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DIPLOMARBEIT

Towards net-zero energy building in Croatia through energy efficiency measures and locally available renewable energy sources: A case study

unter der Leitung von

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ABSTRACT

The final energy consumption in buildings in Europe is more than 40% of the total energy consumption and is growing steadily due to the constant increase in living standards. At the same time, building sector has the highest potential for ecological and energy savings and the implementation of renewable energy sources. Croatia itself is rich in renewable energy resources, especially the Dalmatian region with its Mediterranean climate that, according to UNDP, has a great predisposition for a self-sustainable region. In order to begin to rely on on-site renewable resources a series of activities at the national level, and especially at the local level is required.

Due to the favourable geographic location, concern for the pupils and the environment, the Elementary school Ostrog wants to become the first energy independent school in Croatia, meaning it produces as much energy on site as what is consumed throughout the course of the year.

This thesis focuses on examining the best and most feasible ways to meet the school's need for energy: through combination of energy efficiency measures and implementation of locally available renewable sources. Through a dynamic simulation software two scenarios were applied: the refurbishment of the lighting system and the thermal improvement of the opaque part of the building envelope. The results were compared and evaluated according to the different criteria: electricity and heating demand.

The renewable energy potential on site was calculated and explored if it can cover the school's annual need for electrical energy through installed photovoltaic system and heating demand through biomass from olive pomace.

Finally, the financial costs for proposed measures were calculated, as well as possibilities for financing them.

List of acronyms and abbreviations

ACH	Air exchange rate
AM	Air Mass
CFL	Compact Fluorescent Bulb
EE	Energy Efficiency
ELFO	Extra light fuel oil
EMIS	Energy Management Information System
FC	Fluorescent tube
FIT	Feed-in Tariff
HAL	Halogen Light Bulb
HBS	Heinrich Böll Stiftung
HEP	Croatian national electricity provider
PV	Photovoltaic System
RES	Renewable energy sources
STC	Standard Test conditions
kW	kilowatt
kWh	kilowatt hour
MW	Megawatt
TAS	Thermal Analysis Software
TW	Terawatt
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme

CONTENTS

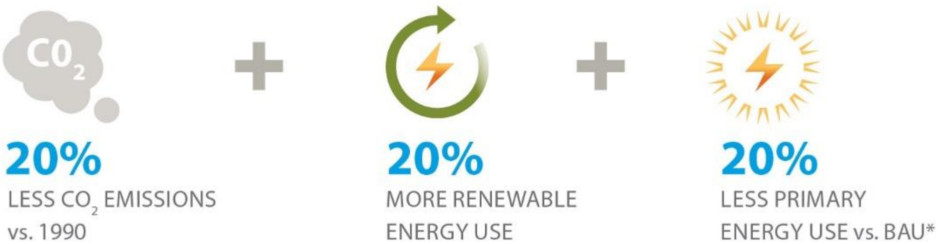
1 INTRODUCTION

The first oil crisis in the seventies of the last century has accelerated the acceptance of the fact that the fossil fuel sources are certainly limited and have to be rationally used. Shortly after that many industrially developed countries have adopted the first laws and regulations on energy savings in the buildings.

The intensive global increase of energy demand and the impact it makes to the environment and society as a whole, leads to the need for long-term observation towards fossil and non-renewable energy sources. In current societies, access to energy is a major factor for sustainability in both developed and developing countries.

According to the UNEP's Sustainable buildings and Climate Initiative report, the building sector now accounts for 40% of total energy consumption, and this figure is constantly growing. At the same time this sector has the highest potential for energy and environmental savings, and therefore energy efficiency is becoming a priority of modern architecture and energy sector.

Due to the widespread energy crisis and the growing impact of energy consumption on the environment, the European Union has in recent years produced documents which set guidelines for the development of energy policy in Europe.
In 2007 the European Council adopted a two-year action plan (2007-2009) to create a common energy policy, which is supplemented by new energy measures for the period up to 2014. This resulted in the adoption of the energy and climate package, which turned into the EU ''20-20-20'' targets that include:



To support the achievement of these objectives, a series of activities at the local and the national level is required. The Republic of Croatia as the EU member state is obliged to assume the guidelines of the European energy policy. (MINGO, 2009)

1.1 Objective

In order to begin to rely on on-site renewable resources a series of activities at the national level, and especially at the local level is required. The topic of this thesis is achieving an energy independent public building, an elementary school, situated in the south of Croatia.

The school is surrounded by the botanical garden and the olive grove, with pupils and teachers interested in ecology and environmental protection, but lacking the resources to bring their building into energy efficient one. This thesis examines the potentials for energy saving measures and the implementation of locally available renewable resources - solar energy and biomass in order to reach self-sufficiency. For this approach a dynamic simulation software, EDSL TAS, was chosen to perform required simulations. Calculations of the building's electricity consumption and heating demand were calculated and compared with the data obtained from the school. Two different states of refurbishment were performed. Further study object was to estimate the costs of each measure and to find the most feasible ways for the school to finance them.

The questions on which this master thesis will answer are:

- Which EE measures are needed to reduce heating requirements of the building?
- What is the building's RES potential on site?
- Can the building become energy independent with that amount of RES on site?
- How much would all the measures cost and what are the possibilities for financing them?

1.2 Motivation

During my study years, I became familiar with the concept of sustainable buildings and sustainable environment, as well as the benefits that such environment can bring to the people who live in it. Promoting efficient use of energy and renewable energy sources is an important part of the strategy on a global and national levels.

It is constantly emphasized that the construction sector has the greatest potential to reduce total energy consumption on a national level, thus directly influencing more comfortable and quality living in the building, longer life span of the building and contribute to environmental protection.

Significant part of the public buildings represent school buildings, and as such are noteworthy part of total energy use. School buildings are very important for society as the number of in school children is large, in Croatia alone already more than half a million.

However in the design of school buildings the obtainment of a good environment is often not considered as priority. In existing school buildings there are very often non optimized systems in term of energy consumption. (Zeiler and Boxem 2013, 282)

One of those examples became the case study building of my Master thesis. The Elementary school Ostrog, situated in small Dalmatian city of Kastel Luksic, built in seventies in an environment buried with construction waste and overgrown with grass. Since then, the teachers together with pupils have been committed to environmental protection. As a result of their dedication, the school is surrounded by the olive grove and a unique botanical garden which was declared as a protected monument of landscape horticulture. This long history of taking care about the environment through generations of kids, encouraged the school to choose energy independency as the way to go.

With this thesis it is important to make an example of good practice for the other schools and to show that national slow politics doesn't have to be an obstacle and that local communities can make changes.

1.3 Thesis structure

This Master Thesis is structured in seven sections. The first section provides introduction into the topic and the main objective. Second section brings background of the relevant topics in this study. Section three provides the methodology and approach to the case study. Section four shows the conducted results and discussions of those results. Section five is the conclusion of the whole study.

Further sections include reference list and appendix

2 BACKGROUND

This chapter describes the background of the study, what sustainable is about, how Republic of Croatia as an EU member state deals with the EU Energy policy through its National Energy Strategy; current situation with renewable energy sources. Furthermore, it gives a brief explanation of the Net-zero energy building concept.

2.1 Sustainable development

"Sustainable development has traditionally been defined as development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs." (Jaramillo-Nieves, Del Rio, 2010, 785)

Sustainable development has a triangular approach as its basis. That considers the tree interrelated dimensions of sustainability: environmental, economic and social.

Environmental

Reduction of local and global pollution (among them, emissions of greenhouse gases), exploitation of the renewable resources in the territory and maintenance of the resilience (ability to adapt to change), integrity and stability of the ecosystem.

Economic

The energy sector has generally been perceived as key to economic development with a strong correlation between economic growth and expansion of energy consumption. (2) Increase of regional per capita income, improvement in the standard of living of the local population, reduction of energy dependence and increase in the diversification of energy supply.

Social

Reducing unemployment and improving the quality of jobs (more permanent jobs), increasing regional cohesion and reducing poverty levels are key actions at local level to achieve social sustainability. For example, activities such as renewable energy deployment should be encouraged. This has a particularly positive psychological impact on the prospects of the young local population. (Jaramillo-Nieves, Del Rio, 2010, 787)

A series of global conferences, from the original 1992 Earth Summit and 2002 World Summit on Sustainable Development to the 2012 Rio+20 Earth Summit, have reiterated the social, economic, and environmental dimensions of sustainability. The definition from the Rio +20 outcome document “The Future We Want” broadens the aims to reducing inequalities for a more equitable social development in balance with natural resource management and ecosystem conservation. (UNDP)

It is always emphasized that the local sustainable development should be of crucial interest for every country. In UNDP’s initiative on empowering and developing local sustainable development, the community, private sector and local government should be in constant interaction. The role of local government in sustainable development is important as it has to engage citizens in decision making process; help to deliver results shaped by local realities and take integrated problem-solving approaches.

2.2 National Energy Strategy

Croatian National Energy Strategy was adopted in 2009 for the period until 2020 in order to harmonize with goals and time framework of strategic documents of the European Union.

There are two key factors in National Energy Strategy: the importance of increasing energy efficiency of the buildings and using energy generated from the locally available renewable resources.

Energy efficiency is recognized worldwide as the most efficient and effective way to achieve sustainable development goals: reducing negative impacts on the environment (produced by the energy sector), reducing carbon emissions, increasing energy supply security by breaking the connection between economic growth and increasing demand for energy, but also a contribution in increasing the competitiveness of national economies. Therefore, energy efficiency should play a key role in the overall national energy policy.

The Republic of Croatia is endowed with a great potential in renewable energy resources. Renewable energies present several advantages, three of which stand out as most appealing:

- Renewable energy is drained from the exploitation of clean, domestic natural resources, thereby reduces energy dependency from third States;
- Their use as a means of improving security of energy supply boosts the development of domestic production of energy equipment and services;

- Finally, the development of renewable energy technologies is crucial towards to the achievement of internationally agreed, binding environmental objectives

According to these advantages, the Republic of Croatia ended up with adopting EU 20-20-20 goals in their National Energy Strategy. (MINGO, National Energy strategy)

2.3 Renewable energy production and potential in Croatia

According to the National Energy Strategy, Croatia is currently importing about 50% of its energy demand. The RES capacities have a positive trend of growth in last couple of years. From the statistics of Croatian Association for Energetics published in February 2015, the total capacity of installed RES power plants amounted for 495 MW.

Except for big hydro power plants that have the biggest share in renewables with the installed capacity of 2097 MW, the wind and solar plants are the most developed among RES. The number of biomass plants is still small.

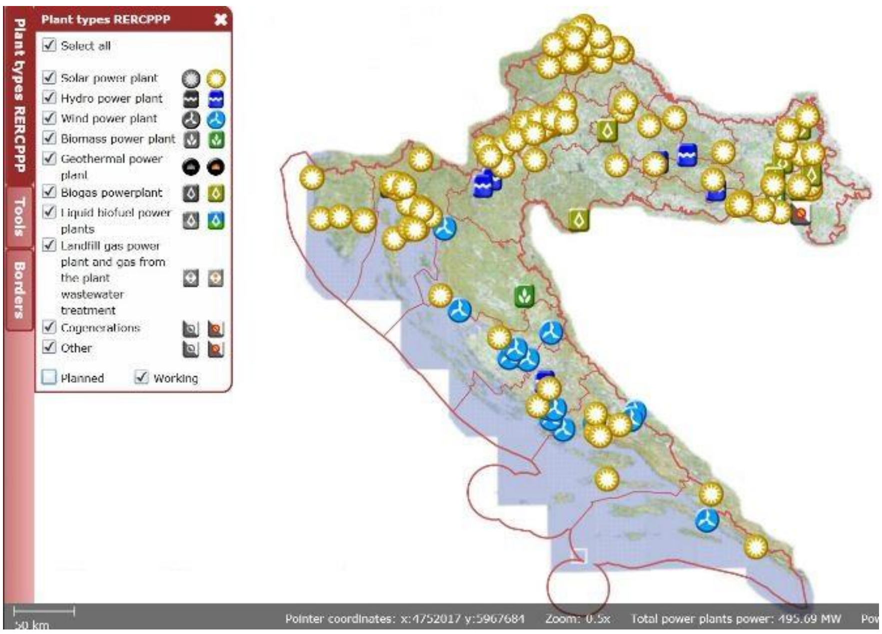


Figure 1 Interactive map of installed RES power plants

(MINGO –Ministry of Economy, Labour and Entrepreneurship of Croatia 2015)

Figure 1 shows the plant types and their distribution across the country. Comparing Table 1 shows the big discrepancy in between currently installed capacities with the RES potential that Croatia has.

Table 1 Comparison of currently installed and potential RES capacities

	Wind	Solar	Biomass
Installed Renewable electricity Capacity 2015 in MW	452	7.8	6.7
Technical potential for installed Ren. Electricity Capacity in MW	6900	53400	1500

The favorable geographical position makes the whole country and especially coastal part rich in natural energy sources such as solar and wind sources which have, according to HBS's study ("North-Adriatic Costal Area as 100% Renewable Electricity Region"), a great predisposition for self-sustainable region.

2.3.1 Electricity generation from photovoltaics

"One must point out, however, that in late Seventies Croatia was among the very few regions in the world that had initiated a solar energy program, responding to the oil crisis in 1973." (UNDP, 2010) Unfortunately, this initiative was stopped by the war in 1990s.

The Adriatic coast (Figure 2) is characterized by a Mediterranean climate with dry and warm summers and wet and mild winters. Having in mind that Adriatic coast is one of the sunniest in the whole Mediterranean with an average of 2600 hours per year the use of solar energy stands out as a logical choice.

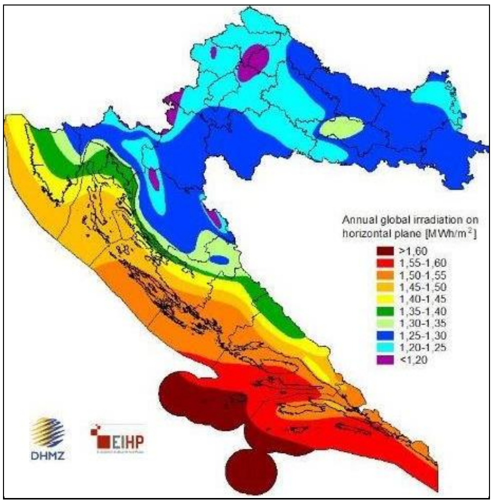


Figure 2 Average annual radiation
(Croatian Meteorological and Hydrological Service 2015)

But, today’s solar reality in the Republic of Croatia is 8.1 W of photovoltaic power per capita, resulting by one of the lowest within the EU. (Wikipedia) Currently, there are 154 installed solar power plants (Figure 3) of total power 7.8 MW in Republic of Croatia, mainly distributed in northern parts of the country.

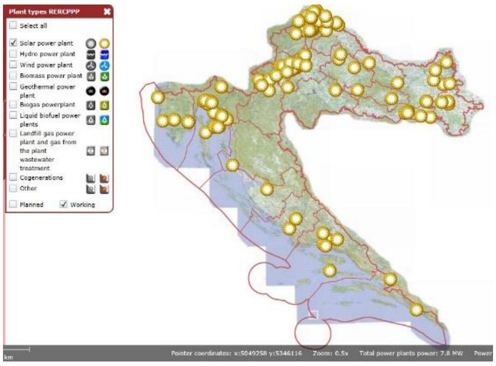


Figure 3 Currently installed solar power plants

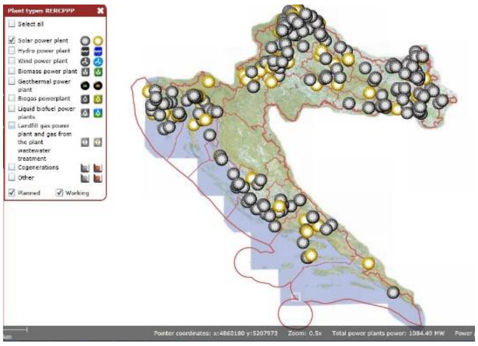


Figure 4 Planned solar power plants

(MINGO –Ministry of Economy, Labour and Entrepreneurship of Croatia 2015)

According to the UNDP’s study, technical potential of solar energy on 1% of the continental part of Croatia is estimated at 830 TWh/annum or close to 10 times of the daily consumption of primary energy in Croatia. With the presumption that 60% of that energy is used for heating and 40 % for electricity generation, it is possible to conclude the following:

- The technical potential to produce heat from solar collectors and the use of passive solar energy (solar architecture) amounts to 175 TWh/annum
- The technical potential to electricity generation from photovoltaic (PV) systems and solar thermal power plants amounts to around 33 TWh/annum

There is a lot of interest shown for solar systems, especially in coastal area (Figure 4), that would result in additional 1076 MW of installed power.

