Renewable Energy Sources for smart sustainable health Centers, University Education and other public buildings

# A study on energy demand, energy efficiency, available renewable energy sources and recommendation for optimal configuration of smart building energy management systems

- Case 3: Faculty of Electrical Engineering, Computer Science and Information Technology Osijek -

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**Title page**

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**Abstract:** This document presents a comprehensive study on energy demand and energy efficiency for the Faculty of Electrical Engineering, Computer Science and Information Technology Osijek public buildings. Furthermore, the study describes the available renewable energy sources that could be used for energy generation in the near vicinity of the public building. After exploring the demand and the potential, the study proposes the optimal configuration of the renewable energy and the smart building energy management systems that would significantly increase the public building efficiency while reducing the energy demand, bringing the public building one step closer to near zero-energy building. This document also gives a short overview of the most important directives and national legislative supporting energy efficiency and renewable sources.



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# 1. Introduction

Energy consumption is constantly increasing since the global population rises and due to the development of industrial sectors, leaving fossil fuel reserves depleted and climate change seriously impacted. Fossil fuels are still dominantly employed for energy harvesting, but finite supply and numerous problems with energy exploitation imply that new solutions have to be incorporated in the energy production process.

Not only that fossil fuels reserves are limited, harder to locate and expensive to transport, but their negative influence on the environment requires active participation in increasing energy efficiency, finding and exploiting of alternate energy sources. The prediction of the finite energy reserves for coal, gas and oil, the most exploited fossil fuels [1], is given in Figure 1.1.

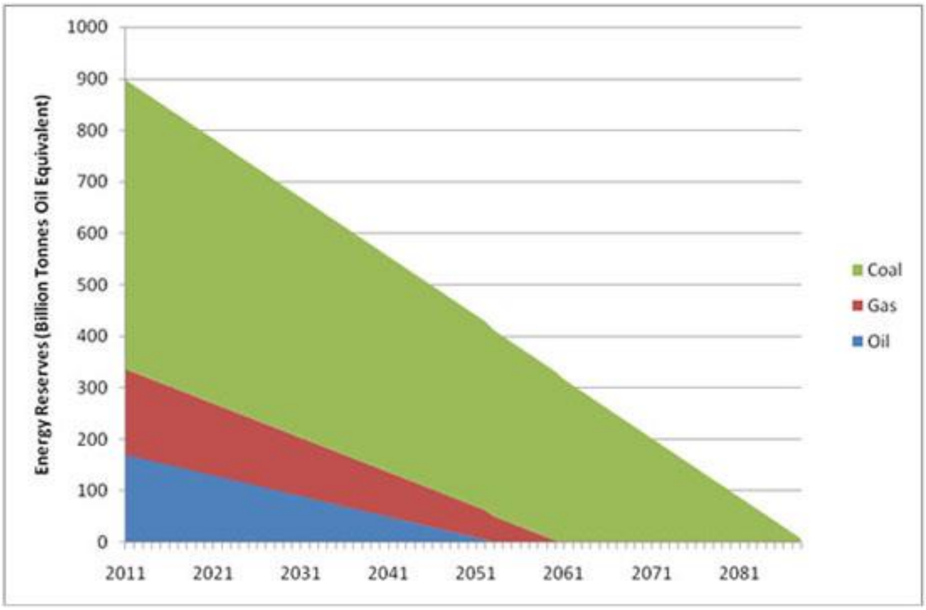



Figure 1.1 *The prediction of fossil fuel energy reserves [1].*

One of the biggest issues associated with the combustion of fossil fuels is carbon emission. In Figure 1.2 carbon dioxide ($CO_2$) emission by a specific type of fossil fuel is given [2]. It can be seen that industrial and economic growth in the last century has contributed to a significant increase in $CO_2$ concentration.

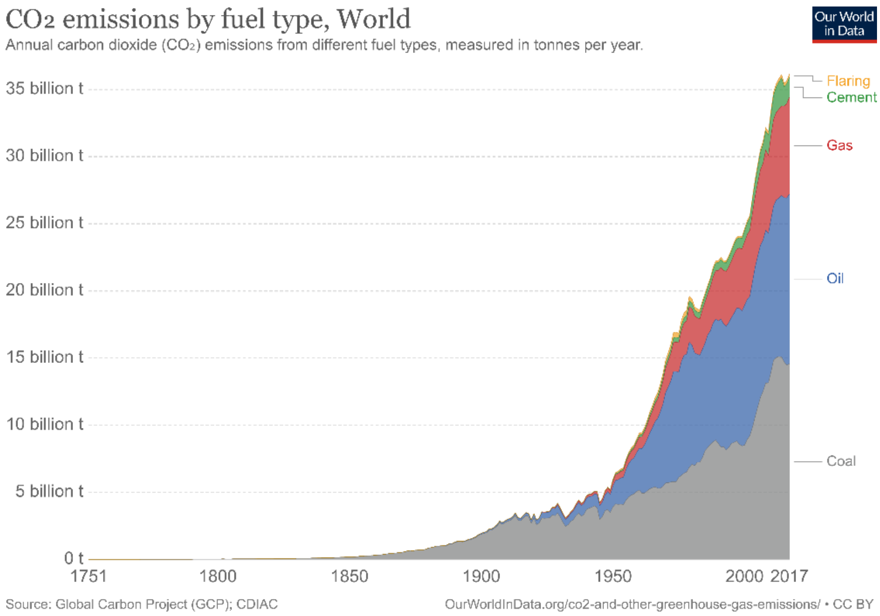



Figure 1.2 *Carbon dioxide ($CO_2$) emission by a specific type of fossil fuel [2].*

Carbon dioxide is a major greenhouse gas and thus extremely contributes to global warming, climate change and ocean acidification. Carbon dioxide concentration in the atmosphere has risen about 43% since the beginning of the industrial revolution in the mid-eighteenth century – half of that since 1980 [3]. In the high economic growth case, world $CO_2$ emissions increase at an average rate of 1.8% annually from 2006 to 2030, as compared with 1.4% in the reference case. For the OECD countries, the projected average increase in the high growth case is 0.6% per year, for the non-OECD countries, the average is 2.6% per year. In the low growth case, world $CO_2$ emissions increase by 1.0% per year from 2006 to 2030, with averages of 0.1% per year for the OECD countries and 1.8% per year for the non-OECD countries. In 2030, total energy-related $CO_2$ emissions worldwide range from a projected 36,930 Mt in the low growth case to 44,108 Mt in the high growth case, which is 19.4% higher than projected in the low growth case [4]. Figure 1.3 predicts $CO_2$ emission based on different scenarios [2]:

- No climate policies: projected future emissions if no climate policies were implemented; this would result in an estimated 4.1-4.8°C warming by 2100 (relative to pre-industrial temperatures);
- Current climate policies: projected warming of 3.1-3.7°C by 2100 based on currently implemented climate policies;
- National pledges: if all countries achieve their current targets/pledges set within the Paris climate agreement, it's estimated average warming by 2100 will be 2.6-3.2°C. This will go well beyond the overall target of the Paris Agreement to keep warming "well below 2°C";

- 2°C consistent: there is a range of emissions pathways that would be compatible with limiting average warming to 2°C by 2100. This would require a significant increase in the ambition of the current pledges within the Paris Agreement;
- 1.5°C consistent: there is a range of emissions pathways that would be compatible with limiting average warming to 1.5°C by 2100. However, all would require a very urgent and rapid reduction in global greenhouse gas emissions.

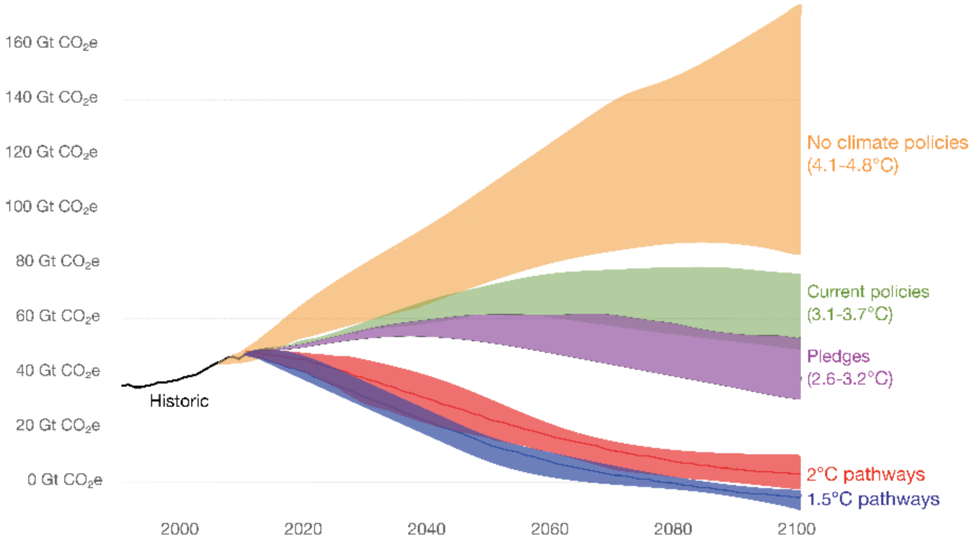



Figure 1.3 *The prediction of the $CO_2$ emission based on different scenarios [2].*

According to the HCWH (Health Care Without Harm) Europe climate report published in Dec 2016 [5], the health sector is a major emitter of greenhouse gasses. For example, in 2012, the total carbon footprint of England's public healthcare sector was 32 million tons of carbon dioxide equivalents ($CO_2$ equivalent refers to a combination of harmful greenhouse gases, not just carbon dioxide), accounting for 38% of public sector emissions in England. This serves to illustrate how the healthcare sector is contributing an enormous amount of harmful emissions, which in turn undermines the health of the same population the sector is meant to heal.

Based on these prognoses, it is clear that is necessary to implement a number of $CO_2$ restriction measures in order to achieve a decrease in the $CO_2$ concentration. One of the measures that can be taken is to increase the reduction of the used energy, for example, with the investment in new equipment that is more energy efficient. Another one is to use alternative energy sources that contribute less to greenhouse gas emissions.

Nowadays, higher energy efficiency is obtained using power electronics. Power electronic devices are present in almost every part of the power system since they enable the conversion of electric power and are used to control power flow and voltage. Power electronic devices are fast and reliable, can provide better power quality and add new functionalities and flexibility to the grid. Without them, the integration of renewable energy

sources into the traditional power network could not be possible. Renewables use technologies that are safe, reliable, affordable and widely available. In order to utilize the best resource locations, many renewable generators have to be located far from existing load canters which leads towards the expansion and decentralization of the power system.

In the last decade, the investment in renewables has drastically increased, which is depicted in Figure 1.4 (large hydropower is not included) [6]. These trends suggest that investors see solar and wind energy as the dominant renewable technologies of the future. The share of renewable energy in the power sector would increase from 25% in 2017 to 85% by 2050, mostly through growth in solar and wind power generation [7].

