. The effect of roof insulation thickness is shown in Figure 9.14 under the assumptions: *AAC Passive 3, geothermal heat pump, double glazed windows, without shades, heating temperature 20 ˚C, cooling temperature 26 ˚C*.

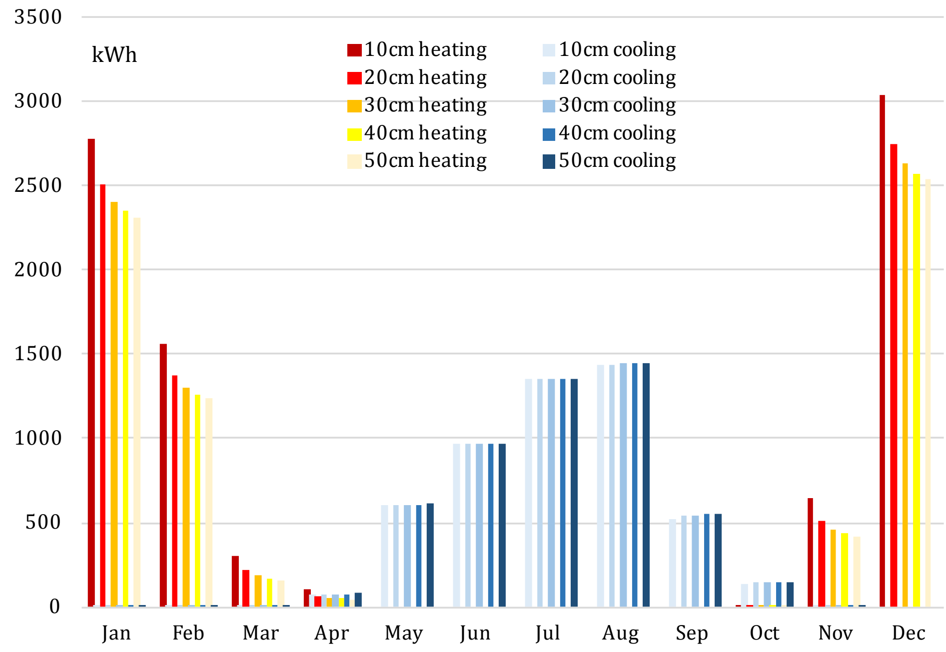


Figure 9.14. *The effect of roof insulation thickness on the energy consumption of Pametnija Zgrada*

SUMMARY OF CHAPTER 9

METHODOLOGY AND RESULTS

This chapter explains the methodology used for the analysis of Pametnija Zgrada, it clarifies the OpenStudio model and it introduces the developed spreadsheet tool.

The results of the symbiosis of these two tools are previewed, and provide inputs towards the concluding chapter and identified areas for further study.

CHAPTER 10

RECOMMENDATIONS FOR FUTURE RESEARCH

The study you have before you, "High Energy Performance, Low Environmental Impact, Affordable: Exploring Passive House implementation for multi-apartment buildings in Serbia" is, to the best of the knowledge of the authors, the first attempt to answer a number of energy-related questions (intertwined with environmental, economic, social and other contexts) of future, sustainable housing in the SEE region. As with any first exploration, more questions are raised than answered, thus the role of this chapter is to summarize possible directions for future research.

There are many difficulties encountered by the authors:

- The lack of economically sound case studies of low-energy buildings or Passive Houses carried out in Serbia, meaning a lack of all the benefits based on these cases:
    - Accumulation of know-how (that could be distributed and/or marketed);
    - Demonstration of success;
    - Capturing reality through monitoring different indicators for further improvement of buildings/systems i.e. further accumulation of know-how;
- The market in Serbia has a relatively poor supply of locally produced environmentally friendly materials;
- The lack of interest on the side of the equipment suppliers/producers for long-term projects such as Pametnija Zgrada.