As most of the households in coastal area and islands are using electricity for heating of domestic hot water, installation of solar thermal systems would mean less electricity consumed. This is especially the case in summer period when preparation of hot water for showering already has a strong impact on electricity peak load as peak load usually happens between 19-21h, along with after-beach or pre-dinner shower takes place.

2.3.2 Biomass

About 97 % of forests in Croatia are of natural origin, that have been developing for ages in their habitats, which makes them one of the most natural, the most stable and the most productive ones in Europe. (Talic at al. 2012)

Consequently, Croatia is abundant in forest biomass, than agriculture biomass and waste, but one should be very careful and selective with regard to their exploitation considering potential multiple devastating effects on the environment. (Runko-Luttenberger,2014) Less than half of the population (47 %) use some type of biomass for space heating, cooking or water heating in.

This percentage is much higher in rural areas, where approximately three fourths of the households (73 %) reported to use biomass for their daily needs, while, on the other hand, the percentage is significantly lower in urban areas (28 %). Regarding the type of biomass, firewood is used by almost all of the households that reported biomass consumption. A very small number of households (4%) use pellets and briquettes or some other type of biomass (mainly tree pruning). (Energy Community)

According to the Croatian Ministry of Economy, Labour and Entrepreneurship, there are only three installed power plants on biomass with the total power of 6.7 MW. All of them are engaged in processing of wood chips into biomass.

What is not yet recognized as the valuable energy source, is olive pomace. In two coastal regions, Istria and Dalmatia (Figure 5), and in more than 150 oil refineries across Croatia more than 30000 tons of olives are annually processed from 30000 hectares of olive groves. 15-17 % or from 4500 to 5100 tons of total amount accounts for olive oil, and on pomace approximately 25000 tons. (Zadar newspapers, 2011)

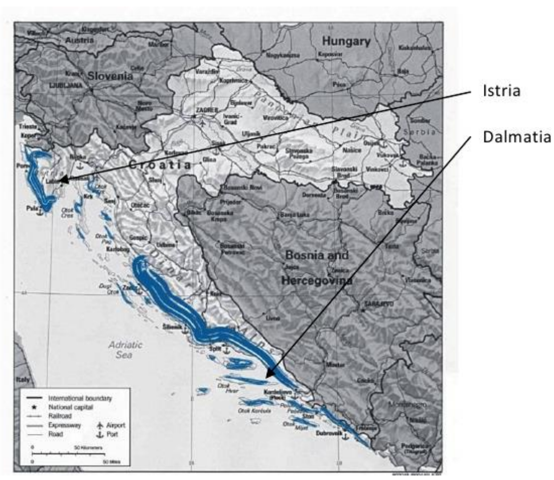


Figure 5 Olive growing and olive oil production regions in Croatia (Intelligent energy Europe 2015)

2.4 The concept of energy independent or net-zero energy building

The basic concept of a Net Zero Energy Building (Net ZEB) is that on-site renewable energy generation covers the annual energy load.

The NET ZEB concept is a building where the weighted supply of energy from the building meets or exceeds the weighted demand and interacts with an energy supply system (grid). Such a building can export energy when the building's system generates a surplus and import energy when the building's system is insufficient to generate the energy required.

The requirements are generally that the demand is covered by renewable energy sources. However, to meet the goal, a low energy demand is an advantage. The general approach to reach Net ZEB could be described as a two-step concept. The first step is to reduce the energy demand by applying energy efficiency measures. The second step is to supply energy, generated by renewable sources, which may be supplied into an external grid when favourable. (Berggren, Hall and Wall 2013, 381)

3 METHODOLOGY

3.1 Overview

This study examines the calculated energy demand for a public building – elementary school, and in further research, evaluates the total energy provided by applied solar system and biomass from olive pomace.

For this purpose, it was necessary to visit the school, talk to the school's responsible about energy consumption within the building, user's habits and obtain the plans in order to create an accurate 3D model in EDSL TAS, the building energy modeling and simulation tool.

Two different retrofit scenarios were applied within the study. In Scenario 1 the lighting system was refurbished, as well as windows and doors. Scenario 2, on the other hand, deals with the refurbishment of the outer envelope according to the Passive Standard House in order to decrease the heating demand of the building.

After applying EE measures through these two scenarios, the renewable energy potential on site was examined. In this study two RES were taken into consideration: solar energy and biomass from olive pomace.

The potential of RES to cover the energy demand of the building will be examined: photovoltaic system to cover the electricity demand and biomass from olive pomace to cover the heating demand. At the end, the cost of the each measure will be calculated, as well as the possibilities to finance them.

3.2 The case study building

3.2.1 Location

The Elementary school "Ostrog" is an educational building situated in the south of Croatia, on the central Dalmatian coast, in a small town of Kastel Luksic (Figure 6).

Kastel Luksic is one of the seven small towns that developed around seven castles under the common name Kastela (meaning: castle). The Kastela region with its Mediterranean tone, picturesque landscape and unique composition of natural environment attracted people since prehistoric times. Once an ancient Greek port, a stopover point for Roman veterans and a summer place for Croatian kings is today a place with mostly family houses and tourist facilities.

Figure 6 Location of the building
(Wikipedia, 2015)

3.2.2 Energy cooperative Kastela

Having in mind the uncertain future of non-renewable energy sources as well as the importance of thinking about future generations, the local people from small Dalmatian city Kastel Luksic formed an energy cooperative “Kastela”.

The desire to change something on a local level encouraged them to establish one of the first energy cooperatives in Croatia. In their beginnings they organized seminars and workshops on sustainable local development in order to raise the awareness about ecology and sustainable behavior towards the environment in their own community.

The cooperative Kastela has one unique member – the Elementary school Ostrog. The primary school Ostrog's path towards energy independence began in 2013 when, in cooperation with the United Nations Development Programme (UNDP) and the project Solar Sunflowers, a small educational solar tracker system of 1kW was installed at the school’s roof. This system meets only a very small portion of the school's energy needs, so the school’s wish is to go one step further and reach the energy independency.

3.2.3 Building geometry and properties

The Elementary school “Ostrog” was built in 1976, as a typical example of construction style of those years. The workspace of the school consists of two floors mostly occupied with classrooms and corridors. The rest is occupied by the cabinets of professors, kitchen, toilets, a few offices, sports hall and associated dressing rooms. (Figures 7,8,9)

Table 2 Basic information of the case study building

Building type	Elementary school
Year of construction	1976
Number of floors	Ground floor + first floor
Net area	2324 m²
Heated net area	2 324 m²
Number of users	450 (from which pupils 400, teachers 50)
Working hours	7 am – 3 pm; weekends are non-working except for special occasions

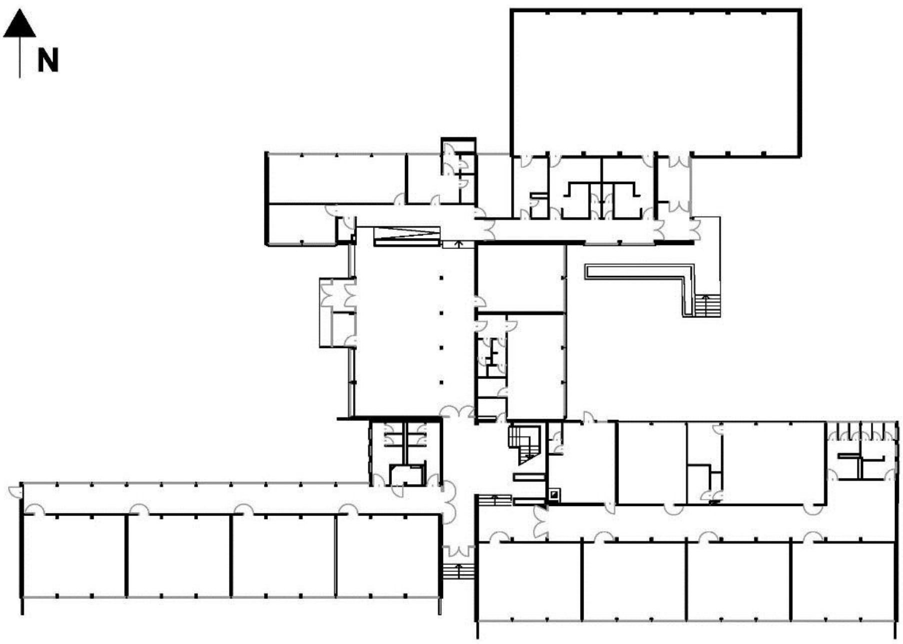


Figure 7 The ground floor

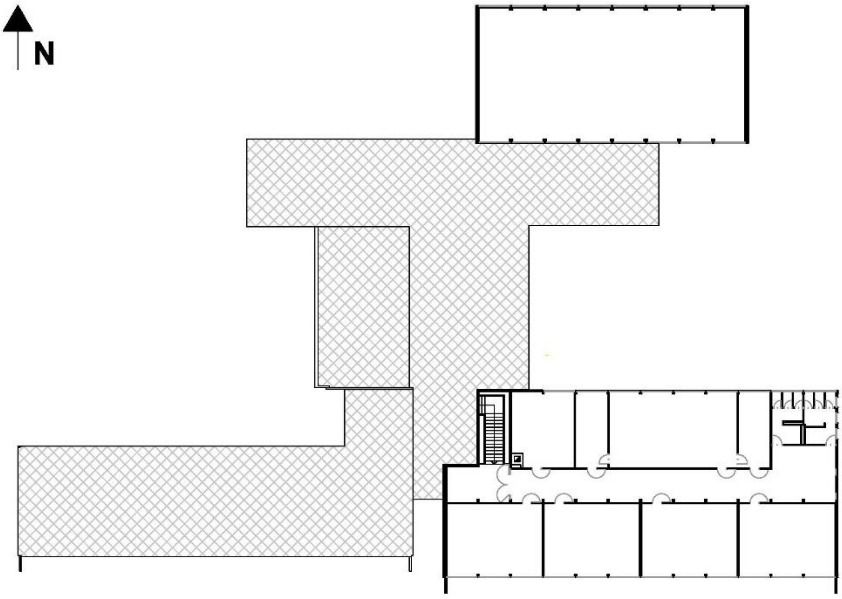


Figure 8 The first floor

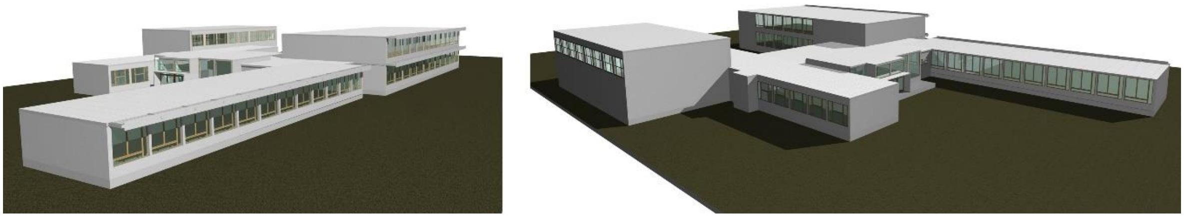


Figure 9 3D model of the building

3.2.4 The opaque part of the building envelope

The school building was built in 1976. This period is characterized by the large and fast-track construction, as well as construction of buildings which today represent the biggest problem in terms of energy consumption. The appearance of new materials, lighter and thinner structures, large glazed surfaces, and poor thermal characteristics without the use of thermal protection characterize this period of construction.

New materials and their diversity resulted in the change of the concept of building construction. Reinforced concrete allows statically "thin" constructive elements which without thermal insulation have large heat losses. Large windows are single glazed. (UNDP, 2010)

The case study building is not exempt from this description, and represents a typical example of the construction of that period - the walls of the building don't have an adequate thermal insulation (mostly a layer of porous concrete embedded on concrete wall).

Exterior walls (U= 1.74 $W.m^{-2}K$) of the building are made of external panels of reinforced concrete (10 cm) with a layer of porous concrete siporex (10 cm), plastered on both sides but without thermal insulation.

Floors on the ground (U= 1.07 $W.m^{-2}K$) consist of concrete base on a layer of gravel crushed stone, hydro insulation, protective layer of concrete, concrete flooring and floor covering (mostly tiles).

The ceiling (U=2.23 $W.m^{-2}K$) above the heated space is massive reinforced concrete ceiling 20 cm thick, with a flat roof hydro insulated with bitumen board.

Openings in outer walls consist of windows, glazed walls and glazed front doors. In recent years it has been invested in new windows with PVC frames and ISO glasses. A smaller part of the openings are the old wooden and iron framed windows with single glazing.

3.2.5 Energy profile of the building

Energy needs of the school are met through electricity supply as well as supply from extra light fuel oil (ELFO). Also, there is an alternative energy production on site with a 1 kW photovoltaic system. Ventilation is obtained naturally. Most of the consumed energy is spent on heating.

As a period for which the energy profile is being made, 5 years (2009-2013) were taken into account. The energy management data is based on *Energy management information system (EMIS)* installed in school, which collects metering data and offers consumption report on monthly level.

3.2.6 Electricity consumption

Since the annual consumption is calculated as the sum of monthly values (Appendix 7.1), the Figure 10 shows the monthly distribution of energy consumption. It is notable that these values are higher in winter months. During the summer months, there is no much need for electricity due to the warmer and brighter days, as well as the fact that school is closed for the pupils from mid-June till beginning of September, and for the school staff from mid-July till the end of August.

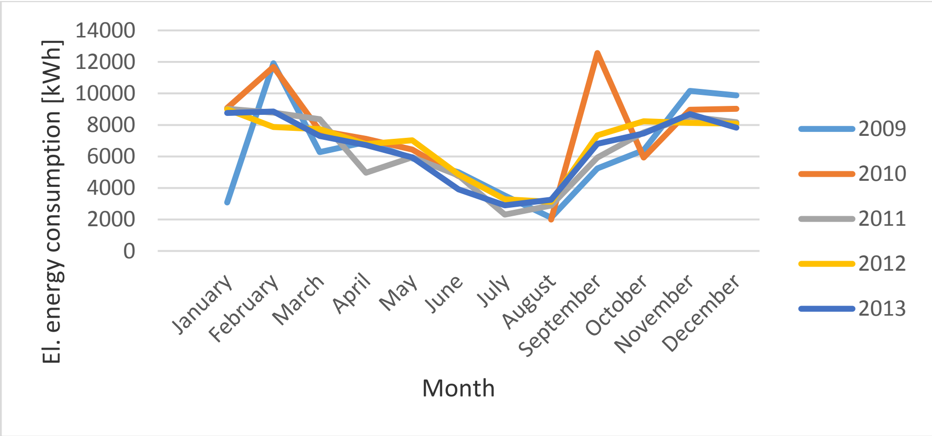


Figure 10 The monthly distribution of the energy consumption

As a reference year for the school's electricity consumption, the 2012 was taken, as it reflects the actual power consumption of school because of the embedded photovoltaic system that generated electricity submits directly into the school.

Electricity on location is used to provide power for all electrical appliances as well as electric lighting.

Electricity consumers in the building are:

- lighting
- split systems (7 units, installed only in offices)
- electrical appliances (computers, printers, electrical water heaters, refrigerators...)