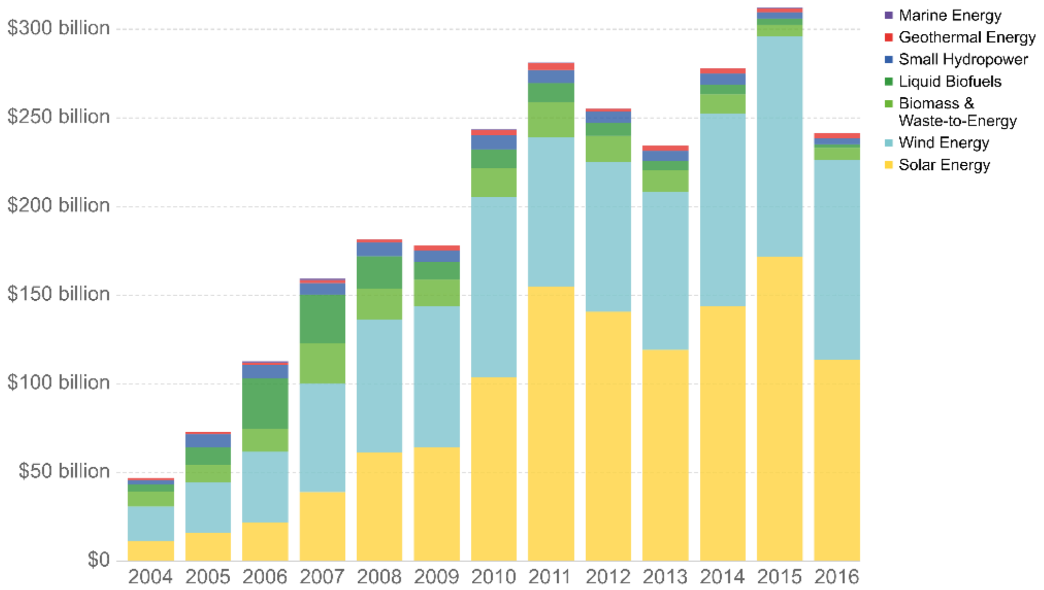



Figure 1.4 *Investment in different renewable energy technologies [6].*

Renewable energy technology should result in less global warming, improved public health through a reduction of air and water pollution, stable electricity price and contribute to the reliability and resilience of the grid. In addition, unlike fossil fuels, energy sources used by renewables are inexhaustible. Therefore, EIA (U.S. Energy Information Administration) projects that renewables will provide nearly half of world electricity by 2050, which is depicted in Figure 1.5 [8].

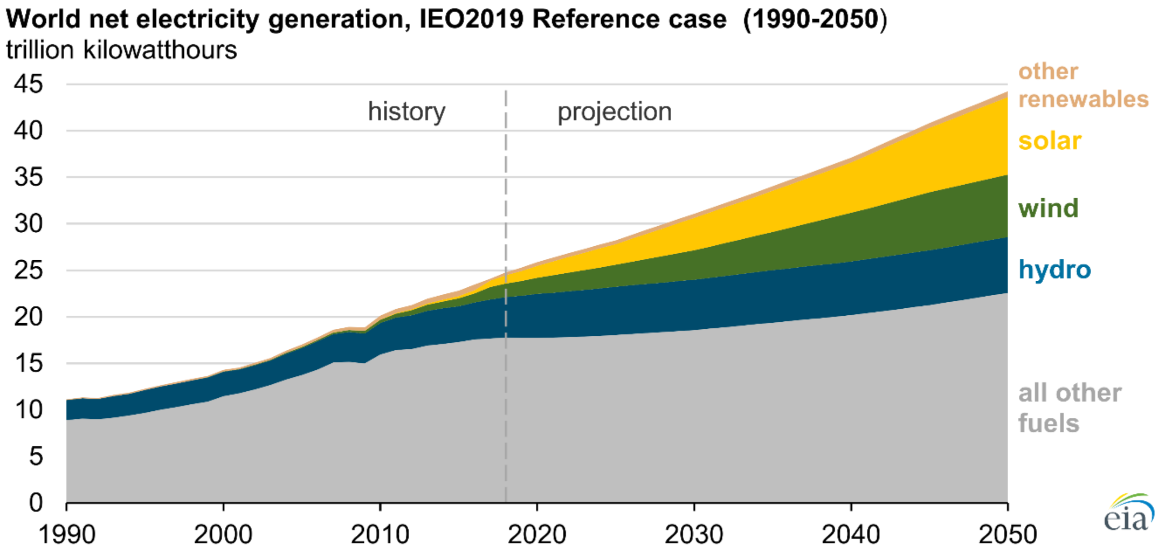



Figure 1.5 *World net electricity generation [8].*

Energy storage systems, such as batteries, supercapacitors, flywheels, thermal storages, etc., play a critical role in the transition of the global energy system toward 100% renewables. As the shares of solar PV and wind energy are going to increase significantly beyond 2030, the role of storage is crucial in providing an uninterrupted energy supply.

Following the $CO_2$ reduction tendency, vehicles that run on fossil fuels should be replaced with electric-powered vehicles. Although currently electric vehicles are more expensive than gasoline-powered vehicles, with time, the running or operating costs of an electric vehicle may be lower than a traditional car (as a result of efficiency gains and lower cost of electricity relative to liquid fuel), so we will begin to get some economic return on our initial investment.

The reduction of greenhouse gasses would help in the decrease in environmental pollution that has become a severe problem. Another measure that can be taken is waste management – a series of actions that aim to reduce the generation and promote the reuse and recycling of solid and hazardous waste. Another benefit that can be obtained is energy recovery. Energy recovery from waste is the conversion of non-recyclable waste materials into usable heat, electricity, or fuel.

Energy efficiency can be increased by reducing the energy consumption of public buildings. This results in substantial energy savings and therefore less usage of fossil fuels. This strategy is recognized and adopted by a number of countries worldwide. A zero-energy building would be a preeminent goal. Of course, this is not possible without the renewables which should cover a part of energy necessities. In order to monitor and control the energy consumption of buildings, Building Energy Management Systems (BEMS) are crucial. BEMS provide real-time remote monitoring and integrated control of a wide range of connected systems, allowing modes of operation, energy use, environmental conditions and so on to be monitored and allowing to optimize performance and comfort. To function correctly they

must be properly designed, installed and commissioned and must have a user interface that is easy to operate.

These issues are addressed in various laws and directives. Adopting the Law on ratifying the Treaty establishing the Energy Community between the European Community and the Republic of Serbia, the Republic of Serbia became an Energy Community member in 2006. The Law on energy efficiency, published in the Official Gazette of RS, No. 25/13 of 15 March 2013, shall regulate the efficient use of energy and energy sources in the energy generation, transmission, distribution and consumption sectors, the energy efficiency policy and energy management system. One of the basic principles that are underlying the efficient use of energy is energy sustainability. The sustainability of energy use shall include reduced energy consumption, better use of available technologies and eco-design requirements, higher efficiency and effectiveness in the use of energy, as well as sustainability from the aspect of environmental impacts by applying the principles of environmental protection [9]. This Law also proposes the formation of an action plan for the energy efficiency of the Republic of Serbia. Currently, The Third Action Plan for Energy Efficiency of the Republic of Serbia is in force. This action plan sets targets in energy efficiency by the end of 2018 and proposes energy efficiency measures that should be taken in the generation and distribution systems and future plans that are in accordance with the implementation of the EU directives.

As a candidate country to become a member state of the European Union, the Republic of Serbia should harmonize its laws with the EU, i.e. with EU directives on energy efficiency. The Energy Efficiency Directive 2012/27/EU is pursuing the overall objective of the energy efficiency target of saving 20% of the Union's primary energy consumption by 2020, and of making further energy efficiency improvements after 2020 [10]. The amending directive (2018/2002) [11] was agreed to update the policy framework to 2030 and beyond. The key element of the amended directive is an energy efficiency target for 2030 of at least 32.5%. The directive allows for a possible upward revision in the target in 2023, in case of substantial cost reductions due to economic or technological developments. It also includes an extension to the energy savings obligation in end-use, introduced in the 2012 directive. Under the amending directive, EU countries will have to achieve new energy savings of 0.8% each year of final energy consumption for the 2021-2030 period.

Another important directive is Directive 2010/31/EU on the energy performance of buildings [12]. This directive introduces a framework for improving the energy efficiency of buildings and proposes a plan in which all new buildings are nearly zero-energy buildings by 31 December 2020.

The Republic of Serbia has adopted the Energy Sector Development Strategy of the Republic of Serbia for the period by 2025 with projections by 2030. Strategic energy development is based on establishing a balance between the production of energy from available sources, energy consumption with a market and socially sustainable character, and more efficient production and the use of a "cleaner" energy from renewable energy sources. This document is in accordance with EU Directives and together with the Law on energy

efficiency and the Third Action Plan for Energy Efficiency presents a foundation for different energy efficiency strategies.

Regarding the abovementioned, it is clear how important is to invest in and implement new technologies that enable higher energy efficiency and thus reduce the impact on climate change and provide energy savings. In order to achieve this, it is necessary to analyse the energy performance profile and determine which elements are critical. This document provides a study of energy demand and energy efficiency for the exemplary facility and inspects the possibility of integration of renewables in order to reduce energy consumption. Also, this study proposes a configuration of the optimal smart building energy systems.

This document compromises the following sections:

- the second section describes the most important directives and national legislative supporting energy efficiency and renewable sources;
- the third section offers insight into the main geographical, meteorological and other features for the public building;
- the fourth section examines current energy demand for the exemplary facility;
- the fifth section investigates the potential for utilization of renewable energy;
- the sixth section deals with optimal energy system topology and configuration for the building energy management system.

# 2. Energy efficiency directives and national legislative for public buildings

According to Global Status Report 2018 published by UN Environment and the International Energy Agency, buildings and construction together account for 36% of global final energy consumption and 39% of carbon dioxide emissions in 2017. In the period from 2010 to 2017, the final consumption of buildings increased by more than 6 EJ [13]. This sector has the highest share of energy and at the same time has the highest potential for energy savings. Looking at the European Union (EU) alone, buildings represent 40% of total energy consumption, as shown in Figure 2.1, and account for 36% of carbon dioxide emissions affecting the overall climate. Statistics show that over 35% of EU buildings are over 50 years old, and over 75% of the building stock is energy inefficient. Renovation of buildings could reduce total energy consumption and reduce $CO_2$ gases by around 5% creating multiple benefits, such as economic, social and environmental in the process [14].