Future research concerning questions opened in this Study should follow the following outlines:

- Questions of possible financing arrangements/tax breaks/subsidies that allow the Pametnija Zgrada concept to have (higher) penetration into the existing market-oriented society;
- Optimization oriented questions like:
    - Optimal properties of building material, mainly their thermal mass properties;
    - Thermal mass is a practical and potentially cheap way to embed a short term accumulator of heating/cooling energy in the building. This study is carried out by observing two materials in practice: wood and autoclaved aerated concrete, and the results faithfully reflect the properties of these materials, but open questions still remain about other materials (or if new materials could be developed) that could potentially be more appropriate for the climate conditions in Serbia or SEE;
    - The optimal size of the domestic hot water (DHW) buffer tank/heating buffer tank;
    - Similarly as with the thermal mass of the main building material, the optimal size of the buffer tanks could further improve the performances of the building;
    - What is the optimal ratio of glazing and wall surfaces depending on the orientation of walls;
    - Since the cost-effectiveness of a Pametnija Zgrada has a very narrow margin, every item of information is important, such as finding the optimal ratio of these two surface areas. Once determined, this could be used as a set of recommendations similarly as recommendations used for the form-factor, as elaborated in Chapter 8.2.
- Questions of awareness-raising and how to reach a wider audience about the importance of the issues explained here;
- Integration of the spreadsheet tool with a Life Cycle Cost Analysis tool, such as the OpenFRM model developed by Ko Gradi Grad;
- And other, related questions.

CHAPTER 11

CONCLUSION

This study was conceived to explore the viability of Passive House implementation in Serbia, and to facilitate the process of launching the flagship development Pametnija Zgrada. The latter 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.

The following points list the key challenges that needs to be met when developing such a project:

- A sustainable building 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 unwantedly 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, by its own nature, undercutting investments in products which stand out for their efficiency and;
- This loop seems closed.

In the long run, there are two possible exits, which largely depend on Serbia's future strategic choices:

- Lowering the emission factor of produced electricity $kgCO_2/kWh$ and/or;
- Raising the price of electricity.

However, answering the challenge of access to affordable, energy-efficient, low impact housing, requires that action is taken prior to such a (possible, but uncertain) policy change. In effect, flagship projects like Pametnija Zgrada have to position themselves in a landscape of delicate cost-efficiency, by carefully balancing the benefits of implementing individual measures, favouring those measures that are cost-effective and discouraging implementation of measures that are not (although the same measures could be very attractive under different conditions, e.g. in Germany). To aid this, a tool for the assessment of the selected set of measures has been developed (some of its results are shown in the chapter Methodology and results).

The Pametnija Zgrada flagship development has proven to be viable (according to the analysis) when implemented as follows:

- The main building materials are (as explained in Chapter 3.1):
  - AAC Passive 3 or;
  - PWCP with rock wool insulation;
- The insulation material is:
  - HD rock wool as explained in Chapter 3.2;
- Windows:
  - Double glazed PVC windows as explained in Chapter 3.3;
- Shades:
  - Low-tech fixed shades, only on the south façade, predominantly as a measure for improving comfort rather than significant improvements of energy efficiency, as elaborated in Chapter 3.3.1;
- HVAC:
  - Decentralized (per floor or per flat) mechanical ventilation with heat recovery coupled with a centralized ground source heat pump as a heating/cooling source with a heat exchanger integrated into the ventilation ducts as elaborated in Chapter 4.5;
- Domestic hot water system:
  - Centralized sealed domestic hot water supply system coupled with the heat pump as elaborated in Chapter 4.6;
- PV power plant as explained in Chapter 5 and;

- Solar chimney only under the conditions that this isn't an expensive addition to a building as elaborated in Chapter 6.4.

Regardless of these recommendations, the fragility of the cost-efficiency of this project under the circumstances in Serbia becomes rather visible when exploring a range of future scenarios (through the implementation of the possibility of a varying future price of electricity (an increase of 3 – 10% per year) and the Discount Rate in Net Present Value (NPV) analysis in the range of 4 – 10%. Namely, the combination of these two values has a more decisive impact on the project than any of the proposed measures. Needless to say, all of the above indicates a lot of room for lobbying and advocacy for a "pametnije društvo" (smarter society).

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FIGURES

TABLES

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