According to the list of electricity consumers (Appendix 7.2) and their belonging installed power and working hours, the biggest energy consumers in the building are (Table 3, Figure 11):

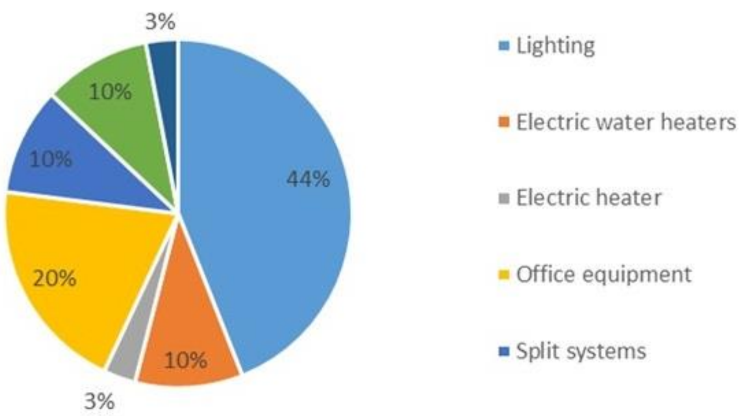


Figure 11 Distribution of the biggest energy consumers

Table 3 The biggest energy consumers

Energy consumers	kW	kWh
Lighting	31.89	36330
Office equipment	14.25	15480
Electric water heaters	7	7840
Split systems	7.7	6640
Kitchen appliances	7	5627
Heating system consumers	2.4	3480
Electric heater	2	1800
Other		4271
Total:	72.235	81468

- **Electrical lighting system**

Electrical lighting system is properly maintained but is extremely energy inefficient and primarily based on the incandescent filament.

According to the conducted list (Appendix 7.3), incandescent bulbs are dominated in the lighting system and account for about 62%. From the other systems, 37% is accounted for fluorescent lighting and 1% for halogen bulbs in outdoor lighting system.

Incandescent lamps are the dominant lighting system according to installed capacity and to electricity consumption (Figure 12 and 13). Incandescent lamps are extremely of low efficiency and poor light utilization.

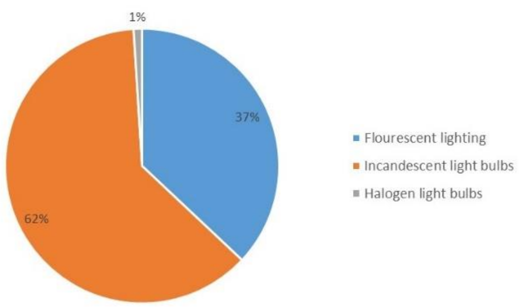


Figure 12 Total installed power

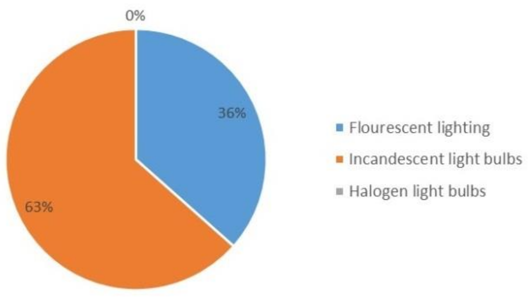


Figure 13 Electricity consumption

Motion sensors are not currently installed in school, but could be very useful in some areas such as toilets, to disable lights when the space is not occupied.
In most areas there is no possibility of light controlling, or using just a part of the light source.

- **The heating system**

The school is heated via a central boiler (Figure 14) system powered on extra light fuel oil (ELFO) with total output of 400 kW, which is located in a separate room on the ground floor of the school.

The heating of the building is obtained with over 78 iron radiators. (Figure 15)

Figure 14 the ELFO boiler for heating

Figure 15 Installed radiator types at school

The radiator circuit is not balanced, which means that the part of the building is overheated, and a smaller portion is insufficiently heated. The heating system on ELFO is the school's primary energy source and by its combustion the boiler produces heat which is further used for water heating system in months of the heating system operation.

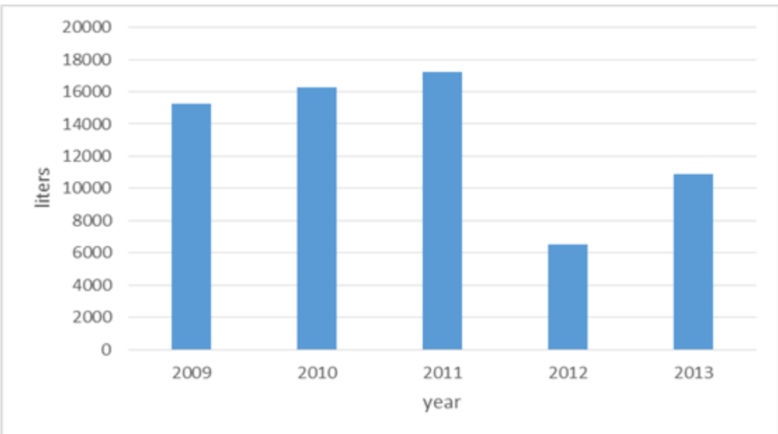


Figure 16 Bought ELFO through the 5-year period

Since the ELFO is ordered in very large amounts (Appendix 7.4.) and on irregular basis (Figure 16), and since there in no record of monthly or annually consumption in EMIS, the average of five-year period was taken as reference consumption.
The reference consumption is 13226 l, or converted into its energy value 132260 kWh. (1l of ELFO = 10 kWh) (Tulimax, 2015)

The boiler efficiency is estimated at 80%, plus additional 3% of minimal losses in branching. According to that, the actual space heating demand is 101840 kWh.
Normalizing the building heating demand by dividing it by the building floor area, the normalized indicator of 43.8 kWh/m2 is obtained, which is a low value due to the conditional interruptions in heating (working – non working part of the day) and lower demand for heating of the building, due to the good geographical position.

- **The cooling system**

The need for cooling in summer period is met by split systems, installed only in certain areas (mostly in offices), and they are in total of 7 that amounts to 7.7 kW electrical power. The annual energy consumption of the system is about 6640 kWh. The consumption is calculated according to the available data on the installed electrical power of the system and the estimated time of the working period of the system. Split systems are irregularly used during cold winter periods for additional heating.

- **Energy production on site**

Alternative energy system, a 1kW photovoltaic system, so called "tracker" has been installed in 2012 at the entrance of the school (Figure 17). The system has been installed for educational purposes and is fully operational. Electricity produced by the system is not stored, but directly consumed on the premises of the school. The annual electricity produced by this system is 1600 kWh.

Figure 17 A solar tracker

3.3 Applied building simulation program

Building simulation software is a powerful tool for predicting heating, cooling and lighting loads of a building as frequently as every hour. EDSL's TAS (thermal analysis simulation) software is widely respected for its accurate analysis and predictions of the thermal properties of a building's design and its ability to predict ongoing energy consumption based on real and localized weather data throughout a year.

Tas Engineering has a modular design and is split into three main programs, the 3D Modeller, Building Simulator and Results Viewer. (edsl.net)

The 3D Modeller is developed specifically for creating building models for simulation. "TAS 3D modeler allows you to trace out your floor plan using CAD drawings. Building floors, building elements, windows, shades and thermal zones are easily created and modified."(edsl.net) Model created at this stage should be exported to the *Building Simulator*.

In the *Building Simulator* all input parameters for construction, occupancy, equipment and weather can be set. The fundamental approach adopted by TAS Building Simulator is dynamic simulation. This technique traces the thermal state of the building through a series of hourly snapshots, providing the user with a detailed picture of the way the building will perform, not only under extreme design conditions, but throughout a typical year. This approach allows the influences of the numerous thermal processes occurring in the building, their timing, location and interaction, to be properly accounted for. (edsl.net)

After all the input data have been defined, the dynamic simulation can be executed and the results will be shown in the *Result Viewer* as a final stage.

The *TAS Results Viewer* allows the user to display results in tabular, graphical, or 3D. The 3D view superimposes the chosen data onto the selected building geometry allowing you to step through hour by hour looking at your 3D model analyzing anything from internal dry bulb temperature, internal solar radiation, aperture flow or any other data output. (EERE 2015)

In terms of renewable energy, TAS requires that the PV panels firstly should be built in 3D Modeller and assigned a material. In addition, the calculation of the PV system output needs to apply TAS PV Macros.

Macros can be used to extract results such as the solar gain output from the solar plants and to display them in tabular or graphical form. The macro calculates the output based on the amount of solar gain incident on the solar panel and the solar panel's characteristics.

"Solar radiation absorbed, reflected and transmitted by each element of the building is computed from solar data on the weather file. The calculation entails resolving the radiation into direct and diffuse components and calculating the incident fluxes using knowledge of the sun's position and empirical models of sky radiation. Absorption, reflection and transmission are then computed from the thermos-physical properties of the building elements. External shading and the tracking of sun patches around room surfaces may be included at the user's option." (EDSL TAS 2012b)

To generate the output result, the PV Macro uses several parameters:

- Efficiency of the PV array
- Inverter efficiency
- Environmental factors

The output of PV Macros gives results for all applied elements for each hour of the year. The results are subdivided into: PV surface output and building total output.

3.4 Initial model

A typical building simulation process starts up with definition of the initial building model. In order to provide a reliable and accurate computer model for the further research simulations, some pre-steps have to be fulfilled: site visit and collecting the building information from target building - collecting the drawings, information of building construction and energy records from EMIS, as well as lighting and appliances operating schedule and user behaviour towards the energy.

When all the data is collected, the process of creating the initial model in 3D Modeller can start. Since TAS is using simple geometrical forms, all freeform surfaces and complex forms should be simplified. The case study building is already simple building with flat roof, so there weren't needs for interventions.

3.4.1 Zoning

Except for entering the accurate data for the geometry of the building, it is necessary to assign zones to the spaces. "A zone is defined as a region of the building in which the air temperature and humidity are assumed to be uniform. A zone may be a single space, part of a space or a collection of spaces." (EDSL TAS)

Having in mind a variety of different spaces with different usage (classrooms, offices, sport hall) and different internal conditions, the case study building is divided into different zones (Figure 18) which vary from single space (sports hall) to collection of spaces (offices, classrooms, hallways).

The total energy consumption of the building will be derived from the sum of the energy requirements of all user zones.

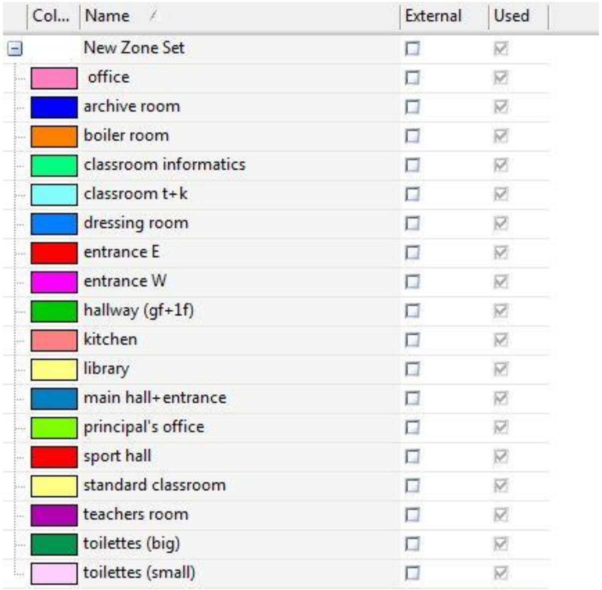


Figure 18 Zones applied to the case study building

3.4.2 Weather data

The hourly based weather data for the reference year 2012 was obtained in a raw format from the local weather station Split Marjan (16.43 E, 43.51 N).

Since EDSL Tas requires .epw format of the weather file, it was necessary to process the data through various steps in Excel, Meteonorm and Energy Plus in order to get the required format.

For the simulation of PV potential on site, a historic weather file for this location was generated from Meteonorm (for temperature period: 2000-2009 and Radiation period 1991-2010). (Appendix 7.5)

3.4.3 Calendar, Day types and Schedule

The Calendar is an important facility for describing the operational aspects of the building and has to be divided into various day types. Day types are used to group together all days in which zones or building elements have the same specification for air movement, internal conditions, aperture openings, feature shading, or substitute building elements. (EDSL TAS)

The school's working hours are from 7 am to 3 pm, and weekends are non-working except for special occasions (not taken into consideration). Three different typical working schedules were assumed for weekdays, weekends and holidays. (Table 4)

Table 4 Typical working schedules

Schedule	Working hours
Weekdays	7 am – 3 pm
Holidays	8 am – 10 am
Weekends	-

3.4.4 Internal conditions

Internal conditions are applied to the zones and to the certain day types in the model. The 'Internal Gains' tab (Table 5) displays the radiant proportion and view co-efficient for lighting, occupancy and equipment.

Table 5 Internal conditions

Gain	Measuring unit	Value
Air exchange (Infiltration and natural ventilation)	air changes per hour (h^{-1})	Daytime:2 Nighttime: 1 Holidays and weekends: 1
Lighting Gain	$W.m^{-2}$	According to the list (Appendix 7.2.)
Occupant Sensible Gain	$W.m^{-2}$	11.25
Equipment Sensible Gain	$W.m^{-2}$	According to the list (Appendix 7.2.)

3.5 Retrofit scenarios

Main intent of this study is to achieve net-zero energy building, hence most of the input parameters will be improved to fulfill the requirements. The most cost-effective way to make the building energy efficient and energy independent from fossil fuels is to reduce its space heating requirements before applying renewable energy systems.

After creating the initial model, or so called “Base case” (BC), the first scenario (S1) will be applying “limited retrofit measures” like changing the lighting system and openings (windows and doors) of the building, according to the Passive standard.

Once these measures are applied, it is possible to pass to the second scenario (S2): reconstruction of the opaque part of the building envelope. The last step will be examining the RES potential on site - PV and biomass. Finally, the costs for each measure will be calculated, as well as possibilities for financing them.