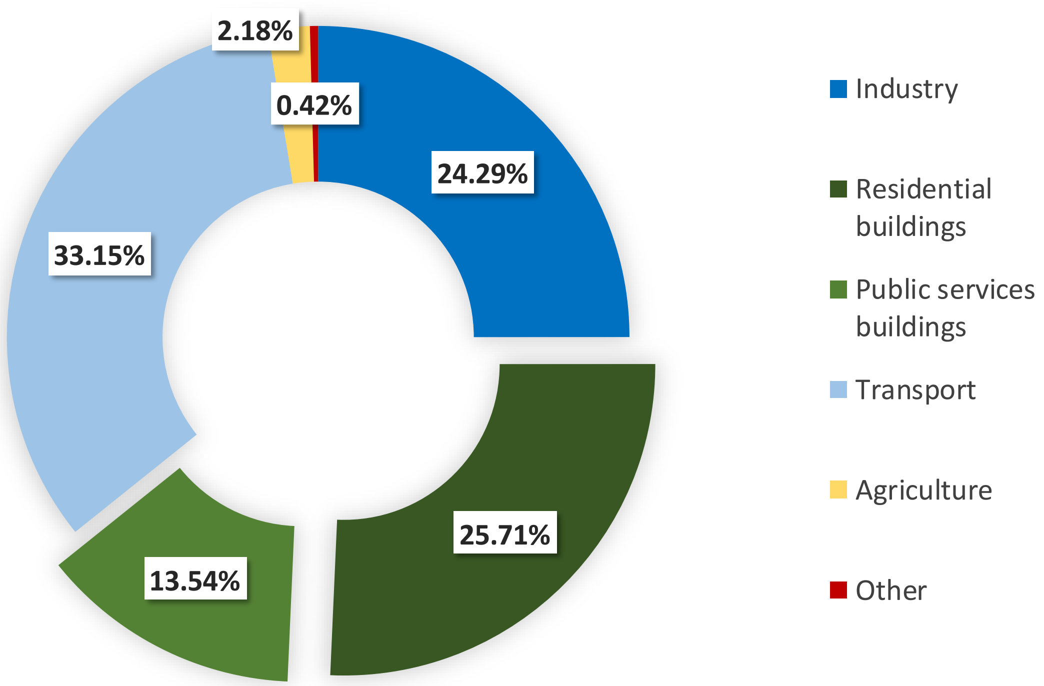



Figure 2.1 *Energy consumption by sector in the EU [15].*

One of the public sectors with the highest energy demand is the healthcare sector. According to the World Bank Group, the healthcare sector generates around 5% of global CO2 emissions annually. Furthermore, it is estimated that around 15,000 hospitals in the EU have high energy demand, not only for electricity, but also for heat. Considering the fact that several million deaths are related to air pollution each year, it can be concluded that the health sector, as one of the largest contributors to air pollution, is affecting human and environmental health in both senses [16].

Referring to the above, the EU has established new guidelines for energy efficiency, in the form of stimulus, financial support and directives, especially for public buildings, which represent large energy consumers.

In order to reduce greenhouse gas emissions and meet the obligations of the Kyoto Protocol, a new directive was issued by the European Parliament on April 23, 2009. Renewable energy directive (2009/28/EC) seeks to increase the control of energy use in Europe and increase the use of energy from renewable sources [17]. Besides, the directive also states that energy savings and increased efficiency must be closely linked to the development of renewable energy. The directive clearly states the mandatory targets for the total share of energy from renewable sources in final gross energy consumption. Article 3 of the Directive sets out mandatory national targets and measures for the use of energy from renewable sources.

*Renewable energy directive (2009/28/EC) Article 3 paragraph 1. states: "Each Member State shall ensure that the share of energy from renewable sources, calculated in accordance with Articles 5 to 11, in gross final consumption of energy in 2020 is at least its national overall target for the share of energy from renewable sources in that year, as set out in the third column of the table in part A of Annex I. Such mandatory national overall targets are consistent with a target of at least 20 % share of energy from renewable sources in the Community's gross final consumption of energy in 2020. In order to achieve the targets laid down in this Article more easily, each Member State shall promote and encourage energy efficiency and energy saving."*

That is, every member of the EU, by the end of 2020, must have a share of 20% from renewable sources in final gross consumption, while promoting energy efficiency and savings. In order to meet the set goals, it is necessary to introduce the required measures.

The EU has agreed to update these regulations in order to meet the obligations under the Paris Agreement on greenhouse gas emissions. The new energy rulebook, called the Clean energy for all Europeans package, is the basis for achieving the goals of the EU. Therefore, Renewable energy directive (2009/28/EC) is revised in December 2018, as part of the Clean energy for all Europeans package [18]. Article 3 of the revised Directive sets out mandatory national targets and measures for the use of energy from renewable sources for 2030.

*Renewable energy directive (2018/2001/EU) Article 3 paragraph 1. states: "Member States shall collectively ensure that the share of energy from renewable sources in the Union's gross final consumption of energy in 2030 is at least 32 %. The Commission shall assess that target with a view to submitting a legislative proposal by 2023 to increase it where there are further substantial costs reductions in the production of renewable energy, where needed to meet the Union's international commitments for decarbonization, or where a significant decrease in energy consumption in the Union justifies such an increase."*

Renewable energy directive (2018/2001/EU) has established a target for the EU to achieve at least 32% of the total energy produced by renewable sources for 2030. Besides, each EU

member is obligated to achieve new energy savings, which is 0,8% of final energy consumption in the period from 2021 to 2013, each year.

Under the Energy Efficiency Directive (2012/27/EU), a set of measures was established to help EU meet the set efficiency targets by 2020 [10]. Increasing energy efficiency can reduce greenhouse gas emissions and mitigate climate changes. Additionally, it can also reduce primary energy consumption, as well as energy imports. More efficiency should also accelerate the spread of innovative technological solutions. The directive stressed that the public sector should be a model for energy efficiency. In addition, public funds for other purposes can be released, due to their high consumption.

*Energy Efficiency Directive (2012/27/EU) paragraph (15) states: "The total volume of public spending is equivalent to 19 % of the Union's gross domestic product. For this reason the public sector constitutes an important driver to stimulate market transformation towards more efficient products, buildings and services, as well as to trigger behavioral changes in energy consumption by citizens and enterprises. Furthermore, decreasing energy consumption through energy efficiency improvement measures can free up public resources for other purposes. Public bodies at national, regional and local level should fulfil an exemplary role as regards energy efficiency."*

Buildings represent a large share of the final consumption of the EU. Therefore, the renovation of residential and commercial buildings, with the aim of increasing their energy efficiency, would help to achieve the efficiency targets set for 2020, by setting long-term strategies.

*Energy Efficiency Directive (2012/27/EU) paragraph (16) states: "Bearing in mind that the Council conclusions of 10 June 2011 on the Energy Efficiency Plan 2011 stressed that buildings represent 40 % of the Union's final energy consumption, and in order to capture the growth and employment opportunities in the skilled trades and construction sectors, as well as in the production of construction products and in professional activities such as architecture, consultancy and engineering, Member States should establish a long-term strategy beyond 2020 for mobilizing investment in the renovation of residential and commercial buildings with a view to improving the energy performance of the building stock. That strategy should address cost-effective deep renovations which lead to a refurbishment that reduces both the delivered and the final energy consumption of a building by a significant percentage compared with the pre-renovation levels leading to a very high energy performance. Such deep renovations could also be carried out in stages."*

As buildings represent the sector with the highest potential for energy savings, they can also help to achieve reduced greenhouse gas emissions by 80-95% by 2050, compared to 1990, as highlighted in the directive.

*Energy Efficiency Directive (2012/27/EU) paragraph (17) states: "The rate of building renovation needs to be increased, as the existing building stock represents the single biggest potential sector for energy savings. Moreover, buildings are crucial to achieving the Union objective of reducing greenhouse gas emissions by 80-95 % by 2050 compared to 1990.*

*Buildings owned by public bodies account for a considerable share of the building stock and have high visibility in public life. It is therefore appropriate to set an annual rate of renovation of buildings owned and occupied by central government on the territory of a Member State to upgrade their energy performance. This renovation rate should be without prejudice to the obligations with regard to nearly-zero energy buildings set in Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (2). The obligation to renovate central government buildings in this Directive complements that Directive, which requires Member States to ensure that when existing buildings undergo major renovation their energy performance is upgraded so that they meet minimum energy performance requirements. It should be possible for Member States to take alternative cost-efficient measures to achieve an equivalent improvement of the energy performance of the buildings within their central government estate. The obligation to renovate floor area of central government buildings should apply to the administrative departments whose competence extends over the whole territory of a Member State. When in a given Member State and for a given competence no such relevant administrative department exists that covers the whole territory, the obligation should apply to those administrative departments whose competences cover collectively the whole territory."*

Intelligent metering systems for measuring energy consumption, which can transmit and receive data, monitor and control the system, can optimize the use of electricity. Furthermore, the use of intelligent metering systems equipped with energy-saving features develops the market for energy services, while the final customers can control individual consumption. The Energy Efficiency Directive points out that at least 80% of consumers must be equipped with intelligent measurements by the end of 2020.

*Energy Efficiency Directive (2012/27/EU) paragraph (27) states: "In relation to electricity, and in accordance with Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity (1), where the roll-out of smart meters is assessed positively, at least 80 % of consumers should be equipped with intelligent metering systems by 2020. In relation to gas, and in accordance with Directive 2009/73/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in natural gas (2), where the roll-out of intelligent metering systems is assessed positively, Member States or any competent authority they designate, should prepare a timetable for the implementation of intelligent metering systems."*

Referring to the above, the Energy Efficiency Directive establishes several important measures, in order to increase energy efficiency in the Union, in order to achieve the 2020 targets. Besides, the directive establishes rules in order to remove obstacles in the energy market, which limits the efficiency of energy supply and its use. One of the goals is that EU energy consumption by 2020 should not exceed 1474 Mtoe of the primary energy or 1078 Mtoe of the final energy consumption.

*Energy Efficiency Directive (2012/27/EU) Article 1 Paragraph 1. states: "This Directive establishes a common framework of measures for the promotion of energy efficiency within the Union in order to ensure the achievement of the Union's 2020 20 % headline target on*

*energy efficiency and to pave the way for further energy efficiency improvements beyond that date. It lays down rules designed to remove barriers in the energy market and overcome market failures that impede efficiency in the supply and use of energy, and provides for the establishment of indicative national energy efficiency targets for 2020."*

The directive set out a long-term strategy to encourage the investment in the buildings' renovation, as highlighted in Article 4.

*Energy Efficiency Directive (2012/27/EU) Article 4 states: "Member States shall establish a long-term strategy for mobilizing investment in the renovation of the national stock of residential and commercial buildings, both public and private."*

Among others, Energy Efficiency Directive measures include long-term renovation strategy for the buildings in each country of EU and improvement of energy efficiency of central governments owned buildings by at least 3% each year, as indicated in Article 5. In addition, Article 7 states that is necessary to make an annual reduction of 1.5% in national energy sales by 2020.