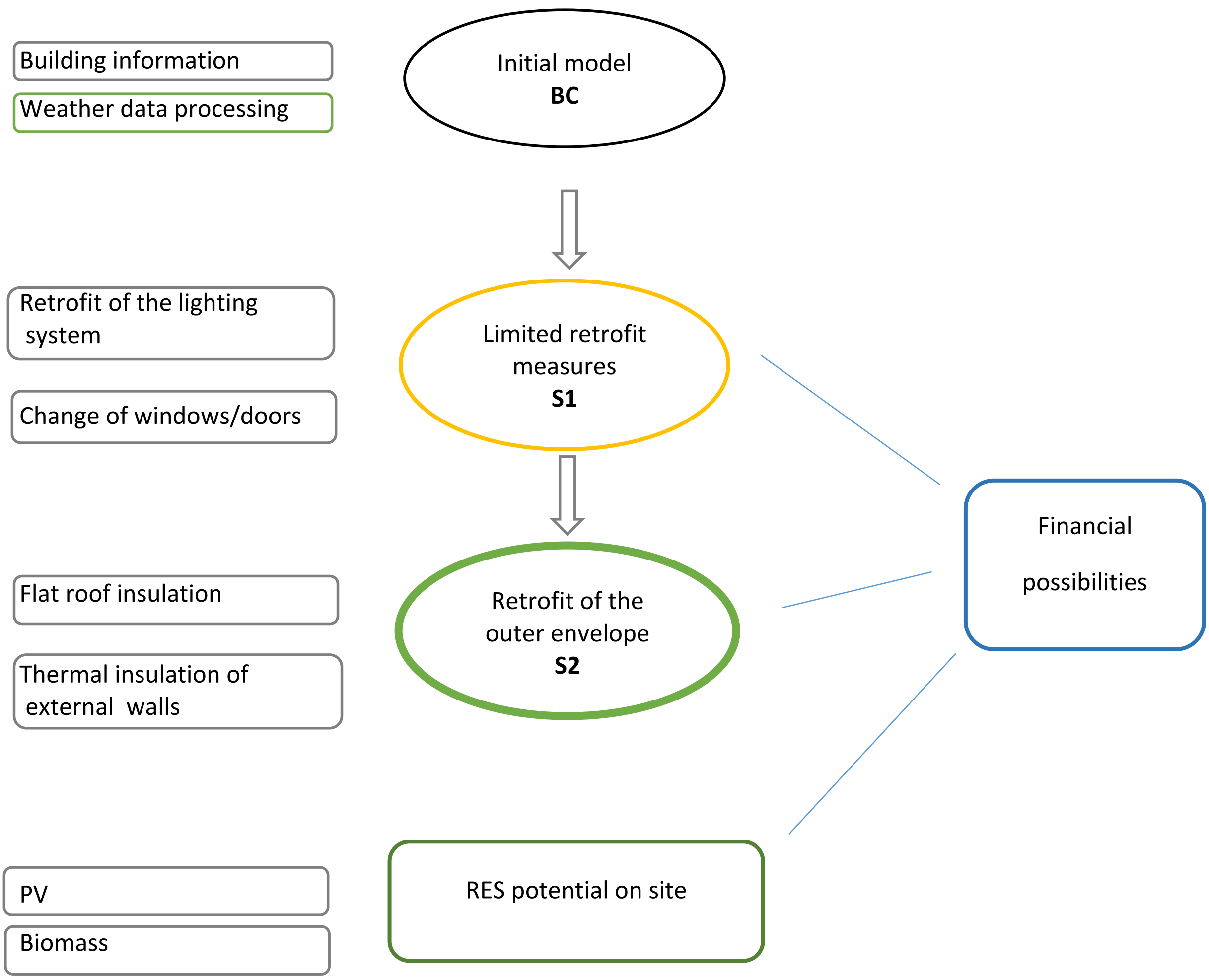


Figure 19 The scheme of the retrofit measures

3.5.1 Current state of the building (Base Case)

The construction elements in the Base Case (Appendix 7.6) are based on the information obtained from school's documentation and plans. (Table 6)

Table 6 Constructional elements and the U-values for BC

Construction	External wall	Ground floor	Flat roof	Window	Door
U - value [$W.m^{-2}K^{-1}$]	1.74	0.96	2.23	5.74	2.0

3.5.2. First step of retrofit (Scenario 1)

The first retrofit step will be applying so called "small measures" which imply the change of lighting system and outer openings according to the Passive House standard. Through energy consumption analysis it is clearly pointed out that a very large portion of electricity consumption is spent on lighting, so with this scenario the electricity demand of the building will be decreased.

Electric lighting is one area where energy savings are possible at reasonable cost in new buildings as well as in retrofit projects. (Gul, Patidar,2014)

- **Reconstruction of the lighting system**

As mentioned before, a total of about 31.9 kW of electric lighting is installed within the school, of which 62% accounts for incandescent light bulbs, 37% for fluorescent tubes (FC) and 1% for halogen light bulbs (HAL) in outdoor lighting system.

Incandescent light bulbs represent one of the most significant potential for energy savings due to the large number of installed units. In modern systems, the illumination with incandescent bulbs is completely out of use and instead the compact fluorescent or so called energy saving bulbs are being used. Energy saving bulbs consume about four to five times less electricity compared to incandescent light bulbs and have a life span six to ten times longer.

The old bulbs on incandescent filament are of very low efficiency and mostly installed in classrooms. This lighting system as such negatively affects concentration and health of students and employees.

Compact fluorescent light bulbs have much higher luminous efficiency and higher luminous flux, which is important in order to raise the level of ambient light. (Table 7)

Table 7 The comparison of the bulb on incandescent filament and energy saving ones

(Eltereh, 2015)

Luminous flux (lm)	The bulb on incandescent filament (W)	Energy saving or compact fluorescent bulb (W)
		
1210	75	18-22
1750	100	23-30

For the retrofit of the lighting system within the school, the outdated bulbs on incandescent filament will be changed with energy saving or compact fluorescent (CFL) bulbs Osram Deluxe intelligent longlife with the specifications (Table 8).

Table 8 The specifications of CFL Osram Deluxe bulbs

(Osram, 2015)

Nominal wattage:	Luminous flux:	Lamp lifetime:	Energy efficiency class
30 W	1940 lm	20000 h	A

Another potential for electricity savings are certainly fluorescent lighting bulbs and tubes, that account for about 37 % in total installed power. According to the current situation, the T-8 fluorescent lighting tubes are of 18W and 36W.

The existing tubes will be changed with energy saving Osram Lumilux T5 HE tubes of 14 W and 28W. (Table 9) T5 type tube is up to 20 % more economical and up to 50% smaller in volume than T8 type.

Table 9 The specifications of the energy saving Osram Lumilux tubes

Nominal wattage:	Luminous flux:	Lamp lifetime:	Energy efficiency class
14 W	1200 lm	24000 h	A+
28 W	2600 lm	24000 h	A+

- **The change of existing openings**

The other measure applied within this scenario is changing the existing single-glazed openings (windows and doors) with energy efficient ones. The largest part of the exterior openings consist of PVC and aluminum windows with ISO glass (Uw = 2.4 $W.m^{-2}K^{-1}$). The windows are not of the latest generation and of high efficiency. A smaller part of windows are single glazed windows with wooden or iron frames with very low efficiency of Uw = 4.8 $W.m^{-2}K^{-1}$ to Uw = 5.2 $W.m^{-2}K^{-1}$

Replacement of existing windows and doors will be in respect with low energy and Passive house standards (Table 10).

With this measure it will be examined how much of the energy for heating will be reduced from the current state (BC).

Table 10 Building element U-values after the replacement of outer openings with Passive house standard ones

Construction	External wall	Ground floor	Flat roof	Window	Door
U - value [$W.m^{-2}K^{-1}$]	1.74	0.96	2.23	**0.8**	**0.8**

3.5.2 Second step of retrofit (Scenario 2)

As mentioned in the chapters before, the case study building represents a typical building of the 70's, when the thermal insulation wasn't much in use. From this fact comes the necessity for the second retrofit - the reconstruction of the opaque part of the building envelope. This implies improving the construction components according to the low energy and Passive standard house. (Table 11)

- **Flat roof insulation**

The existing thermal transmittance of flat roof is U = 2.23 $W.m^{-2}K^{-1}$. As the existing roof is outdated, and users complain about the constant leaking during the rainy days, it is necessary to refurbish it and add the adequate thermal insulation.

- **Thermal insulation of external walls**

As mentioned before, the external envelope of the school building doesn't have thermal insulation and through this measure the adequate insulation will be embodied in order for the wall to satisfy the Passive House standard.

More details of the composition of all construction elements for each scenario can be found in Appendix 7.6.

Table 11 Building element U-values after the retrofit of the opaque part of the building envelope according to Passive House Standard

Construction	External wall	Ground floor	Flat roof	Window	Door
U - value [$W.m^{-2}K^{-1}$]	**0.12**	**0.96**	**0.11**	0.8	0.8

3.6 Renewable energy sources on site

In addition to applying energy efficiency measures for reducing space heating requirements and assuring healthier environment and high level of comfort for building users, the realization of the self-sufficient building requires the activation of renewable energy sources. This study examines the potential of covering the school's annual energy demand with two types of renewable energy presented on site: solar energy and the biomass.

The photovoltaic system (PV), its size and potential to cover the building's electricity demand through the year is evaluated in this study.

In this case biomass energy refers to renewable energy from olive pomace that the school is left with after making the olive oil from their olive grove.

3.6.1 Solar PV system

To meet the electricity demand of the case study building, a photovoltaic system has been applied. The annual amount of solar radiation on a horizontal surface, in the area of Kastel Luksic is 1600 kWh.m^{-2} (Croatian Meteorological and Hydrological Service). 75% of that energy radiates in the warmer half of the year (from April to October).

Solar panels are usually mounted on rooftops or building facades. The optimum angle of inclination to the horizontal depends on the latitude, time of the year for which is determined and on the purpose of the solar system.

The best efficiency is obtained with the southern orientation and an inclination of 30-37° for the southern part of Croatia. Just for comparison, the optimal inclination in continental part of the country would be 45° or more. (UNDP, 2010)

The case study building has a flat roof, and it is found out that 30° inclination gives the best output for this location.

- **PV panel input parameters**

PV modules are defined by their peak power output under standard test conditions (STC). These are when the incident solar radiation on them is 1 kW per square meter, the temperature of the module 25 degrees Celsius and the air mass (AM) 1.5. EDSL TAS Macro gives the opportunity to set several parameters of the panel as well as AC inverter. In Table 12 PV panel and inverter parameters as a basic for the PV calculations (EDSL TAS 2012a) the photovoltaic panel output is shown in W.m^{-2} which is produced by the PV array as a function of irradiance and the inverter AC output as a function of PV panel DC output. Further the PV panel power is reduced due to environmental factors. (Table 13)

Table 12 PV panel and inverter parameters as a basis for the PV calculation (EDSL TAS 2012a)

Data point	PV panel parameters		Inverter parameters	
	Irradiance [kW.m⁻²]	Array output [W.m⁻²]	Total PV output [% of max]	Inverter efficiency [%]
1	0.1	6.670	0.0	0.0
2	0.2	15.560	2.5	35.0
3	0.4	31.110	5.0	70.0
4	0.5	40.000	10.0	85.0
5	0.6	48.890	20.0	89.0
6	0.8	66.670	30.0	93.0
7	1.0	82.220	100	93.0

Table 13 PV panel power reduction due to environmental factors (EDSL TAS 2012a)

Reduction due to…	Value [-]
Dirt (%)	7.00
Diodes and wiring (%)	3.00
Ageing (% reduction per year):	0.20
Panel age (years)	0.00
Total reduction due to age (%)	0.00

- **On and off grid PV systems**

Today, fully functioning solar PV installations operate in both build environments and remote areas where it is difficult to connect to the grid or where there is no energy infrastructure. PV installations that operate in isolated locations are known as stand-alone systems. In built areas, PV system can be mounted on top of the roofs or can be integrated into the roof or building façade.

Grid connected system

A grid connected PV system consists of solar panels, one or several inverters, a power conditioning unit and grid connection equipment.

When a PV system is connected to the local electricity network, any excess power that is generated can be fed back into the electricity grid. Under the FiT regime, the owner of the PV system is paid according the law for the power generated by the local electricity provider. This

Type of PV system is referred to as being “on-grid”.

Stand-alone, off-grid and hybrid systems

Off-grid PV system have no connection to an electricity grid. An off-grid system is usually equipped with batteries, so power can still be used at night or after several days of low irradiation. An inverter is needed to convert the DC power generated into AC power for use in appliances.

Most standalone PV systems fall into one of three main groups: off-grid industrial applications; off-grid systems for the electrification of rural areas; consumer goods. (Green Peace, 2011)

The case study building will be connected to the local electrical grid.

3.6.2 Biomass

The school is currently using extra light fuel oil (ELFO) for heating, which is one of the most expensive on the market and by CO2 emissions the most damaging.

The school’s olive grove is founded in 1983 and located on an area of about 5000 square meters. It contains 42 olive varieties in 170 trees from all Mediterranean countries, and thus represents one of the richest collections of olive groves on the Croatian coast.

In intensive plantations olive’s lifetime lasts more than 50 years and can be divided into several periods. Non-productive period lasts for the first 5 years, 6 to 7 – year old tree is in the period of initial cropping. From 7th to 30th year is a period of full cropping and from the economic standpoint the most important period. Between 30th and 50th year is a period of reduced cropping. (Stari Grad municipality)

The amount of fruit that one olive tree will give depends on the size of the tree, mostly important on its crown size.

According to the energy cooperative "Kastela", whose member is the school, there are 300 tons of olive pomace annually available within the cooperative. The collected olive pomace can be processed, chipped and formed into pellets.

- **From olive to olive pomace pellets**

The process of extracting the olive oil from olives traditionally starts with cleaning the olives and removing the stems, leaves and twigs left with the olives. The second step is crushing the olives into a paste. The purpose of crushing is to tear the flesh cells to facilitate the release of the oil from the vacuoles.

The next step consists in separating and filtering the oil from the rest of the olive components. The filtered oil is a so-called extra virgin olive oil. (Olive Oil Source 2015)

The residues that remain after the virgin olive oil extraction process are called olive pomace or olive cake. (Figure 20)

But the whole process of extracting doesn't stop here. After the first and high quality olive oil is separated from the rest of the olive components, another phase of extraction can start. This phase consists of extraction the remaining oil from the olive pomace, from where approximately 5-8% of the oil can be additionally extracted. The oil extracted on this way is so-called olive pomace oil.

Olive pomace is a byproduct of the olive oil production process and is a premium quality agricultural biomass fuel. The olive fruit with 12-30% oil content means in biomass terms that the total waste generation is nearly 75% of the olive harvest. Based on the olive cultivar about 4 to 8 kilos of olives are needed to produce just 1 liter of olive oil. But briefly every liter of olive oil produced results in roughly 5 kilos of waste-olive pomace. (WPM 2015)

Olive pomace is a dark colored paste consisting of crushed olive pits (also called olive stones or kernels), olive husk/skin, pulp, some pomace oil and waste waters. Sometimes the pits are separated from the vegetable parts and waste waters. The olive pits are a form of solid biomass and can be burned directly.

The olive pomace is processed, dried and formed into pellets (Figure 21), with the following characteristics: (Table 14)

Figure 20 Olive pomace (WPM 2015)

Figure 21 Olive pomace pellets (WPM 2015)

Table 14 The characteristics of olive pomace pellets (Oliveketts 2015)

Size:	Small pieces 1-3 cm
Calorific value:	17 - 19 MJ
Moisture (humidity) :	~ 10%
Oil Content :	below 3%
Ash content :	6-10%

3.7 Financing the retrofit measures

Croatian education system is mainly financed and managed by the public sector. Unlike universities who besides being financed by the state usually generate their own income, primary and secondary schools always depend on the state funds.

This means that each school gets a certain amount of money each year that is mostly spent on the wages of employees, energy bills, computerization of primary schools and equipping the libraries.

For any bigger investment, the school has to seek for additional funds, which can take years.

Financial models can be divided into two categories: traditional and new ways of financing.

3.7.1 Traditional ways

- *Ministry of Environmental and Nature Protection* which provide subsidies for energy refurbishment of the buildings (possible to get 40 to 80% of grants)
- *Environmental Protection and Energy Efficiency Fund (together with European Regional Development Fund)* opened a call for funds ensured for 2015 - for energy refurbishment and use of renewable resources in educational institutions that can get up to 95% of grants
- *Croatian Bank for Reconstruction and Development (HBOR)* offers loans for public and private entities investing in energy efficiency and renewable energy projects. Minimum loan is 13000 € and loans can cover up to 75 % of the estimated investment value without VAT
- *EU Means :* European Investment Fund (EIF), European Investment Bank (EIB), Structural funds

3.7.2 New way of financing RES projects – crowdfunding

Crowdfunding is the practice of funding a project or venture by raising monetary contributions from a large number of people, typically via the internet.

There are basically four different types of crowdfunding: donation, reward, equity and debt.

In *donation-based* crowdfunding, the crowd gives money or some other resource because they want to support the cause.

In *reward-based* crowdfunding, individuals forming the crowd give money to a business in exchange for a “reward,” typically the product or service that that particular company produces or provides. Reward-based crowdfunding has been made popular by crowdfunding sites such as Kickstarter and Indiegogo.

With *equity-based* crowdfunding, members of the crowd become part-owners of the company or of the project for which the funds are being raised. In other words, the company sells some or all of its shares to the members of the crowd. As equity owners of the company, the crowd realizes a return of its investment and, assuming the company performs well, receives a share of the profits, in the form of a dividend or distribution.

Debt crowdfunding is the last type. In this type of crowdfunding, the company raising money does not sell shares, but instead borrows money from the crowd. The individuals lending the money receive the company's legally binding commitment to repay the loan at certain time intervals and at a certain interest rate.

4 RESULTS AND DISCUSSION

4.1 Overview

This chapter presents the simulation results performed with EDSL TAS software – building modelling and simulation tool. The results are divided into three main sections. Firstly, the building's total energy demand is showed. This includes electricity consumption and heating demand. The electricity consumption simulation results are presented for Scenario 1 in comparison to Base case. The heating demand simulation results are presented for two scenarios (S1 and S2) of thermal refurbishment in comparison to BC.

Further, the solar system output is presented, as well as calculations for biomass. Finally, financial costs for each measure are estimated. In the last paragraph the case study building is described as the eligible energy producer that sells the energy produced by the solar system to the grid.

4.2 Building's Total Energy Demand

In order to create an energy consumption pattern for the Base case (BC) it was necessary to talk to the school's responsible and collect the energy records from EMIS, information about energy consumers, its installed power and working hours.

Scenario 1 (S1) includes the retrofitting of outdated lighting system with energy saving one and the change of single glazed windows and doors to energy efficient ones according to the Passive House standard.

The replacement of the existing 204 bulbs on incandescent filament (of 75 and 100 W) with 204 CFL bulbs brought significant savings in annual energy consumption of 17717 kWh per year.

The detailed list of existing and proposed luminaires and the corresponding savings is shown in a Table 15:

Table 15: The replacement of ILB with CFL and the corresponding savings

	Type of luminaire	N. of luminaires	Installed power [kW]	Annual consumption [kWh]
Installed system	ILB 75 W and 100 W	204	19.8	22910
New system	CFL 30 W	204	4.49	5193
Savings	Savings in installed power [kW]			15.31
	Savings in annual electricity consumption [kWh/annual]			17717

The replacement of existing 147 T-8 tubes with 147 T-5 tubes also brought savings in annual energy consumption with the total of 4724 kWh per year. The detailed list of existing and proposed luminaires and the corresponding savings is shown in a Table 16:

Table 16 The proposed replacement of T-8 with T-5 tubes and corresponding savings

	Type of luminaire	N. of luminaires	Installed power [kW]	Annual consumption [kWh]
Installed system	T-8 FL 2x18 W	48	2.14	1850
	T-8 FL 4x18 W	23	2.12	1693
	T-8 FL 2x36 W	67	6.08	8176
	T-8 FL 3x36 W	7	0.97	1188
	T-8 FL 4x36 W	2	0.37	422
New system	T-5 FCE 2x14 W	48	1.42	1232
	T-5 FCE 4x14 W	23	1.37	1092
	T-5 FCE 2x28 W	67	3.89	5229
	T-5 FCE 3x14 W	7	0.62	767
	T-5 FCE 4x28 W	2	0.24	285
Savings	Savings in installed power [kW]			4.14
	Savings in annual electricity consumption [kWh/annual]			4724

In total, the estimated annual electricity consumption after the first step refurbishment decreased for 30% from the BC. (Table 17)

Table 17 Electricity demand before and after refurbishment

Electricity demand (BC)	Electricity demand (S1)
73594 kWh	51823 kWh

The Figure 22 shows the comparison in between BC and S1 electrical energy demand on a monthly basis, while the monthly values and comparisons can be found in (Appendix 7.7.)

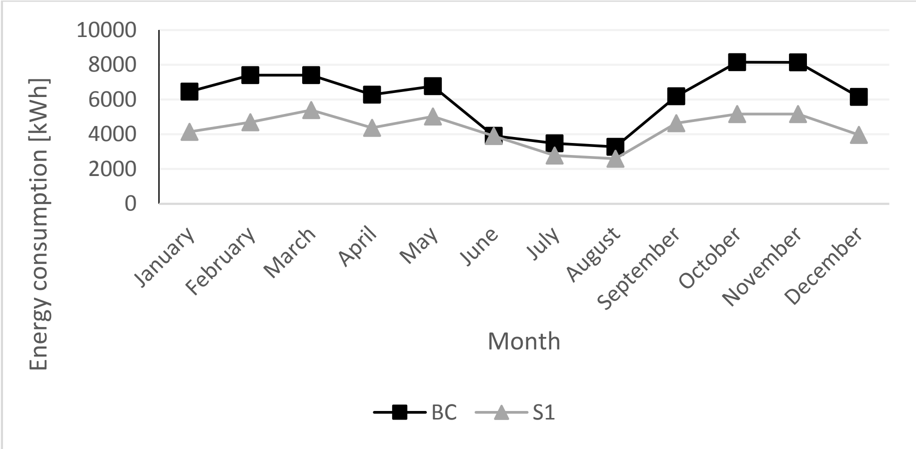


Figure 22 Electricity consumption – comparison for BC and S1

4.2.1 Comparison of daily profiles

In order to fully understand energy consumption of the building, the daily average electricity profile was made. Daily consumption in BC is an assumption based on interview with the school authorities and a list of energy consumers and their working times (Appendix 7.2.).

For this purpose, three typical days were selected from three different months: June as summer month, July as the month when the school is partially closed and November as winter month.

The figures below follow a general trend when the profile starts rising at the certain point of the day (6.30 am) and continues to increase until the building opening hours (7 am), to its peak value at 10 am in every month. There is a decrease at 11 am (lunch break) when pupils are out of the building. After that, the winter month marks the consumption increase till 2.30 pm. On the other hand, summer months mark decrease in consumption due to the fact that lighting is off during the afternoon period.

At 3 pm, the school is closed, and the consumption returns to its low base level of 2kWh in winter month and 1kWh in summer months.

June is taken into consideration as the summer month that doesn't have high lighting demand because of longer and brighter days. The need for lighting is noted in morning hours, due to the shade coming from the nearest botanical garden.

Figure 23 shows the electricity consumption before and after refurbishment. The refurbishment in S1 brought ca 23% of savings in electricity consumption. (Table 18)

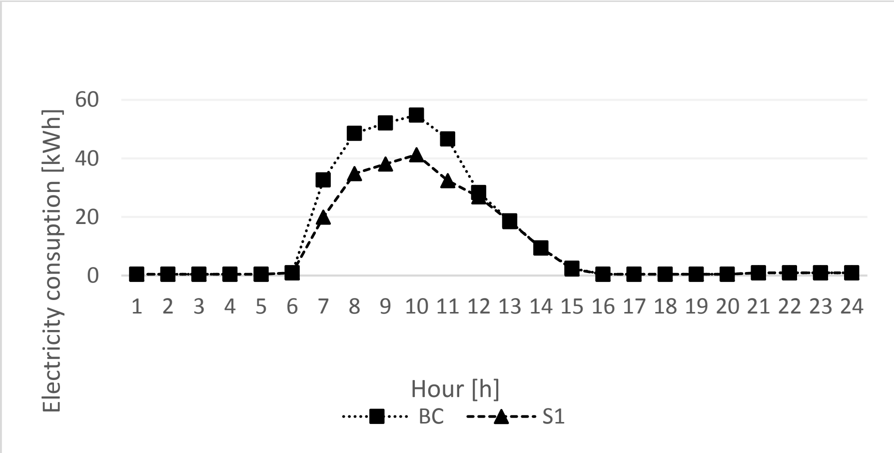


Figure 23 Daily electricity consumption for June - BC and S1

Table 18 Electricity consumption for BC and S1 (month of June)

BC	**S1**
302 kWh	232 kWh

The month of **July** is chosen as "holiday" month in the school year; but this doesn't mean that the school remains completely closed. In the first part of the month (first two weeks), the school is opened for teachers and small number of pupils, mainly for those who come for prolonged classes and correction term. Other than that, teachers have teaching sessions for the end of the school year. During the working part of the month the consumption is mainly distributed from 7am till 12 am (Figure 23), and after that decreases. The peak consumption occurs at 10 am.

The Figure 24 shows the daily electricity consumption before and after refurbishment. The refurbishment in S1 brought ca 14 % of savings in electricity consumption. (Table 19)

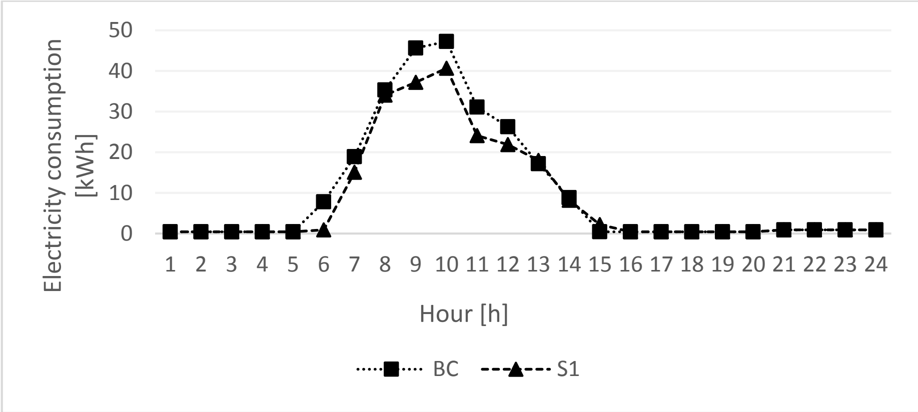


Figure 24 Daily user profile for July - BC and S1

Table 19 Electricity consumption for BC and S1 (month of July)

BC	S1
246 kWh	210 kWh

As for the winter month, the month of **November** was chosen, as a month that has constant and high energy consumption during working hours. During this month the lighting is constantly on (in the school building and in the sports hall), electric heaters and split systems for heating as well.

The Figure 25 shows the electricity consumption before and after refurbishment. The refurbishment in S1 brought ca 39 % of savings in electricity consumption. (Table 20)

Table 20 Electricity consumption for BC and S1 (month of July)

BC	S1
398 kWh	241 kWh

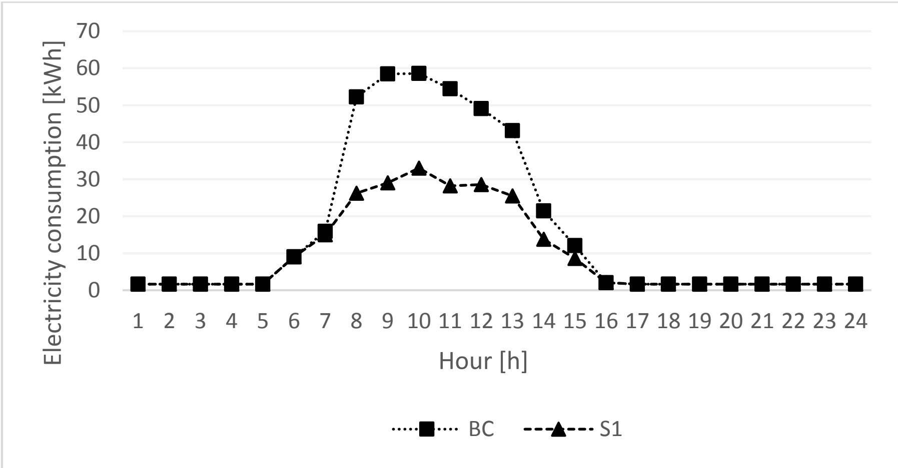


Figure 25 Daily user profile for November - BC and S1

From the three typical days in three different months of the year, it is noted that the month of November has the highest savings due to the refurbishment of lighting system. In this month, the lighting system is constantly in use during the working hours, unlike the two summer months, when the lighting is a minor electricity consumer.

4.3 Heating demand

This section presents the heating demand simulation results for all three scenarios proposed for thermal refurbishment. The results of dynamic simulation for a year-long period contain sets of hourly data, summed in monthly and annual values as presented in the following graphs in this chapter.

The following is a brief guide on the developed scenarios in terms of opaque part of the building envelope of the study case building: Base case (BC) represents current state of the building with the current building envelope thermal quality. Scenario 1 (S1) represents the limited interventions on the building: the change of outer openings - windows and doors according to the Passive standard. Scenario 2 (S2) represents improvement of the building envelope according to the Passive House Standards.

Both scenarios of thermal refurbishment, S1 and S2 show significant reduction in terms of heating demand. (Figure 26) The obvious expectation that a Passive House standard building will have the lowest heating demand is proofed in the following figure:

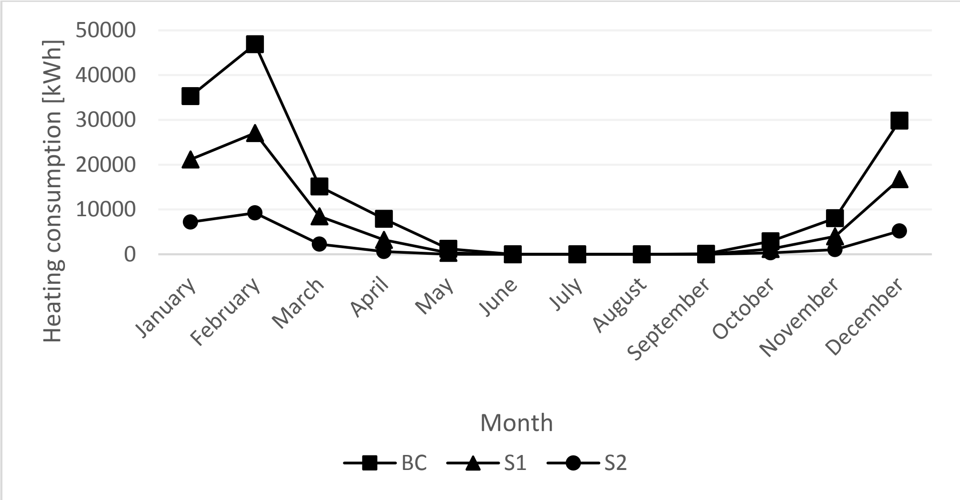


Figure 26 Heating demand, comparison BC-S1-S2

The heating demand occurs in winter months, from October to April, and in that period significant savings can be accomplished.

The comparison of the annual heating demand trough all three scenarios is given in the Table 21:

Table 21 Heating demand in all three scenarios

BC	S1	S2
147259 kWh	82244 kWh	25835kWh

Comparison of the three scenarios according to the kWh/m2 of heating demand:

Table 22 Heating demand according to kWh/m2 in all three scenarios

BC	S1	S2
63 kWh/m2	35 kWh/m2	11 kWh/m2

The comparison shows that heating demand in S1 decreased for ca. 44% compared to BC. The best case scenario, S2 records the decrease of 82% according to BC scenario.

Results of the monthly heating demand according to the three proposed scenarios can be seen in Appendix 7.8.

4.4 Renewable energy on site

This chapter shows the output results of photovoltaic system on site and its potential to cover the annual electricity demand, as well as the calculation of available biomass from olive pomace and its potential to cover the building's annual need for heating.

4.4.1 PV electricity generation

On the basis of the weather file for typical year, the photovoltaic electricity generation is calculated. The software calculated the data hourly, which were then summed up to monthly and annual total.

By covering the most of the roof area (Figures 27 and 28) with photovoltaic panels with the surface area of 641 m2, the total electricity production comes up to 52002 kWh. (Appendix 7.9.)

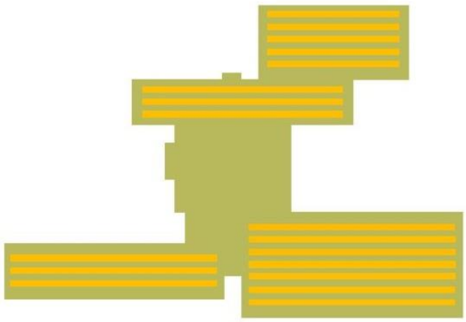


Figure 27 Installed PV on the roof (from above)

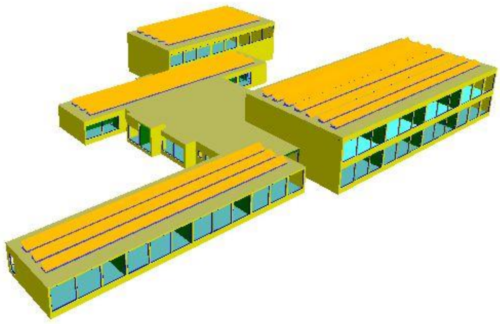


Figure 28 Installed PV on the roof 3D model

The figure below shows the total energy production by PV system throught the months. The monthly energy production can be seen in Appendix 7.10.