*Energy Efficiency Directive (2012/27/EU) Article 5 Paragraph 1. states: "Without prejudice to Article 7 of Directive 2010/31/EU, each Member State shall ensure that, as from 1 January 2014, 3 % of the total floor area of heated and/or cooled buildings owned and occupied by its central government is renovated each year to meet at least the minimum energy performance requirements that it has set in application of Article 4 of Directive 2010/31/EU."*

*Article 7. Paragraph 1. States: "Each Member State shall set up an energy efficiency obligation scheme. That scheme shall ensure that energy distributors and/or retail energy sales companies that are designated as obligated parties under paragraph 4 operating in each Member State's territory achieve a cumulative end-use energy savings target by 31 December 2020, without prejudice to paragraph 2. That target shall be at least equivalent to achieving new savings each year from 1 January 2014 to 31 December 2020 of 1,5 % of the annual energy sales to final customers of all energy distributors or all retail energy sales companies by volume, averaged over the most recent three-year period prior to 1 January 2013. The sales of energy, by volume, used in transport may be partially or fully excluded from this calculation."*

Energy efficiency is recognized as a crucial and element of highest priority, therefore the Energy Efficiency Directive (EED) (2012/27/EU) is revised in 2018, and has set a new efficiency target for 2030 of at least 32.5% [17].

*The Energy Efficiency Directive (2018/2002) states: "Directive 2012/27/EU is amended as follows: (1) in Article 1, paragraph 1 is replaced by the following: '1. This Directive establishes a common framework of measures to promote energy efficiency within the Union in order to ensure that the Union's 2020 headline targets on energy efficiency of 20 % and its 2030 headline targets on energy efficiency of at least 32,5 % are met and paves the way for further energy efficiency improvements beyond those dates. This Directive lays down rules designed to remove barriers in the energy market and overcome market failures that impede efficiency in the supply and use of energy, and provides for the establishment of indicative national*

*energy efficiency targets and contributions for 2020 and 2030. This Directive contributes to the implementation of the energy efficiency first principle."*

New target for 2030 is that EU energy consumption by 2030 should not exceed 1273 Mtoe, which is more then 200 Mtoe less than target for 2020. Besides, the Waste Framework Directive (2008/98/EC) has defined a framework for waste management and set two new goals for 2020. Those state that 50% of certain waste materials from households should be prepared for re-use and recycling, and 70% construction and demolition waste should be prepared for re-use, recycling and other recovery. Among others, the Waste Framework Directive governs the waste oils. During 2006 the EU has spent around 5,8 million tons of lubricant oil. Around 50% of used oil becomes waste oil, which is approximately 3 million tons of waste oil each year. Annex II of the Waste Framework Directive, promotes energy production from waste in case that waste recycling is not the environmentally preferable, in order to improve energy efficiency.

The main goal of the EU's long-term strategy is to achieve zero-carbon emission by 2050, as it represents part of the Clean energy for all Europeans packages. Considering that public buildings are one of the largest consumers of energy and, therefore, highly contribute to air pollution, improvement in energy efficiency in buildings can contribute to achieving carbon neutrality.

The European Commission offers a number of Directives on energy efficiency, the Energy Performance Building Directive (2010/31/EU) [15], along with Energy Efficiency Directive, is the legislative for promoting the energy performance of buildings. EPBD proposed a series of measures in order to improve the energy performance of buildings, in form of long-term renovation strategies. The Directive also provides that national authorities must establish a financing plan for programs aimed at increasing the energy efficiency of buildings.

The directive emphasizes that all members must set energy efficiency requirements in order to optimize energy consumption in existing buildings, which can be applied to new buildings. Article 8 highlights the systems that must be found in the requirements.

*Energy Performance Building Directive (2010/31/EU) Article 8 Paragraph 1. states: "Member States shall, for the purpose of optimizing the energy use of technical building systems, set system requirements in respect of the overall energy performance, the proper installation, and the appropriate dimensioning, adjustment and control of the technical building systems which are installed in existing buildings. Member States may also apply these system requirements to new buildings. System requirements shall be set for new, replacement and upgrading of technical building systems and shall be applied in so far as they are technically, economically and functionally feasible. The system requirements shall cover at least the following:*

*(a) heating systems;*

*(b) hot water systems;*

*(c) air-conditioning systems;*

*(d) large ventilation systems; or a combination of such systems."*

The directive requires the use of intelligent metering systems in the renovation of buildings and in each newly constructed building. In addition, it is proposed to encourage the use of the monitoring and control systems, all with the aim of saving energy, as indicated in article 8.

*Energy Performance Building Directive (2010/31/EU) Article 8 Paragraph 2. states: "Member States shall encourage the introduction of intelligent metering systems whenever a building is constructed or undergoes major renovation, whilst ensuring that this encouragement is in line with point 2 of Annex I to Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity. Member States may furthermore encourage, where appropriate, the installation of active control systems such as automation, control and monitoring systems that aim to save energy."*

Directive proposed an ambitious plan for all new buildings must be nearly zero-energy by December 31, 2020, and all new public facilities, constructed after December 31, 2020, must be nearly zero-energy buildings (NZEB), as indicated in article 9.

*Energy Performance Building Directive (2010/31/EU) Article 9 Paragraph 1. states: "Member States shall ensure that:*

*(a) by 31 December 2020, all new buildings are nearly zero energy buildings; and*

*(b) after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings.*

*Member States shall draw up national plans for increasing the number of nearly zero-energy buildings. These national plans may include targets differentiated according to the category of building."*

The directive mandates that the public sector should be a role model for other buildings and all members should take measures and set targets to encourage the renovation of buildings in order to achieve zero-energy.

*Energy Performance Building Directive (2010/31/EU) Article 9 Paragraph 2. states: "Member States shall furthermore, following the leading example of the public sector, develop policies and take measures such as the setting of targets in order to stimulate the transformation of buildings that are refurbished into nearly zero-energy buildings, and inform the Commission thereof in their national plans referred to in paragraph 1."*

Energy Performance Building Directive (2010/31/EU) is amended on May 30, 2018 with new directive, as a part of Clean energy for all Europeans' package [19]. Among others, directive states that the monitoring and automation of buildings have proven to be efficient, especially in large systems, and that there lie a huge potential for significant energy savings.

*Energy Performance Building Directive (2018/844/EU) Paragraph 37. states: "Building automation and electronic monitoring of technical building systems have proven to be an effective replacement for inspections, in particular for large systems, and hold great potential to provide cost-effective and significant energy savings for both consumers and businesses. The installation of such equipment should be considered to be the most cost-effective alternative to inspections in large non-residential and multi-apartment buildings of a sufficient size that allow a payback of less than three years, as it enables action to be taken on the information provided, thereby securing energy savings over time. For small-scale installations, the documentation of the system performance by installers should support the verification of compliance with the minimum requirements laid down for all technical building systems."*

The directive added an article on a long-term renovation strategy, which mandates that all buildings, both public and private, must be renovated in order to increase energy energy efficiency by 2050.

*Energy Performance Building Directive (2018/844/EU) Article 1 Paragraph 2. states: "Each Member State shall establish a long-term renovation strategy to support the renovation of the national stock of residential and non-residential buildings, both public and private, into a highly energy efficient and decarbonized building stock by 2050, facilitating the cost-effective transformation of existing buildings into nearly zero-energy buildings. Each long-term renovation strategy shall be submitted in accordance with the applicable planning and reporting obligations and shall encompass:*

*(a) an overview of the national building stock, based, as appropriate, on statistical sampling and expected share of renovated buildings in 2020;*

*(b) the identification of cost-effective approaches to renovation relevant to the building type and climatic zone, considering potential relevant trigger points, where applicable, in the life-cycle of the building;*

*(c) policies and actions to stimulate cost-effective deep renovation of buildings, including staged deep renovation, and to support targeted cost-effective measures and renovation for example by introducing an optional scheme for building renovation passports;*

*(d) an overview of policies and actions to target the worst performing segments of the national building stock, split incentive dilemmas and market failures, and an outline of relevant national actions that contribute to the alleviation of energy poverty;*

*(e) policies and actions to target all public buildings;*

*(f) an overview of national initiatives to promote smart technologies and well-connected buildings and communities, as well as skills and education in the construction and energy efficiency sectors; and*

*(g) an evidence-based estimate of expected energy savings and wider benefits, such as those related to health, safety and air quality."*

***National and EU legislation on energy efficiency in public buildings in Serbia***

Adopting the Law on ratifying the Treaty establishing the Energy Community between the European Community and the Republic of Serbia, the Republic of Serbia became an Energy Community member in 2006. The Law on energy efficiency, published in the Official Gazette of RS, No. 25/13 of 15 March 2013, shall regulate the efficient use of energy and energy sources in the energy generation, transmission, distribution and consumption sectors, the energy efficiency policy and energy management system. One of the basic principles that are underlying the efficient use of energy is energy sustainability. The sustainability of energy use shall include reduced energy consumption, better use of available technologies and eco-design requirements, higher efficiency and effectiveness in the use of energy, as well as sustainability from the aspect of environmental impacts by applying the principles of environmental protection [9]. This Law also proposes the formation of an action plan for the energy efficiency of the Republic of Serbia. Currently, The Third Action Plan for Energy Efficiency of the Republic of Serbia is in force. This action plan sets targets in energy efficiency by the end of 2018 and proposes energy efficiency measures that should be taken in the generation and distribution systems and future plans that are in accordance with the implementation of the EU directives.

As a candidate country to become a member state of the European Union, the Republic of Serbia should harmonize its laws with the EU, i.e. with EU directives on energy efficiency. The Energy Efficiency Directive 2012/27/EU is pursuing the overall objective of the energy efficiency target of saving 20% of the Union's primary energy consumption by 2020, and of making further energy efficiency improvements after 2020 [10]. The amending directive (2018/2002) [11] was agreed to update the policy framework to 2030 and beyond.

The Republic of Serbia has adopted the Energy Sector Development Strategy of the Republic of Serbia for the period by 2025 with projections by 2030 (Official Gazette of the Republic of Serbia, No. 53/2013). Strategic energy development is based on establishing a balance between the production of energy from available sources, energy consumption with a market and socially sustainable character, and more efficient production and the use of a "cleaner" energy from renewable energy sources. This document is in accordance with EU Directives and together with the Law on energy efficiency and the Third Action Plan for Energy Efficiency presents a foundation for different energy efficiency strategies.

As one of the packages of measures under the Stabilization and Association Agreement, the Republic of Serbia has committed itself to the implementation of the European Union directives and, by a decision of the Council of Ministers from October 2015, undertook to comply with the Energy Efficiency Directive 2012/27/EU.

The Energy Efficiency Law (Official Gazette of the Republic of Serbia, No. 25/2013) was adopted by the National Assembly of the Republic of Serbia on March 15, 2013. The law regulates the conditions and means of efficient use of energy, energy efficiency policy, energy management system, etc. The law goals are to make efficient use of energy by:

- Increasing the security of energy supply and its more efficient use,

- Increasing the competitiveness of the economy,
- Reducing the negative environmental impacts of the energy sector and
- Encouraging responsible behavior towards energy, based on the implementation of energy efficiency policies and energy efficiency measures in the sectors of energy production, transmission, distribution and consumption.