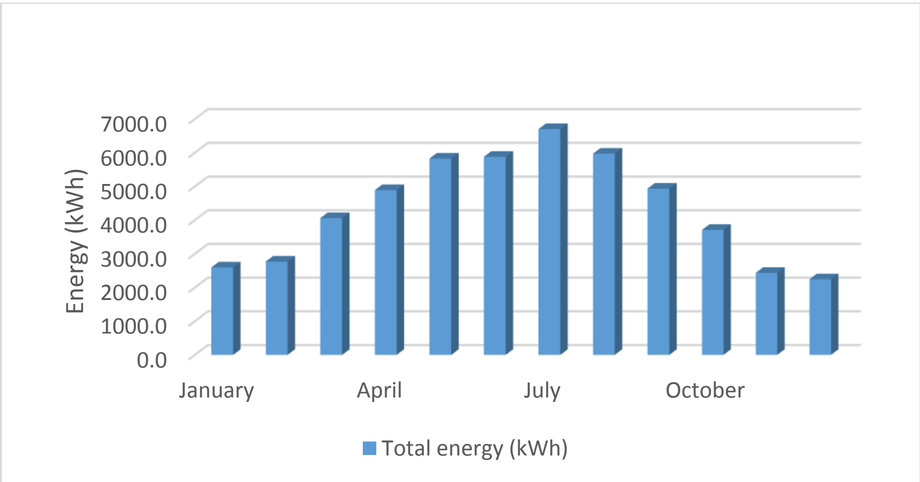


Figure 29 Monthly PV production in kWh

4.4.2 Electricity consumption / PV production on site

As defined before, the retrofit of lighting system brought significant savings in electrical consumption of the building, and consequently lowered the electricity bills. The purpose of installing PV system is to try to cover the annual energy demand of the building.

Table 23 Electricity demand (S1) and PV output

	S1	PV output
January	4141	2594
February	4693	2769
March	5393	4058
April	4376	4889
May	5022	5822
June	3900	5878
July	2780	6700
August	2591	5971
September	4642	4934
October	5163	3709
November	5160	2434
December	3962	2244
Total:	**51823**	**52002**

From the Table 23 it is clear that there is electricity production through the whole year, but the peak occurs in summer months from May till September. The comparison of the electricity demand and production shows that this area of PV can produce just the same amount of kWh as the building needs.

It is also notable from the Figure 30 that the PV production can't cover the monthly electricity needs of the building. It can only cover summer month's demand (April-September), with its peak production in July. The school remains mostly closed during June, July and August when the PV produces surplus of energy.

In this case a grid-connected photovoltaic power system is the best option, since it is possible to sell the energy to the local energy supplier.

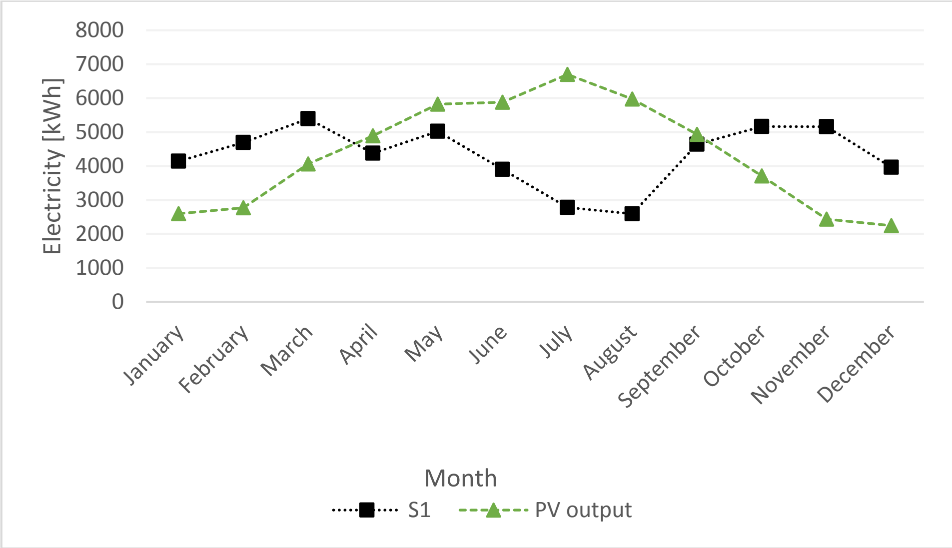


Figure 30 Monthly electricity demand and PV output

- **Electricity consumption / PV production on a daily basis**

As seen from the previous chapter, the energy generated by a PV is not enough to cover the consumption on monthly basis during winter months. Still, it is necessary to check if it can cover some of the typical operating days after the refurbishment in S1.

The three typical days from months of June, July and November were taken as an example.

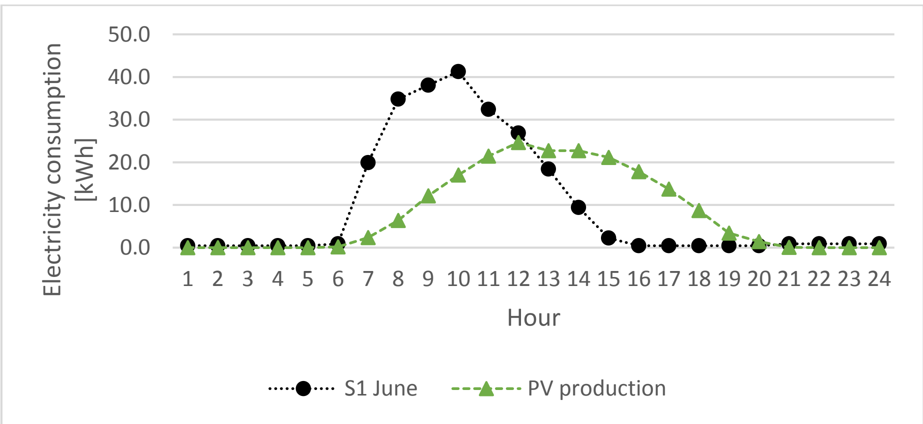


Figure 31 Daily average electricity demand and PV production (June)

Daily electricity consumption: **232 kWh**

Daily PV production: **196 kWh**

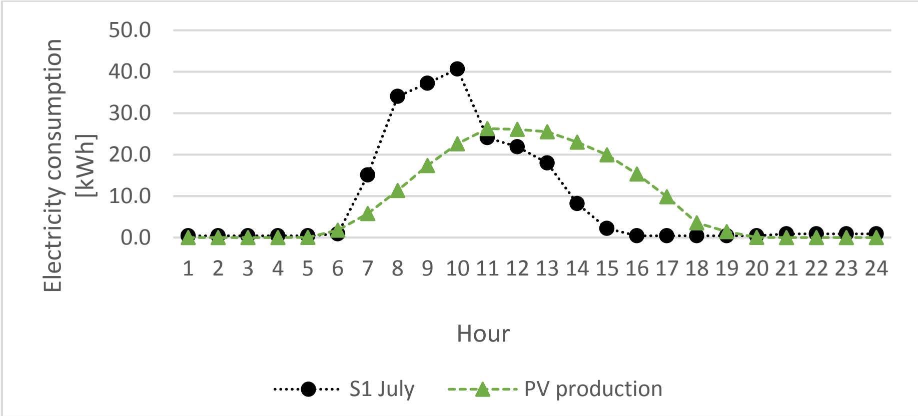


Figure 32 Daily average electricity demand and PV production (July)

Daily electricity consumption: **210 kWh**

Daily PV production: **210 kWh**

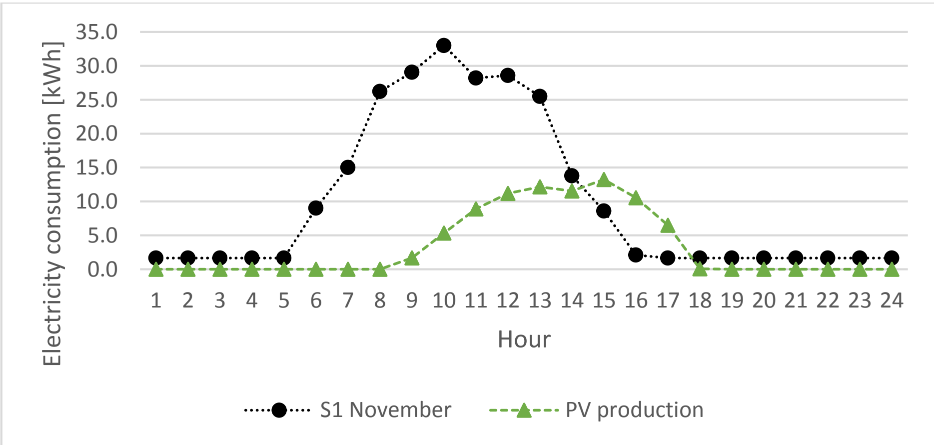


Figure 33 Daily average electricity demand and PV production (November)

Daily electricity consumption: **241 kWh**

Daily PV production: **81 kWh**

Figures 31, 32, and 33 demonstrate that the energy generated by a PV is not enough to cover the typical operating day in school for the months of June and November. In case of June, the PV production can cover 84% of daily needs for electrical energy. As for the month of November PV production in that winter period, when the production is lower, can cover only 1/3 of daily electricity needs. Energy generated from PV can cover the typical day in July, or produce exactly the same amount as demand is. The PV's interaction with the grid will be described in the following chapters.

4.5 Biomass potential for heating

From the responsible in school's garden, it is found out that in average year each olive tree gives 20 – 30 kg of olive fruit.

If the mean value of 25 kg is taken into calculation it means that school gets 4,250 kg of olives every year.

170 olive trees x 40 kg = 4250 kg

If calculated that the total waste generation is nearly 75% of the olive harvest, the number of 3188 kg of olive pomace is given.

3188 kg x 75% = 3188 kg of pomace

1kg of olive pomace pellets has value of 5 kWh, which means that available amount of pomace on site has value of 15940 kWh.

3188 kg x 5 kWh = 15940 kWh

Since the olive grove is getting older and consequently the olive crop will get lower with years, it shouldn't be the problem for the school to acquire the pomace for free from the nearby producers or from the energy cooperative whose member it is. The olive residues are not yet recognized as a valuable energy source, but still treated as a waste and not as secondary product in the Dalmatian region, as well as in the rest of Croatia. Some mills deposit pomace in the mill vicinity or release it in the environment. There are very few cases of using pomace for energy purposes.

From the financial point of view - pellets, chips and olive pomace are at least 50% cheaper compared to extra light fuel oil (ELFO).

Compared energy values:

1 l of ELFO = 10 kWh

1kg of pellets = 5 kWh (depending on moisture content)

The advantage of this energy source is that biomass boilers can be installed in an existing boiler room. Given the size of the boiler room and the free space in the immediate vicinity, it is possible to set one container of pellets with size of 5 to 10 m3 of which can fit 4-8 tons of pellets.

After the refurbishment applied in Scenario 2 (S2) it is calculated that the heating demand is 25835 kWh annually, as seen in chapter 4.3. The amount of olive pomace that the school gets from its olive garden is lower than the heating demand of the building. (Table 24)

Table 24 Comparison of heating demand in S2 and biomass production on site in kWh

Heating demand S2 (kWh)	Biomass production (kWh)
25835	15940

4.6 The costs of the measures for refurbishment

This chapter examines how much of financial resources the school needs to implement the proposed measures for achieving net-zero energy building. The summary of the measures and needed investment is calculated in Tables below.

The tables of all investments are divided into three groups: the retrofit of the lighting system (Table 25), the thermal insulation of the opaque part of the building envelope (Table 26) and the implementation of PV system and the change of existing boiler on ELFO with the one on pellets. (Table 27) The prices are taken from the price list of the producers, or found out from the repairer specialized in certain area (installation of biomass tank).

From the tables below it is visible that the implementation of PV system and the reconstruction of heating system would cost the most, 63026 €. The total cost of all proposed measures would be 131221 €.

Table 25 Investment calculation for the retrofit of the lighting system

Measure	**Description**	**Unit price (€)**	**Quantity**	**Estimated cost (€)**
Change of incandescent lamps	Lamp CFL 30W/827	7.3	204	1496
Change of ILB lamps	Removal of the old lamp and the installation of new	6.6	119	785
	Lamp FCE 14W, T5	3.6	188	677
	Lamp FCE 28W, T5	4.3	107	460
	Lamp FCE 2x14 W	36	94	3384
	Lamp FCE 1x28 W	36	7	252
	Lamp FCE 2x28	38.6	43	1660
The change of lighting in the sports hall	Removal of the old lamp and the installation of new	10.6	28	297
	Lamp FCE 2x28W	64	28	1792
	Lamp FCE 28W, T5	4.2	56	235
Total:				**11038**

Table 26 Investment calculation for the thermal insulation of outer envelope

Measure	Description	Unit price (€/m2)	Area (m2)	Estimated cost (€)
The change of windows	Removal of existing windows	3.3	25	83
	Purchase and installation of new windows	146	25	3650
Flat roof insulation	The implementation of thermal insulation	34.6	966	33424
	The refurbishment of the existing hydro insulation	20	600	20000
Total				**57157**

Table 27 Investment calculation for the implementation of PV system and biomass boiler system

Measure	Description	Estimated cost (€)
PV modules	PV modules	10284
	AC inverter	2206
	Construction and mounts on the flat roof of the school	2189
	Cables, connectors, bonds	749
The change of heating system	Disassembly of the existing boiler, the entire pipe distribution within the boiler in the heating system distributors	10000
	Boiler on biomass from 300kW	5762
	Pellet burner with regulation	10440
	Pellet supply transporter	4840
	Device for the production of compressed air	873
	An air compressor	1307
	Cyclone, fan, controller, sensors	2711
	Installation of biomass boilers and storage tanks heat	3200
	Release of a biomass boiler in operation	400
	Divider	533
	Collector	533
	Shut-off and regulatory valves	2666
	Installation of other elements in the boiler room	1000
	Chimney reconstruction	3333
Total:		63026

In the Methodology chapter (Section 3.7), the traditional and new ways of financing retrofit measures were described. Since the Croatian Environmental Protection and Energy Efficient Fund together with the European Regional Development Fund have a call for energy refurbishment and use of renewable sources in educational institutions that can get up to 95% of grants, this seems like the best option to finance the proposed measures.

On this way the school would be able to get 95% of €131221, which amounts to €124659. The additional 5% or € 6562 could be co-financed by the Croatian Educational system, or the school could try crowdfunding.

4.7 School as energy producer

In the summer months, when the school is closed and the demand for energy is decreased, the surplus energy produced by PV goes directly into the city's electrical grid. On this way school becomes an eligible electricity producer.

An eligible producer is a subject that in an individual facility produces both electricity and thermal energy, using waste or renewable energy resources in an economically viable manner consistent with environmental protection.

According to the Regulation on Incentives for the production of electricity from renewable energy sources and cogeneration (Official Gazette no. 33/07, 11/08, 128/13), adopted by the Croatian Government, from 1 July 2007 began with guaranteed feed-in-tariff for production from renewable energy sources and cogeneration of all electricity customers in the Republic of Croatia.

Under the new Tariff System for the production of electricity from renewable energy sources and cogeneration, Official Gazette no. 133/13 an incentive price of 1 kWh of electricity in integrated solar power plants up to 10 kW, without the use of thermal solar collectors is 0.25 €.

The Table 28 shows the amount of energy generated by PV system, and the annual income when sold to the grid with the price of 0.25 €.

Table 28 The demonstration when selling produced energy by PV into the grid

Annual energy production from PV [kWh]	kWh	52002
Feed-in tariff item for electricity production (integrated photovoltaic system)	€ /kWh	0.25
Annual income from generated electricity	€	13000

On the other hand, when buying the electricity from the national electricity company (HEP), users of public services (like case study building is) apply to tariff determined in accordance with the "Methodology for determining the amount of tariff items for a guaranteed supply of electricity".

When buying the electricity from the national energy company (HEP), the price of 1kWh costs 0.17 €.

If the school would buy the same amount it can produce by PV on its own roof (52002 kWh) from HEP, the calculation would look like in Table 29.

Table 29 The demonstration when buying the electricity from the grid

Electricity bought from the grid	kWh	52002
Tariff item	Euro/kWh	0.17
Annual cost for bought electricity	Euro	8840

These two tables show that the selling price is higher than the purchasing price, which brings to the conclusion that the best option for the school is to sell the produced energy to the local electrical grid, and then buy it from the national operator. In that case, the school would earn some money on differences in prices, as shown in the Table 30

Table 30 Differences in prices (sold electricity vs. bought electricity)

Annual income from sold electricity into the grid	13000 €
Annual cost for bought electricity from the national energy operator (HEP)	8840 €
Difference (annually):	4160€

4.8 The benefits of net-zero school

As mentioned in the definition of Sustainable development, and its triangular approach, there are many benefits of sustainable development. This section deals with the benefits of energy independent school for the school itself and for the local community.

4.8.1 The benefits for the school

Energy independence of the school will contribute to energy saving on local level and encourage the exploitation of locally available resources, reduce electricity and heating costs, reduce emissions and increase the comfort of the building.

Money saved on energy bills can be invested into school equipment, computer labs, books for school library, excursions and better education in general. On this way children will be more motivated to change their behaviour towards energy, and to save more.
A healthy, productive learning environment with better indoor air quality will bring more concentrated pupils and increase occupant's satisfaction.

4.8.2 The benefits for the local community

Energy independent public buildings (for example schools) have multiple benefits on local sustainable development. Many cities and counties are combining planning and sustainability activities to balance local growth, energy use, and goals for a healthy environment, and in this way to fulfil the three pillars of sustainable development.

Having an energy independent school means that someone will have to maintain the systems and the building in general, so it is highly possible that the new jobs will be created.

The local people will become united in goal to develop the local community on sustainable way and keen to do more such projects.

Energy independency of the whole Split-Dalmatia county can be a way to go in the future: with great geographical position, higly motivated locals and educated children, the sustainable development shouldn't be in question.

Anyway, the future of sustainable energy sector rests in a number of small, locally distributed renewable energy sources, owned by local communities, and providing them with direct benefits.

5 CONCLUSION

The aim of this study was to examine the potential to reach energy independent or net-zero energy public building – elementary school in the south of Croatia. For this purpose two scenarios were simulated in EDSL TAS software in order to satisfy a net-zero energy concept. The first scenario deals with the refurbishment of lighting system and the change of windows and doors on the building. In the second scenario, the thermal refurbishment of the opaque part of the building envelope was applied. The goal of both scenarios was to lower the energy demand of the building.

Furthermore, the locally available renewable sources were introduced: the photovoltaic system was applied in order to cover building's electricity demand and biomass from olive pomace in order to cover the heating demand. Finally, the investment cost were calculated for each proposed measure.

The simulation demonstrates that the refurbishment of the lighting system brings 30% reduction in electricity consumption compared to the current state of the building. But what is more important, the proposed energy saving bulbs have longer life span and consume less energy than the outdated bulbs on incandescent filament, as well as bring higher illuminance and healthier environment for the building users.

Another simulation, the thermal improvement of the opaque part of the building envelope, showed- as expected- a notable lower heating demand compared to the current state. Savings from 44% to 82% can be achieved if just the building thermal envelope and windows are improved according to the Passive House standards.

The photovoltaic system of 641 m2 of collector area produces about 52002 kWh electricity per year, which is enough to cover the building's annual electricity demand. The whole energy produced by the system will be sold to the local electrical grid, and then bought by the national energy supplier. In this way the school becomes eligible electricity producer, and falls into feed-in tariff system.

The biomass produced from the school's olive grove amounts to ca. 3188 kg annually or 15940 kWh, which is not enough to cover the heating demand simulated in the best case scenario with the result of 25835 kWh. Since the school is a part of the local energy cooperative which has 300 tons of olive pomace at their disposal annually, it shouldn't be a problem to obtain as much as needed for free.

Since the schools in Croatia depend on the state funds, the financial costs for proposed measures were carried out, as well as the possibilities for financing. The Environmental Protection and Energy Efficiency Fund together with the European Regional Development Fund has a call for energy refurbishment and use of renewable resources in educational institutions that can get up to 95% of grants. This seems like the best option for now.

The output result seem to confirm the initial intention – the achievement of net-zero energy building, good example of local sustainable development and the great example to the other educational buildings to choose the way of energy independency and by that teach their students responsible behavior towards energy and environment.

6 REFERENCES

Berggren, B., Hall, M., Wall, M., 2013. LCE analysis of buildings – Taking the step towards Net Zero Energy Buildings. In *Energy and Buildings 62,* pp. 381-391

Dragun, G., 2011. Komina- visokovrijedno organsko gnojivo (Pomace - highly valuable organic fertilizer). Zadarski list, 3rd of December, Online edition. Available from: http://www.zadarskilist.hr/clanci/03122011/komina---visokovrijedno-organsko-gnojivo

Green Peace, 2011. *Solar generation 6. Solar photovoltaic electricity empowering the world*. Internet. Available from: http://www.greenpeace.org/international/Global/international/publications/climate/2011/Final%20SolarGeneration%20VI%20full%20report%20lr.pdf Accessed: 1.07.2015.

Gul, M.S., Patidar, S. 2014. Understanding the energy consumption and occupancy of a multi-purpose academic building. In: *Energy and Buildings 87,* pp. 155-165

EDSL TAS. 2012a. *Software Vesion 9.2.1.3.* Environmental Design Solutions Limited, Great Britain

EDSL TAS. 2012b. TAS Manual. Environmental Design Solutions Limited, Great Britain

Energy Community. Biomass *Consumption Survey for Energy Purposes in the Energy Community; Croatia-National Report.* Internet. Available from: https://www.energy-community.org/portal/page/portal/ENC_HOME/DOCS/1378190/ECS_Biomass_Consumption_Study_Croatia__FINAL.pdf Accessed: 2.05. 2015.

HBS. Heinrich Boell Stiftung. *Green New Deal - North-Adriatic Coastal Area as a 100% Renewable Electricity Region (unpublished)*

Jaramillo-Nieves, L.; Del Río, P. Contribution of Renewable Energy Sources to the Sustainable Development of Islands: An Overview of the Literature and a Research Agenda. *Sustainability* 2010, *2*, 783-811.

MINGO. 2009. Ministry of Economy, Labour and Entrepreneurship. *Energy strategy of the Republic of Croatia.* Internet. Source available from: http://weg.ge/wp-content/uploads/2013/05/Croatia-Energy-Strategy-2009.pdf

MINGO. Ministry of Economy, Labour and Entrepreneurship. RES interactive map. Internet. Available from: http://oie-aplikacije.mingo.hr/InteraktivnaKarta/ Accessed: 2.07. 2015

Olive Oil Source. *Extraction Process*. Internet. Available from: http://www.oliveoilsource.com/page/extraction-process Accessed: 20.07.2015

Olivketts. *Olive Biomass for Energy. The most efficient alternative to coal.* Internet. Available from: http://www.olivketts.com/biomass.html Accessed: 15.07.2015

Stari Grad Municipality. *Olive cultivation.* Internet. Available from: http://www.opcina-starigrad.hr/HTML/Uzgoj_maslina.html Accessed: 15.07.2015.

Runko Luttenberg, 2014. *Technological challenges in environmental protection.* Internet. Source from: http://bib.irb.hr/datoteka/702741.Runko_Luttenberger_dit2014.pdf Accessed: 5.03. 2015.

UNDP, 2013. United Nations Development Programme. *Programming Sustainable Local Development: A Handbook for Eastern Europe and Central Asia.* Internet. Source available at: http://www.scribd.com/doc/192730300/Programming-Sustainable-Local-Development-A-Handbook-for-Eastern-Europe-and-Central-Asia Accessed: 15.03. 2014.

UNDP, 2010. United Nations Development Programme. *A handbook for energy certification of building in Republic of Croatia http://www.encert-eihp.org/wp-content/uploads/2013/02/Prirucnik-za-energetsko-certificiranje-zgrada-1.pdf*

Talic at al. 2012. *Biomass in Croatia - Report on the situation of biomass (production, supply, use) as fuel in Croatia, and RES in education as an answer to renewable market demands.* Internet. Available from: http://www.adameurope.eu/prj/9352/prd/2/2/P-REPORT_CROATIA_E.pdf Accessed: 6.05. 2015.

UNEP SBCI. United Nations Environment Programme. *Buildings and Climate change: A summary for Decision-Makers.* Internet. Available from: http://www.unep.org/sbci/pdfs/SBCI-BCCSummary.pdf Accessed: 15.04. 2014.

Wikipedia. 2015. The free encyclopedia. Internet. Available from: https://en.wikipedia.org/wiki/Solar_energy_in_the_European_Union Accessed: 5.05. 2015.

WPM. Wood Pellet Morocco. *Making Olive Pomace into Fuel Pellets in Morocco.* Internet. Available from: http://www.wood-pellet-mill.com/Solution/making-olive-pomace-into-pellets.html Accessed: 15.07.2015.

Tulimax. Internet. Available from: http://www.htenerco.fi/index.php/en/bioenergy-heating/fuel-comparison Accessed: 3.05.2015.

Zeiler, W., Boxem G, 2013. Net-zero energy building schools. In *Renewable Energy*, 49, pp. 282-286.

6.1 List of tables

6.2 List of figures

7 APPENDIX

7.1 Electricity consumption – monthly values

Month	2009	2010	2011	2012	2013
January	3080	9080	9029	8990	8763
February	11920	11680	8781	7871	8851
March	6280	7640	8362	7734	7303
April	6920	7120	4965	6787	6718
May	5880	6440	5950	7024	5946
June	5000	4760	4800	4857	3910
July	3520	-	2311	3287	2899
August	2120	2001	2889	3124	3250
September	5240	12561	5936	7337	6808
October	6400	5931	7523	8239	7467
November	10160	8960	8527	8136	8688
December	9880	9029	8175	8080	7833

7.2 The list of electricity consumers

- **Lighting system**

Room	Type of luminaire	N. of luminaires	N.of lighting fixtures	Power of the luminaire (W)	Power of the ballast (W)	Total installed power (kW)	Working hours (h)	Total electricity consumption (kWh)
Boiler room	FL 2x36W	4	2	36	10	0.37	104	38
	ILB 100W	1	1	100		0.10	104	10
	FL 20W	1	1	20		0.02	104	2
Outdoor lighting	HLB 150W	3	1	150		0.45	156	70
Standard classroom (8,4 x 6,3 x v3,4)	ILB 75W	2	1	75		0.15	1230	185
	ILB 100W	12	1	100		1.20	1230	1,476
Classroom for informatics	FL 3x36W	4	3	36	10	0.55	1230	679
Classroom for engineering	FL 3x36W	3	3	36	10	0.41	1230	509
Entrance	FL 2x18W	12	2	18	5	0.55	800	442
Tolilets	FL 2x18W	3	1	18	5	0.07	1350	93
	FL 2x36W	3	1	36	10	0.14	1350	186
	ILB 100W	3	1	100		0.30	1350	405
Classroom (x 7)	ILB 100W	84	1	100		8.40	1230	10,332
	ILB 75W	14	1	75		1.05	1230	1,292
Hallway	FL 4x18W	8	4	18	5	0.74	800	589
Tolilets	FL 2x18W	2	2	18	5	0.09	1350	124
	FL 2x36W	2	2	36	10	0.18	1350	248
	ILB 100W	2	1	100		0.20	1350	270
Hallway	FL 2x18W	11	2	18	5	0.51	800	405
Classroom (x 4)	ILB 100W	48	1	100		4.80	1230	5,904
	ILB 75W	8	1	75		0.60	1230	738
Classroom	FL 2x36W	4	2	36	10	0.37	1230	453
Hallway	FL 2x18W	13	2	18	5	0.60	800	478
Archive room	ILB 100W	3	1	100		0.30	104	31
Archive room	ILB 100W	3	1	100		0.30	104	31
Tolilетes	FL 2x18W	2	2	18	5	0.09	1350	124
	FL 2x36W	2	2	36	10	0.18	1350	248
	ILB 100W	2	1	100		0.20	1350	270
Main hall	FL 4x18W	12	4	18	5	1.10	800	883
Office	FL 2x36W	1	2	36	10	0.09	1200	110
Teachers room	FL 2x36W	6	2	36	10	0.55	1200	662
Toliletes (x 2)	ILB 100W	4	1	100		0.40	1350	540
Principals office	FL 2x36W	2	2	36	10	0.18	1200	221
Office	FL 2x36W	3	2	36	10	0.28	1200	331
Hallway	FL 4x18W	3	4	18	5	0.28	800	221
Office	FL 2x36W	2	2	36	10	0.18	1200	221
Kitchen	ILB 100W	5	1	100		0.50	630	315
Library	FL 4x36W	2	4	36	10	0.37	1200	442
Hallway	FL 2x18W	4	2	18	5	0.18	800	147
Toiletes	ILB 100W	2	1	100		0.20	1350	270
Dressing room	ILB 100W	4	1	100		0.40	1350	540
Archive	ILB 100W	2	1	100		0.20	104	21
Sport hall (23,7m x 12m x h6,4)	FL 2x36W	28	2	36	10	2.58	1600	4,122
Office	ILB 100W	1	1	100		0.10	1200	120
Office	FL 2x36	6	2	36	10	0.55	1200	662
Entrance	FL 2x18	1	2	18	5	0.05	800	37
Outside entrance	FL 2x36	4	2	36	10	0.37	1825	672
Total:						**31.49**	**1,011**	**36,170**

- **Electrical appliances**

Electrical appliances	N. of units	Power of the unit (W)	Total power (kW)	Working hours (h)	Total electricity consumption (kWh)
PC + monitor	30	300	9	1440	12960
Projector	3	200	0.6	500	300
TV	9	300	2.7	400	1080
Video device	1	150	0.15	400	60
Split system	2	1700	3.4	800	2720
Printer	3	200	0.6	600	360
Electric water heater	2	2000	4	1120	4480
Fridge	3	1200	3.6	1095	3942
Coffee machine	1	800	0.8	132	105.6
Electric water heater	2	1500	3	1120	3360
Microwave	1	800	0.8	132	105.6
Coffee machine	1	800	0.8	1092	873.6
Printer	1	1200	1.2	600	720
Split system	2	1500	3	960	2880
Split system	1	1300	1.3	800	1040
Electric heater	1	2000	2	900	1800
Electric oven	1	2000	2	400	800
Water cooker	1	1000	1	600	600
Heating system consumers	1	2400	2.4	1450	3480
Total			**42.35**		**41666.8**

7.3 The lighting system (bulb types)

	Type of luminaire	N. of luminaires	N.of lighting fixtures	Power of the luminaire (W)	Power of the ballast (W)	Total installed power (kW)	Total electricity consumption (kWh)
Flourescent lighting	FL 2x18W	48	2	18	5	2.14	1,850
	FL 4x18W	23	4	18	5	2.12	1,693
	FL 2x36W	67	2	36	10	6.03	8,175
	FL 3x36W	7	3	36	10	0.97	1,188
	FL 4x36W	2	4	36	10	0.37	442
Incandescent light bulb	ILB 75W and 10	200	1	75, 100	-	50.89	22,910
Halogen light bulbs	HLB 150W	3	1	150	-	0.45	70
Compact fluorescent lighting	CFL 20W	1	1	20	-	0.02	2

7.4 ELFO bought through the years

Year	liters (l)
2009	15271
2010	16289
2011	17197
2012	6505
2013	10870

7.5 Typical year generated from Meteonorm

SPLIT\MARJAN
Location name

43.51
Latitude [°N]

16.43
Longitude [°E]

144450
WMO

122
Altitude [m a.s.l.]

IV, 1
Climate region

Standard
Radiation model

Standard
Temperature model

Perez
Tilt radiation model

2000–2009
Temperature period

1991–2010
Radiation period

Additional information

Uncertainty of yearly values: Gh = 3%, Bn = 5%, Ta = 0.3 °C
Trend of Gh / decade: -
Variability of Gh / year: 5.4%
Radiation interpolation locations: Satellite data