The mentioned law prescribes the existence of minimum energy efficiency requirements, as well as an action plan for the energy efficiency of the Republic of Serbia. Currently, the Third Energy Efficiency Action Plan of the Republic of Serbia Official Gazette of the Republic of Serbia, br. 25/2013) for the period until 2018 is available. This action plan defines the goals for total energy savings in the Republic of Serbia for 2018 and proposes basic frameworks for implementing measures to increase energy efficiency. The main target for 2018 was a reduction of 0.7254 Mtoe, which was about 9% of the reference energy consumption in 2008. Given the development of energy efficiency measures to date, and a savings of 0.37 Mtoe in the period 2010-2015, representing 93% of the measures envisaged for the same period, about 50% of the target remains in 2018, which is an achievable scenario if all the envisaged energy efficiency measures are implemented. This also means a significant increase in energy efficiency in the public sector, especially in public buildings and facilities used by various republic, provincial and local institutions.

***National and EU legislation on energy efficiency in public buildings in Croatia***

On October 31st 2019, the Croatian Government adopted and forwarded to Parliament a draft of new Energy Strategy of Croatia in the period until 2030 with an outlook for the period until 2050, which envisages a much higher share of energy from renewable sources, greater energy efficiency and a reduction of greenhouse gas emissions. The Energy Strategy considers three different energy development scenarios:

- S0, a scenario with no further adjustments of measures, or changes to the regulatory framework;
- S1, a scenario of fast energy transition in Croatia and the EU;
- S2, a scenario of energy transition at an average pace in Croatia.

It is expected that Croatian overall energy consumption will reduce partially due to the decreasing population, but also because more efficient technologies are being incorporated in common consumer products, building energy efficiency and industry. In the next ten years, the overall consumption of energy is expected to reduce by 1% in S2, and by 5% in S1. The overall consumption of energy is expected to be drastically reduced by 2050, by 17% in S2, and by 26% in S1. Renewable energy sources are expected to increase their share of the overall consumption by 10% by 2030 in S2 (from 21.8% in 2017 to 31.5% in 2030), and by a further 15% by 2050 (from 31.5% in 2030 to 46.3% in 2050). The S1 midterm predictions remain the same (31.5% in 2030), but in long term, it predicts a far greater share of renewable energy sources in overall consumption – rising to 56.2% in 2050.

Energy Efficiency in Public Buildings in Croatia

Croatia as a member of EU is obliged by all EU legislations regarding the energy efficiency in (public) buildings including:

- Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency (Official Journal of the European Union, L 156, 19.6.2018, p. 75–91),
- Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC (Official Journal of the European Union, L 315, 14.11.2012, p. 1-56) Special edition in Croatian: Chapter 12 Volume 004 p. 202 - 257

In the Republic of Croatia, Law (Act) on Energy Efficiency has been passed in 2014 (Official Gazette of the Republic of Croatia, No. 127/14). This Law regulates the field of energy efficiency, including:

- adoption of plans at local, regional and national level for improving energy efficiency and their implementation,
- energy efficiency measures,
- energy efficiency obligations: obligations of the energy regulatory authority, transmission system operator, distribution system operator and energy market operators in connection with the transmission, i.e. transport and distribution of energy, obligations of energy distributors, energy suppliers and / or water, in particular activity of energy services
- determination of energy savings
- consumer rights in the application of energy efficiency measures.

Amendments in 2018 (Official Gazette of the Republic of Croatia, No. 116/2018) has been passed to amend discrepancies with the Directive 2012/27/EU on energy efficiency which could call in question the realization of mandatory goals of sustainable development: reduction of negative environmental impact of energy sector, improvement of energy supply security, fulfilling the energy demand and implementation of international obligations of Republic of Croatia in GHG emissions reduction by encouraging energy efficiency measures in all areas of energy consumption and production [Energy in Croatia 2018].

Currently in Croatia, the Fourth National Energy Efficiency Plan of the Republic of Croatia for the Period from 2017 to 2019 is a document that meets the obligations incented in the EPBD Directive (recast) (2010/31/EU), the EED directive (2012/27/EU) and the Directive on the deployment of alternative fuels infrastructure (2014/94/EU). In the 4th NEEAP the main

holders of the increase of energy efficiency in the buildings sector are programmes for energy renovation of multifamily housing and commercial non-residential buildings. The interest for the Programme of energy renovation of multifamily housing has been exceptionally high and has garnered great success. Amendments to the Programme have allowed that all citizens of Croatia apply directly to the EPEEF, and the procedure of submitting an application for an incentive has been simplified by changing the definition of a family house. In 2016 the co-financing programme has been additionally adapted due to the use of resources of European funds within the OPCC. The aim of the Programme is the increase of energy efficiency of existing houses, reduction of energy consumption and emissions of CO2 into the atmosphere and the reduction of monthly costs for energy sources, with an overall improvement of the quality of life.

The national energy renovation target of 3 % of the total floor area of heated and/or cooled buildings owned and occupied by its central government and amounts to 0.00489 PJ/year. Calls for co-financing of energy refurbishment and use of renewable energy sources in public buildings are being issued in Croatia on regular basis. Furthermore, buildings used by public administration in Croatia built in 2018 onwards, i.e. all buildings for which building permit was requested after 31st December, 2017 have to be constructed as nearly zero energy buildings defined in Technical ordinance on rational energy use and thermal protection in buildings (Official Gazette of the Republic of Croatia, No. 128/15) in order to secure timely implementation of Directive on energy performance of buildings requirements in public buildings. Amendments of former regulation simplify building compliance proof, further enforce integral energy refurbishment of buildings and include additional near zero energy building (nZEB) declaration of buildings.

# 3. The main features of the locations and the buildings for the exemplary facilities

Faculty of Electrical Engineering, Computer Science and Information Technology occupies two buildings, first in the street Kneza Trpimira 2B and second in campus of Josip Juraj Strossmayer University of Osijek (Cara Hadrijana 10B). Faculty buildings are located in city of Osijek in Slavonia-Baranja county. Geographical locations of buildings are North latitude 45° 33′ 24.82′′, East longitude 18° 41′ 44.24′′ for building in Trpimirova street and North latitude 45° 33′ 23.88′′, East longitude 18° 42′ 42.85′′ for building in Cara Hadrijana street.

Faculty building in Trpimirova street is located at k.č.br. 5985/9, K.O. Osijek, as shown in situation in Figure 3.1 Near the faculty building, Student Center, high school center and recreational center are located while few blocks away, old town of Osijek - fortress Tvrđa (citadel) is situated. Faculty building in Cara Hadrijana street is located at k.č.br. 6660/1, k.o. Osijek, as shown in situation in Figure 3.2. Faculty building is a part of Josip Juraj Strossmayer University of Osijek campus alongside few other faculties. Near the building, Clinical Hospital Center Osijek is situated.

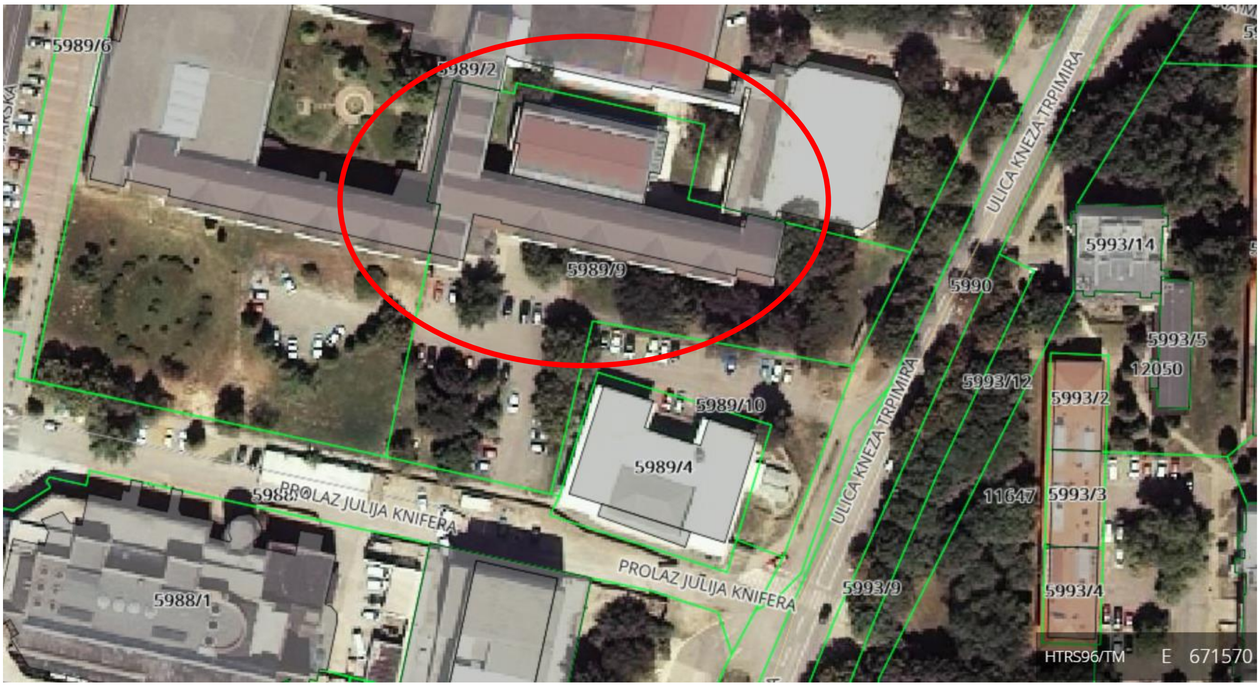



Figure 3.1 *Location of Faculty of Electrical Engineering, Computer Science and Information Technology Osijek building in Trpimirova street [20].*


Figure 3.2 *Location of Faculty of Electrical Engineering, Computer Science and Information Technology Osijek building in Cara Hadrijana street [20].*

Both Faculty buildings are a three-story building equipped with offices, classrooms and laboratories. Besides that, building in Cara Hadrijana has basement floor while building in Trpimirova does not. Totally, both Faculty buildings are equipped with 27 laboratories, of which 9 computer laboratories, 18 classrooms and 52 offices. Total area of Faculty building in Trpimirova is 4500 $m^2$ while for the building in Cara Hadrijana street is 3700 $m^2$. Figure 3.3 and Figure 3.4 show main entrance to the Trpimirova street and Cara Hadrijana street buildings.

Figure 3.3 *The main entrance to the building in Trpimirova street.*

Figure 3.4 *The main entrance to the building in Cara Hadrijana street.*

The Faculty of Electrical Engineering, Computer Science and Information Technology Osijek is established in 1987. Building in Trpimirova street is integrated with building of high school center while the building in Cara Hadrijana street was obtained, restored and put into operation in 2006. The basic role of the facility is to provide space for classrooms,

offices and laboratories needed for education and research activities of students in the field of electrical engineering, computer science and IT. Through the years, number of students and staff was constantly increasing, therefore, new offices, classrooms and laboratories were made.

Most of the time, especially while performing general tasks, employees and faculty members work in offices (Figure 3.5). Offices are usually equipped with computers and air conditioners, while depending on the case they may have other smaller consumers. Offices contain between 1 and 5 workplaces, usually 2.

In addition, most teaching activities are performed in classrooms. An example of one classroom hall with 168 student seats in given in Figure 3.6. The number of student places in classrooms varies depending on the facility from few tenths to few hundreds. Some classrooms contain computers and projectors, but the largest consumption is mainly the lighting system.

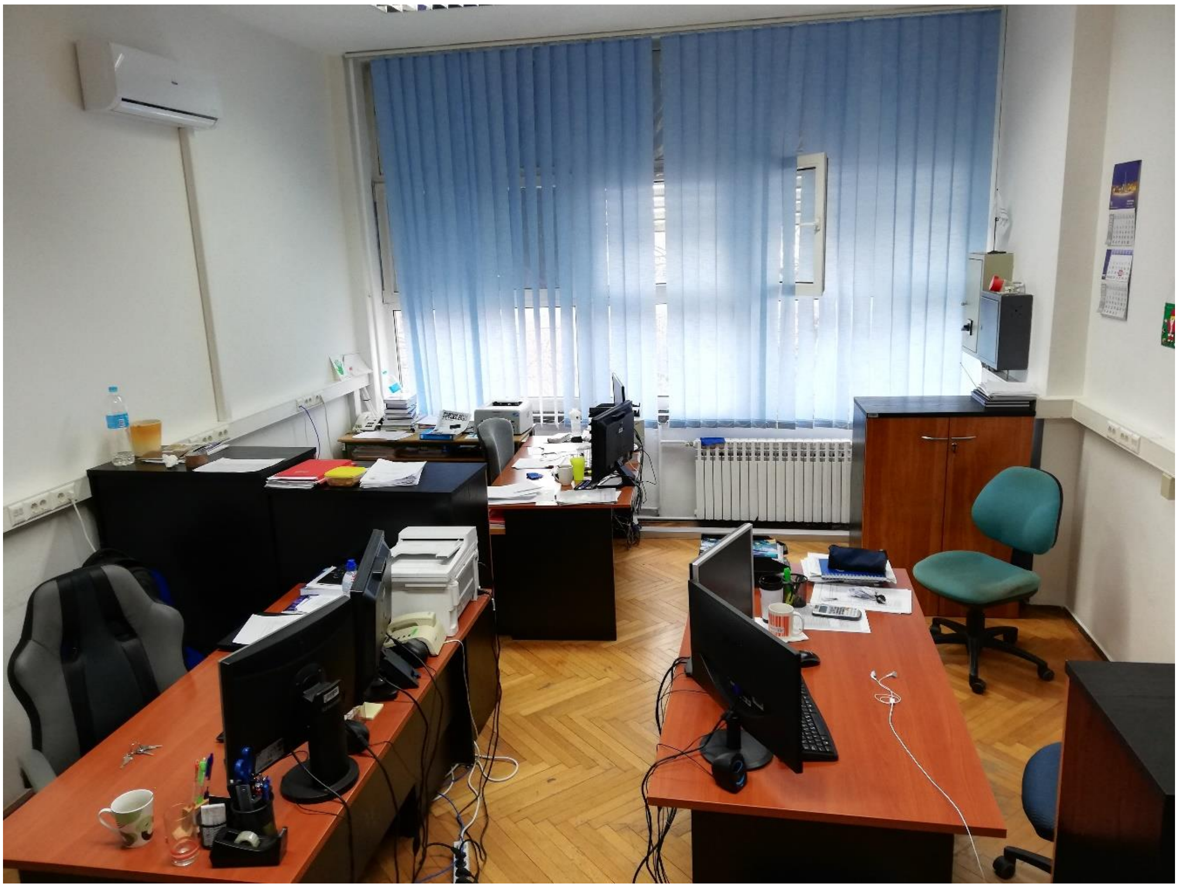


Figure 3.5 – *Office in building in Trpimirova street with three workplaces.*

Figure 3.6 – *Classroom in building in Cara Hadrijana street with 168 student seats and 1 teaching position.*

Figure 3.7 shows an example of a computer lab classroom with 24 student and 1 teaching position. The classroom is used to teach and to test students' knowledge using appropriate software. The computer lab classrooms have up to 24 places for students, as well as one place for teaching staff. In accordance with the purpose of the space, computers are the most common consumers and due to their large number, the power supply to these classrooms must be carefully carried out.

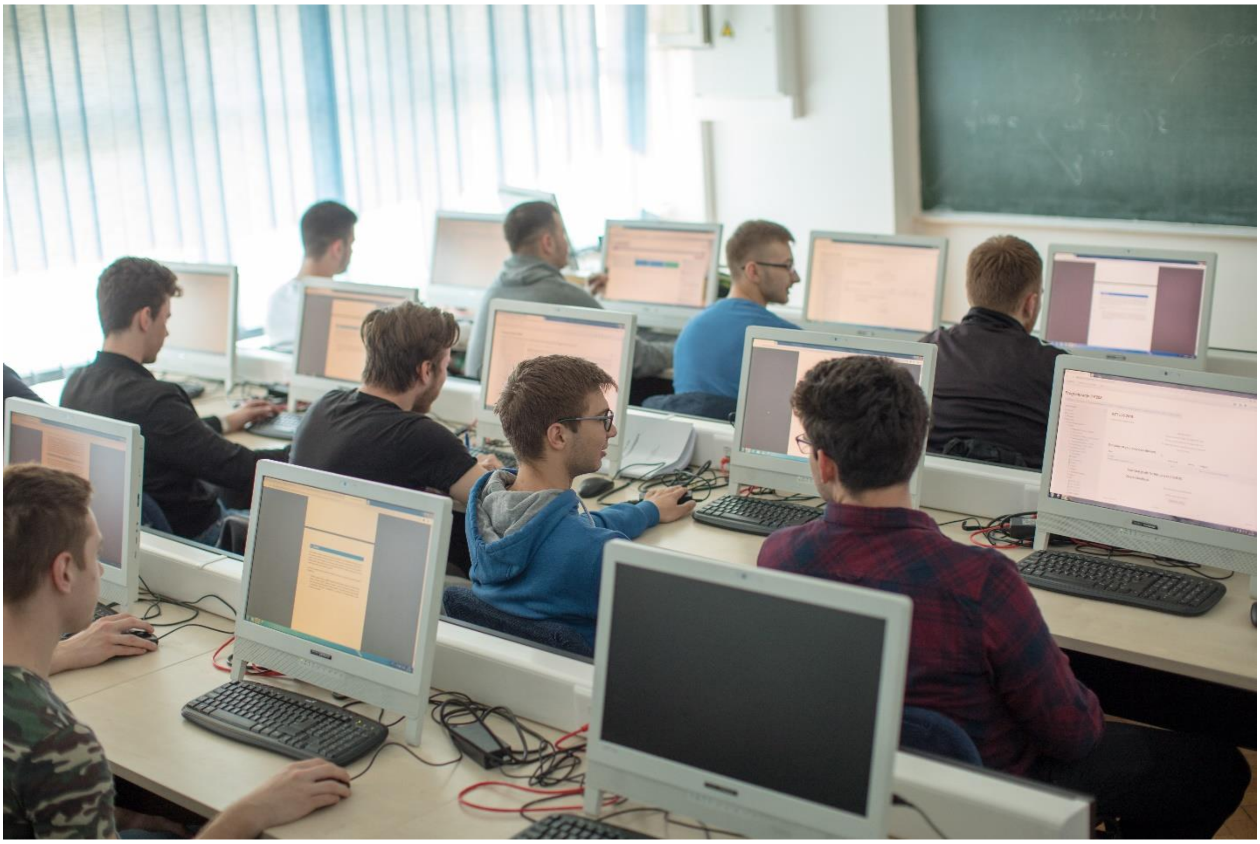


Figure 3.7 – *Example of one computer lab classroom in building in Trpimirova street.*

Figure 3.8 shows an example of a single laboratory. The laboratory is a space intended for experimentation in a controlled environment for the purpose of practical teaching of students, as well as for scientific research work. The equipment in the laboratories, depending on their purpose (study program) may be different, but often the consumers of the highest power are in these rooms. Of course, this does not have to mean the highest power consumption, since the operation of the devices in laboratories is generally short-lived. Except for specific consumers, neither lighting nor a certain number of computer sites should be neglected.

Figure 3.8 – *An example of a laboratory for electric machines in building in Trpimirova street.*

Figure 3.9 shows general-purpose spaces such as communication spaces. The most common type of consumers in these areas is lighting and consumers of plumbing infrastructure.

Figure 3.9 – *General purpose rooms in building in Trpimirova street.*

## 3.2. Climate conditions in the surrounding area

Continental Croatia is characterized by temperate continental climate and throughout the whole year it is marked by very variable atmospheric conditions because of circulation zone of mid-latitudes. Main feature of the climate is a diversity of weather situations with intense and frequent interchanges during the year caused by low or high air pressure moving complexes, usually like vortices hundreds and thousands of kilometers in diameter. Furthermore, continental Croatia climate is also modified by the Mediterranean maritime influence, which weakens by distancing towards the east. The next, more local than regional, factor that influences the climate is orography which, on the windward side of the orographic obstacle, makes easier the amplification of short-term heavy precipitation while on the leeward side generates appearance of precipitation shadow. Finally, these conditions also depend on the current season [21].

Stationary anticyclonic weather types with low clouds or fog and a very gentle air flow are beneficial for frost occurrence during the winter. On contrary, fast-moving cyclonic

weather types (cyclone and trough) in spring result in frequent and unforeseen weather changes, varying from cold to warm, calm to windy or dry to rainy periods. During summer, small air pressure gradient results in a cooling night breeze blowing down mountain slopes interrupted by cold fronts passing through bringing fresh Atlantic air. Consequently, this results in strong air mixing, increased wind, thunder and showers from dense clouds with vertical development. Autumn is distinguished by intervals of calm anticyclonic weather, but there are also rainy days caused by passing cyclones. Autumn starts with warm and sunny days and fresh nights with much dew and low fog while at the ending conditions transform to cold, foggy, and gloomy [21].

Crucial source of information for Croatia's wind energy potential estimation is the wind atlas. Maps given in Figure 3.10 and Figure 3.11 show average wind speed (m/s) and mean wind power density (W/m$^2$) maps at 10 m and 80 m above ground. Given maps are a result of atmospheric numerical model and represent an average value in a grid cell of 2 km x 2 km [22].