Month	G_Gh	G_Bn	G_Dh	Lg	Ld	N	Ta	Td
	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[octas]	[°C]	[°C]
January	71	105	36	7538	4466	5	8.1	0.3
February	93	119	45	9999	5510	5	8.4	0.1
March	146	139	74	15624	9010	5	11.5	3.4
April	198	162	101	21406	12243	5	15.4	7.3
May	247	214	113	26767	14126	4	21.0	10.6
June	264	217	120	29037	14975	5	24.8	13.8
July	278	262	107	30462	14029	4	27.4	14.7
August	237	238	87	26048	11337	4	26.9	15.2
September	183	186	81	20004	10467	4	21.5	11.7
October	116	138	52	12779	6851	5	17.8	10.4
November	72	97	37	7856	4794	5	13.1	5.9
December	57	104	25	6103	3389	5	9.4	1.7
Year	163	165	73	17802	9266	5	17.1	7.9

meteonorm

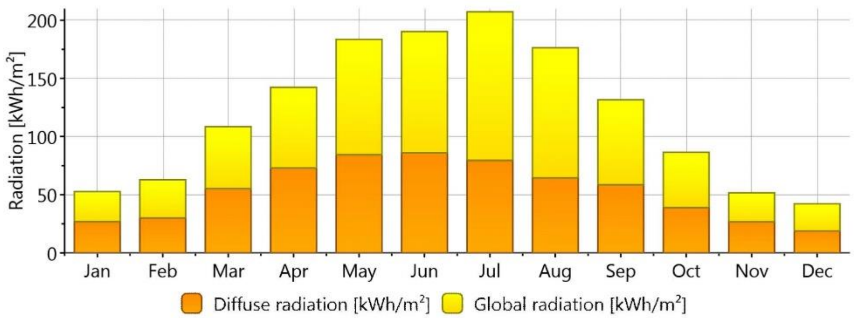
meteonorm V7.1.2.15160 1/4

7.6

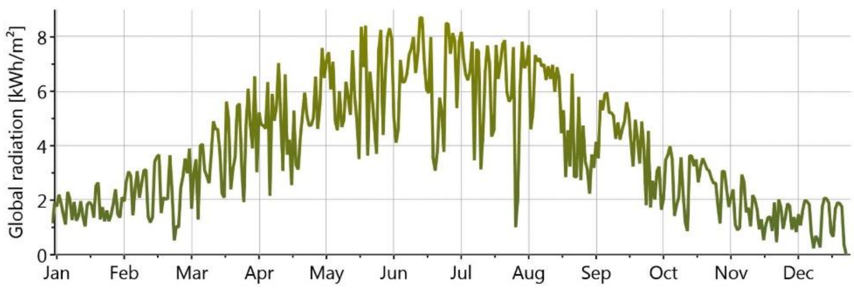
Month	RH	p	DD	FF
	[%]	[hPa]	[deg]	[m/s]
January	58	999	0	4.5
February	56	999	0	4.8
March	57	999	113	5.0
April	58	999	113	4.3
May	52	999	113	3.6
June	50	1000	0	3.2
July	46	1000	0	3.4
August	49	1000	0	3.2
September	54	1000	0	4.0
October	62	999	0	4.0
November	62	999	0	5.1
December	59	999	0	5.1
Year	55	999	20	4.2

Gh: Mean irradiance of global radiation horizontal
Bn: Irradiance of beam
Dh: Mean irradiance of diffuse radiation horizontal
N: Cloud cover fraction
Lg: Global luminance
Ta: Air temperature
RH: Relative humidity
Td: Dewpoint temperature
DD: Wind direction
FF: Wind speed
p: Air pressure

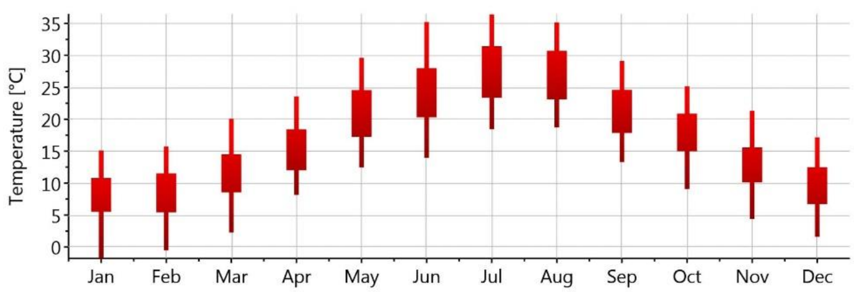
Monthly radiation



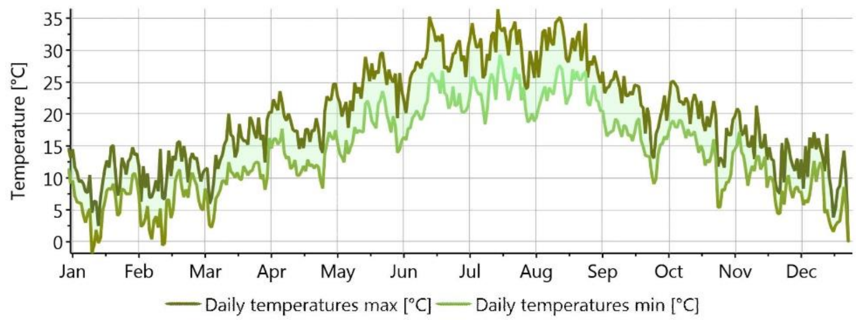
Daily global radiation



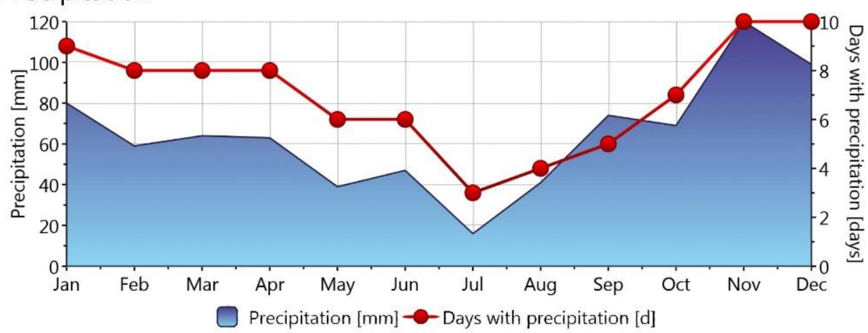
Monthly temperature



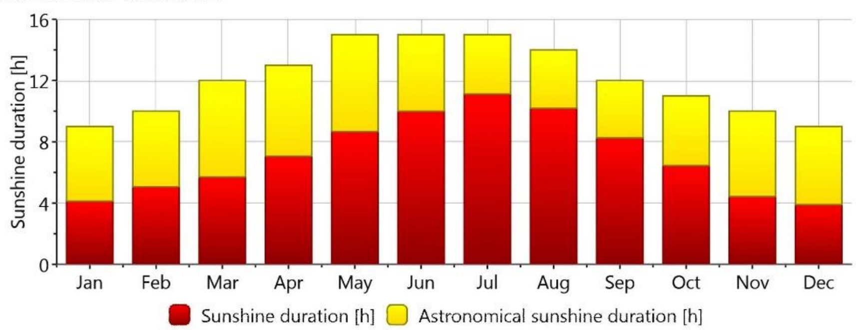
Daily temperature



Precipitation



Sunshine duration



7.7 Construction components for BC, S1, S2

• Base case

Construction	M-Code	Width(mm)	Conductivity(W/mC)	Vapour Diffusion Factor	Density(kg/m³)	Specific Heat (J/kg*°C)	U-Value(W/m²K)
Ceiling	ceramic tiles	5.0	1.3	9999.000	2300.0	1000.0	2.384
	r. concrete ceiling	200.0	2.2	100.000	2400.0	1100.0	
	plaster inside	10.0	0.68	10.000	1200.0	900.0	
	concrete screed	70.0	1.4	15.000	2000.0	1080.0	
Ground floor	ceramic tiles	5.0	1.3	9999.000	2300.0	1000.0	0.966
	floor coating	20.0	0.21	1.000	1400.0	1400.0	
	concrete screed	125.0	1.4	15.000	2000.0	1080.0	
	hydroinsulation	30.0	0.05	1.000	150.0	900.0	
	gravel	75.0	0.7	2.000	1800.0	1000.0	
Inside wall	plaster inside	10.0	0.68	10.000	1200.0	900.0	2.043
	brick	100.0	0.5	5.000	900.0	880.0	
	plaster inside	10.0	0.68	10.000	1200.0	900.0	
Outside wall	plaster inside	10.0	0.68	10.000	1200.0	900.0	1.74
	aerated concrete	100.0	0.3	6.800	320.0	1094.0	
	reinforced concrete	100.0	2.3	14.800	2600.0	840.0	
	plaster outside	10.0	0.7	25.000	1600.0	1110.0	
Roof	plaster inside	10.0	0.68	10.000	1200.0	900.0	2.23
	concrete reinforced 2	200.0	2.2	9999.000	2400.0	1000.0	
	hydroinsulation	30.0	0.8	1.000	150.0	900.0	
	ceiling tile	15.0	0.09	9999.000	250.0	1000.0	
Window	4 mm clear glass	4.0					5.74
Wooden frame door	wooden frame window	50.0	0.152	1.000	0.1	9999.0	2

• Scenario 1

Construction	M-Code	Width(mm)	Conductivity(W/mC)	Vapour Diffusion Factor	Density(kg/m³)	Specific Heat (J/kg*°C)	U-Value(W/m²K)
Ceiling	ceramic tiles	5.0	1.3	9999.000	2300.0	1000.0	2.384
	r. concrete ceiling	200.0	2.2	100.000	2400.0	1100.0	
	plaster inside	10.0	0.68	10.000	1200.0	900.0	
	concrete screed	70.0	1.4	15.000	2000.0	1080.0	
Ground floor	ceramic tiles	5.0	1.3	9999.000	2300.0	1000.0	0.966
	floor coating	20.0	0.21	1.000	1400.0	1400.0	
	concrete screed	125.0	1.4	15.000	2000.0	1080.0	
	hydroinsulation	30.0	0.05	1.000	150.0	900.0	
	gravel	75.0	0.7	2.000	1800.0	1000.0	
Inside wall	plaster inside	10.0	0.68	10.000	1200.0	900.0	2.043
	brick	100.0	0.5	5.000	900.0	880.0	
	plaster inside	10.0	0.68	10.000	1200.0	900.0	
Outside wall	plaster inside	10.0	0.68	10.000	1200.0	900.0	1.74
	aerated concrete	100.0	0.3	6.800	320.0	1094.0	
	reinforced concrete	100.0	2.3	14.800	2600.0	840.0	
	plaster outside	10.0	0.7	25.000	1600.0	1110.0	
Roof	plaster inside	10.0	0.68	10.000	1200.0	900.0	2.23
	concrete reinforced 2	200.0	2.2	9999.000	2400.0	1000.0	
	hydroinsulation	30.0	0.8	1.000	150.0	900.0	
	ceiling tile	15.0	0.09	9999.000	250.0	1000.0	
Window	4 mm clear glass	4.0					5.74
Wooden frame door	wooden frame window	50.0	0.152	1.000	0.1	9999.0	2

- **Scenario 2**

Construction	M-Code	Width(mm)	Conductivity(W/mC)	Vapour Diffusion Factor	Density(kg/m³)	Specific Heat (J/kg*°C)	U-Value(W/m²K)
Ceiling	ceramic tiles	5.0	1.3	9999.000	2300.0	1000.0	2.384
	r. concrete ceiling	200.0	2.2	100.000	2400.0	1100.0	
	concrete screed	70.0	1.4	15.000	2000.0	1080.0	
	plaster inside	10.0	0.68	10.000	1200.0	900.0	
Ground floor	ceramic tiles	5.0	1.3	9999.000	2300.0	1000.0	0.96
	floor coating	20.0	0.21	1.000	1400.0	1400.0	
	concrete screed	125.0	1.4	15.000	2000.0	1080.0	
	hydroinsulation	30.0	0.05	1.000	150.0	900.0	
	gravel	75.0	0.7	2.000	1800.0	1000.0	
Inside wall	plaster inside	10.0	0.68	10.000	1200.0	900.0	2.043
	brick	100.0	0.5	5.000	900.0	880.0	
	plaster inside	10.0	0.68	10.000	1200.0	900.0	
Outside wall	plaster inside	10.0	0.68	10.000	1200.0	900.0	0.12
	aerated concrete	100.0	0.3	6.800	320.0	1094.0	
	reinforced concrete	100.0	2.3	14.800	2600.0	840.0	
	am1ins\15 (polystrene, expanded * 2)	220.0	0.03	59.000	140.0	1380.0	
	plaster outside	10.0	0.7	25.000	1600.0	1110.0	
Roof	plaster inside	10.0	0.68	10.000	1200.0	900.0	0.11
	concrete reinforced	200.0	2.2	100.000	2400.0	1100.0	
	hydroinsulation	30.0	0.05	1.000	150.0	900.0	
	am1ins\15	230.0	0.03	59.000	140.0	1380.0	
	am1concl\1	30.0	1.4	34.000	2360.0	1030.0	
	am1aggr\21	60.0	1.44	34.000	2080.0	1058.0	
Window	6mm K Glass. Defaults used: Light Transmittance=0.89, Light Relectances 0.08						0.8
	15MM AIR (UPWARD FLOW - TRANSPARENT)						
	6mm K Glass. Defaults used: Light Transmittance=0.89, Light Relectances 0.08						
	15MM AIR (UPWARD FLOW - TRANSPARENT)						
	6mm K Glass. Defaults used: Light Transmittance=0.89, Light Relectances 0.08						
Wooden frame door	wood, soft, 75mm, 3in (HF-B11)	120.0	0.13	9999.000	593.0	2510.0	0.8

7.8 BC-S1 comparison of electrical energy demand

Month	BC	S1
January	6456	4141
February	7403	4693
March	7403	5393
April	6275	4376
May	6770	5022
June	3915	3900
July	3479	2780
August	3274	2591
September	6187	4642
October	8144	5163
November	8141	5160
December	6147	3962

7.9 Monthly heating demand in BC/S1/S2

Month	BC	S1	S2
January	35304	21183	7195
February	46886	27072	9206
March	15127	8459	2266

April	7911	3227	621
May	1206	325	12
June	0	0	0
July	0	0	0
August	0	0	0
September	101	5	0
October	2876	1184	322
November	8028	4020	1024
December	29817	16768	5189
Annual	**147259**	**82244**	**25835**

7.10 PV area and orientation

Name	Area (m2)	Building element	Orientation (deg)
PV surface 1	74	PV sunside	180.00 (S)
PV surface 2	26	PV sunside	180.00 (S)
PV surface 3	26	PV sunside	180.00 (S)
PV surface 4	42	PV sunside	180.00 (S)
PV surface 5	38	PV sunside	180.00 (S)
PV surface 6	40	PV sunside	180.00 (S)
PV surface 7	42	PV sunside	180.00 (S)
PV surface 8	76	PV sunside	180.00 (S)
PV surface 9	40	PV sunside	180.00 (S)
PV surface 10	38	PV sunside	180.00 (S)
PV surface 11	83	PV sunside	180.00 (S)
PV surface 12	36	PV sunside	180.00 (S)
PV surface 13	40	PV sunside	180.00 (S)
PV surface 14	42	PV sunside	180.00 (S)
Total:	**641**		

7.11 Monthly energy production

Month	Energy production [kWh]
January	2593.7
February	2769.4
March	4058.3
April	4888.9
May	5822.3
June	5877.8
July	6700.3
August	5971.4
September	4933.5
October	3708.5
November	2433.7
December	2243.7
Total:	**52002**