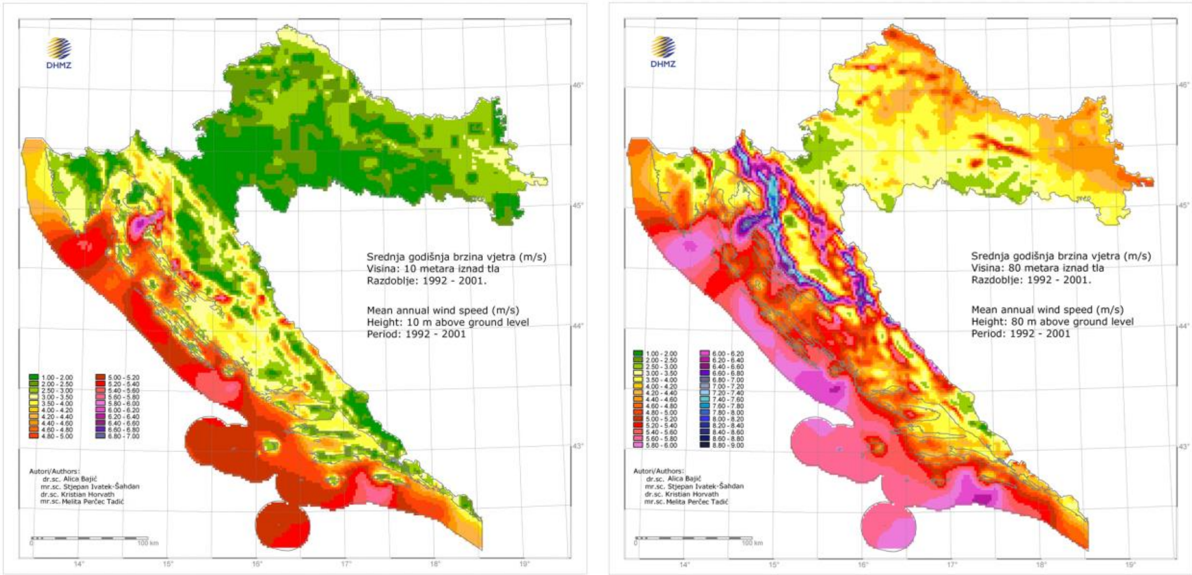



Figure 3.10 – *Mean annual wind speed in Croatia (m/s) [22].*

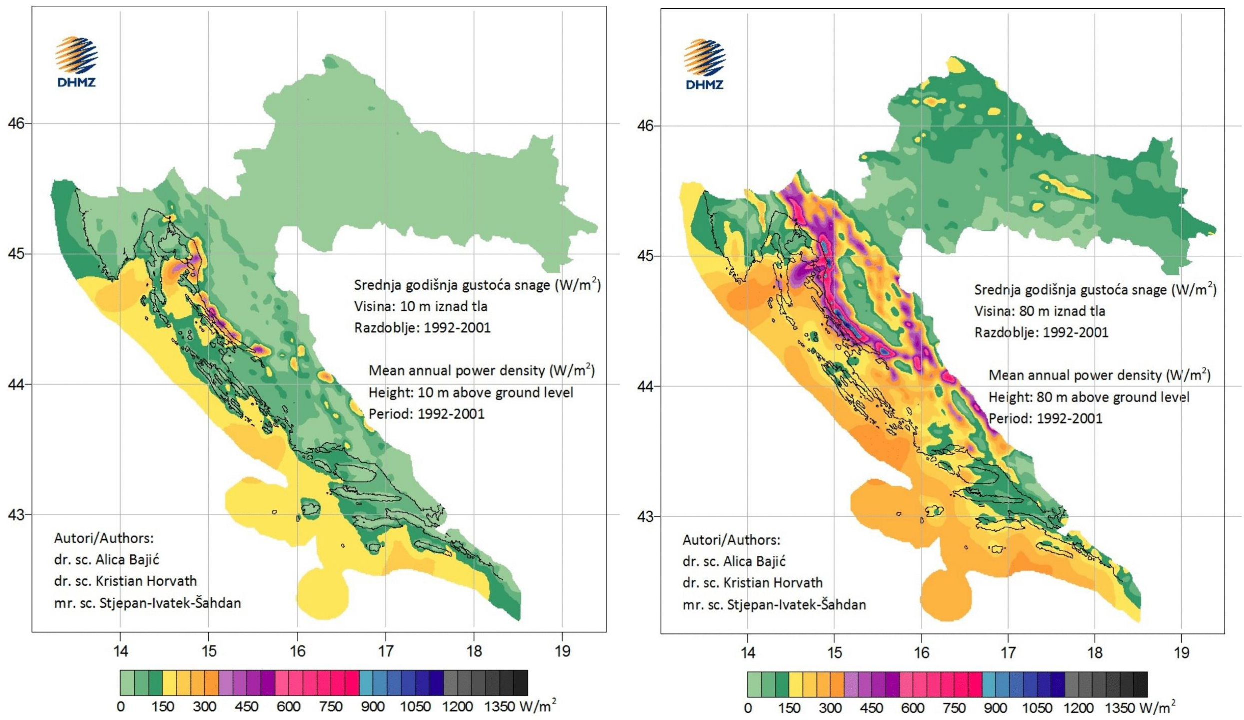



Figure 3.11 *Mean annual power density in Croatia (W/m$^2$) [22].*

Table 3.1 shows monthly mean and extreme values of climatological parameters in the period from 1999 to 2018 (according to data of the Croatian Meteorological and Hydrological Service). Osijek is at an average altitude of 90 m, with an average temperature of 11 ℃ during the year, and with an average temperature of -0.6 ℃ in January and 21.7 ℃ in July. The lowest measured temperature was -27.1 ℃ in July, while the highest

measured temperature was 40.3℃ in August and September. The total annual average rainfall is 692.9 mm and the average number of days with snow cover is 23.

*Table 3.1 Monthly mean and extreme values of climatological parameters for Osijek [23].*

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Avg | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Temperature [°C]** | | | | | | | | | | | | |
| **Mean** | -0.6 | 1.3 | 6.3 | 11.6 | 16.6 | 19.8 | 21.7 | 20.9 | 16.7 | 11.3 | 5.8 | 1.3 |
| **Absolute maximum** | 19 | 23 | 26.9 | 30.9 | 36 | 39.6 | 40.3 | 40.3 | 37.4 | 30.5 | 25.8 | 21.3 |
| **Absolute minimum** | -27.1 | -26.4 | -21.0 | -6.8 | -3.0 | 1.0 | 4.7 | 5.1 | -1.2 | -8.6 | -15.7 | -23.2 |
| **Daylight hours [h]** | | | | | | | | | | | | |
| **Total** | 59.7 | 86.3 | 142.9 | 182.1 | 226.5 | 247.1 | 276.3 | 261.6 | 191.8 | 150.4 | 75.1 | 52.0 |
| **Rainfall** | | | | | | | | | | | | |
| **Volume [mm]** | 45.4 | 42.7 | 45.7 | 57.8 | 70.3 | 82.4 | 61.3 | 58.8 | 55.5 | 59.5 | 59.8 | 53.7 |
| **Maximum snow height [m]** | 52 | 93 | 49 | 22 | - | - | - | - | - | - | 40 | 60 |
| **Number of days** | | | | | | | | | | | | |
| **Clear** | 3 | 4 | 5 | 5 | 5 | 6 | 9 | 11 | 9 | 7 | 3 | 2 |
| **Foggy** | 6 | 4 | 2 | 1 | 0 | 0 | 1 | 1 | 2 | 4 | 6 | 7 |
| **Rainy** | 7 | 7 | 10 | 12 | 13 | 12 | 10 | 9 | 9 | 10 | 11 | 10 |
| **With frost** | 7 | 7 | 7 | 2 | 0 | 0 | 0 | 0 | 0 | 3 | 6 | 8 |
| **With snow** | 6 | 6 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 5 |
| **Icy day ($t_{min}$ ≤ -10°C)** | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| **Frosty day ($t_{min}$ < 0°C)** | 9 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 6 |
| **Cold day ($t_{min}$ < 0°C)** | 23 | 18 | 11 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 8 | 19 |
| **Warm day ($t_{max}$ ≥ 25°C)** | 0 | 0 | 0 | 2 | 11 | 18 | 24 | 23 | 12 | 2 | 0 | 0 |
| **Hot day ($t_{max}$ ≥ 30°C)** | 0 | 0 | 0 | 0 | 2 | 6 | 11 | 10 | 3 | 0 | 0 | 0 |

# 4. Current energy demand overview for the public building

## 4.1. The electrical infrastructure of the exemplary object and consumption analysis

In order to implement different strategies for the increase of energy efficiency, it is necessary to analyze the electrical installation infrastructure of the object, as well as existent power supply units and the consumption of electrical energy in the exemplary object.

Here, building in Trpimirova and Cara Hadrijana street as a part of the Faculty of Electrical Engineering, Computer Science and Information Technology Osijek, will be referred to as exemplary objects.

### 4.1.1. The power supply of the building in Trpimirova street

Building in Trpimirova street is supplied from the low voltage distribution network. Point of common coupling of building and network is integrated cabinet placed outside, on the wall of the building equipped with electricity meter. Metering cabinet (Figure 4.1 left) and main distribution cabinet (Figure 4.1 right) are connected PP00-Y 4 x 35 + 25 mm$^2$ with cooper cable. Main fuses are rated at 200 A with gL characteristic. In the main distribution cabinet of the building, 4 low voltage feeders lead to building loads. Each feeder is protected with 35 A fuse with gL characteristic and uses PP00-Y 5 x 16 mm$^2$ copper cable. Single line diagram of main distribution cabinet is given in Figure 4.2.

Considering that the object was connected to the power grid infrastructure during the object construction period, the document that provides the permission for the object connection was not available for this study at the time of creation.

Furthermore, 10 kW photovoltaic system was installed on the building roof in Trpimirova street and integrated into electric power network. AC side of the photovoltaic system inverter is connected by PP00-A 4 x 16 mm$^2$ + P/F 16 mm$^2$ cable to the metering cabinet (distribution network). Single line diagram of photovoltaic system is given in Figure 4.3.

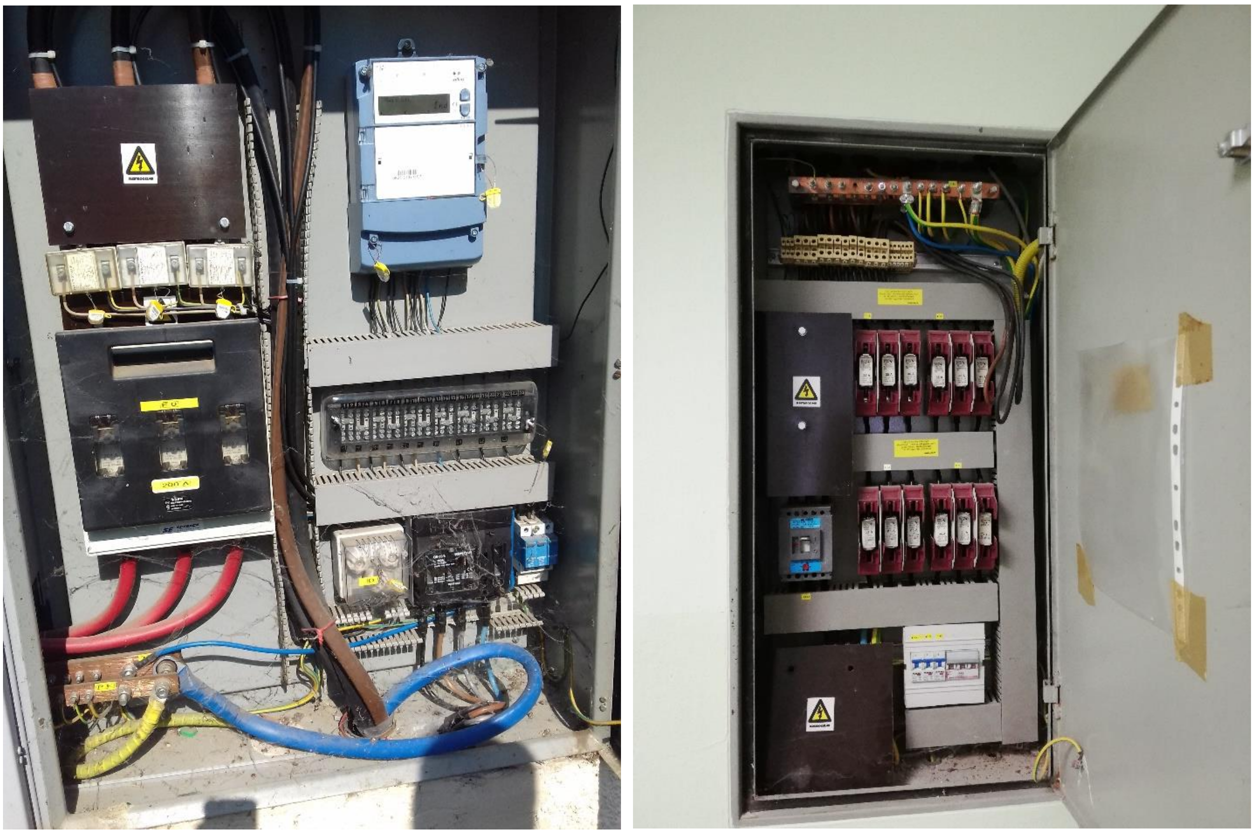


Figure 4.1 – *Metering and main distribution cabinet in building in Trpimirova street.*

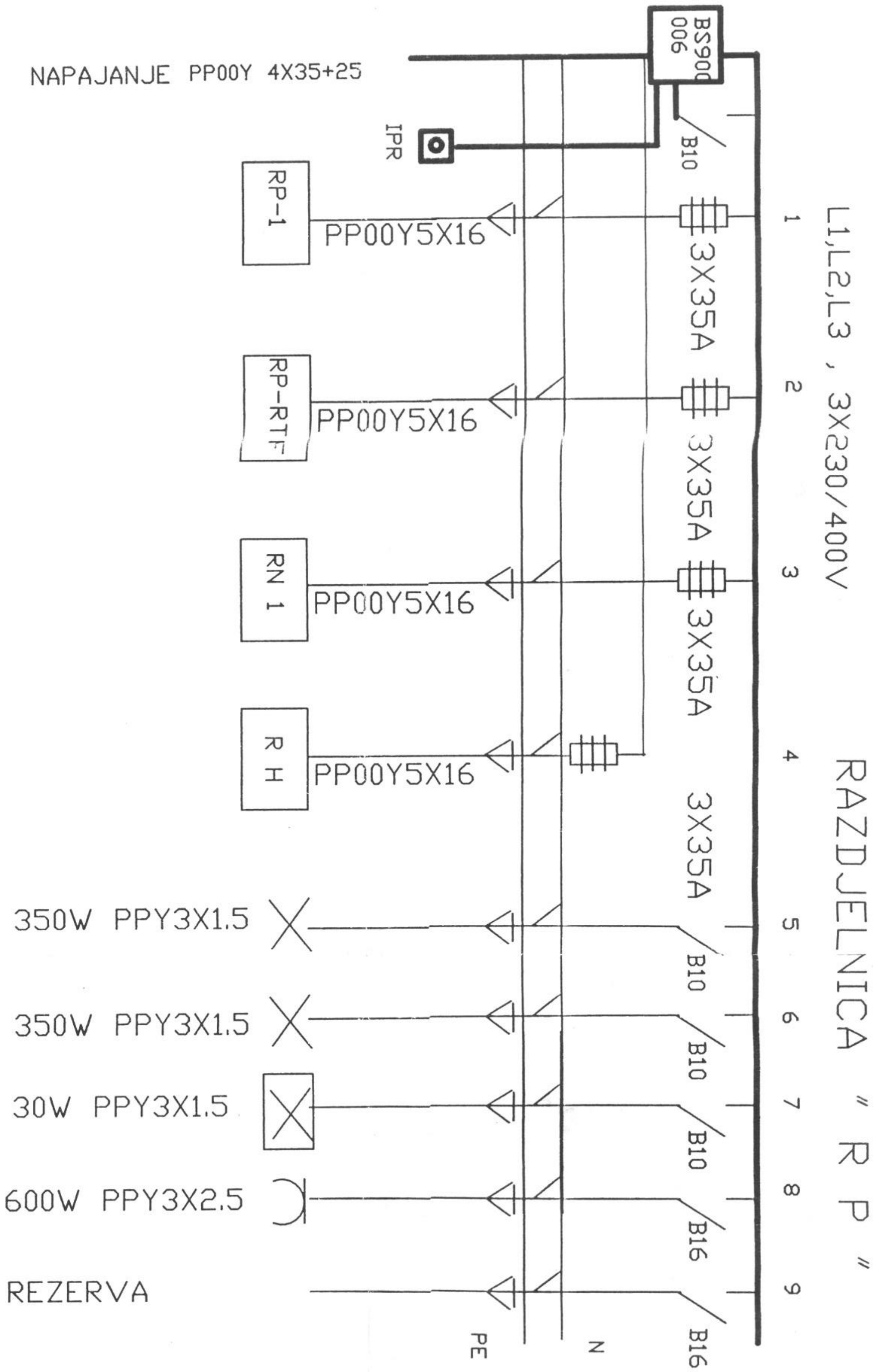



Figure 4.2 *Main distribution cabinet single line diagram of the building in Trpimirova street.*

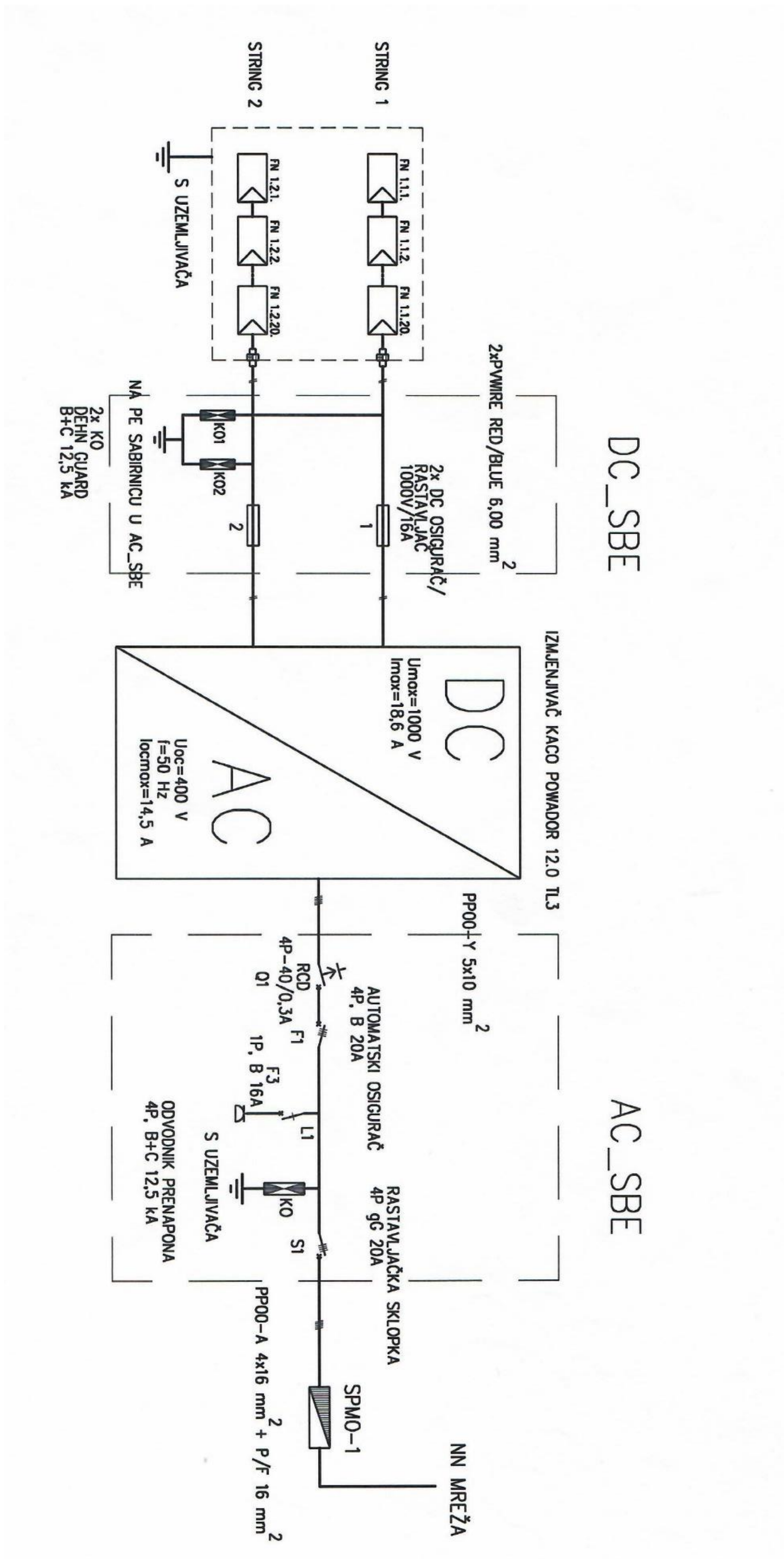



Figure 4.3 *Single line diagram of 10 kW photovoltaic plant on the building roof in Trpimirova street.*

## 4.1.2. The power supply of the building in Cara Hadrijana street

Building in Cara Hadrijana street is supplied from the low voltage distribution network. Point of common coupling of building and network is integrated cabinet placed outside, on the wall of the building equipped with electricity meter. Metering cabinet (Figure 4.4) and main distribution cabinet (Figure 4.5) are connected with XP00-A 2 x (4 x 185 mm2) cable. Main fuses are rated at 630 A with gG characteristic. In the main distribution cabinet of the building, 6 low voltage feeders lead to other building cabinets and 1 reserve feeder for elevator which is not yet constructed. Feeders are protected with various rated currents from 25 A to 280 A with gG characteristic and use various cables which are given in Figure 4.6.

Figure 4.4 *Metering cabinet on wall building in Cara Hadrijana street.*

Figure 4.5 *Main distribution cabinet in the building in Cara Hadrijana street*

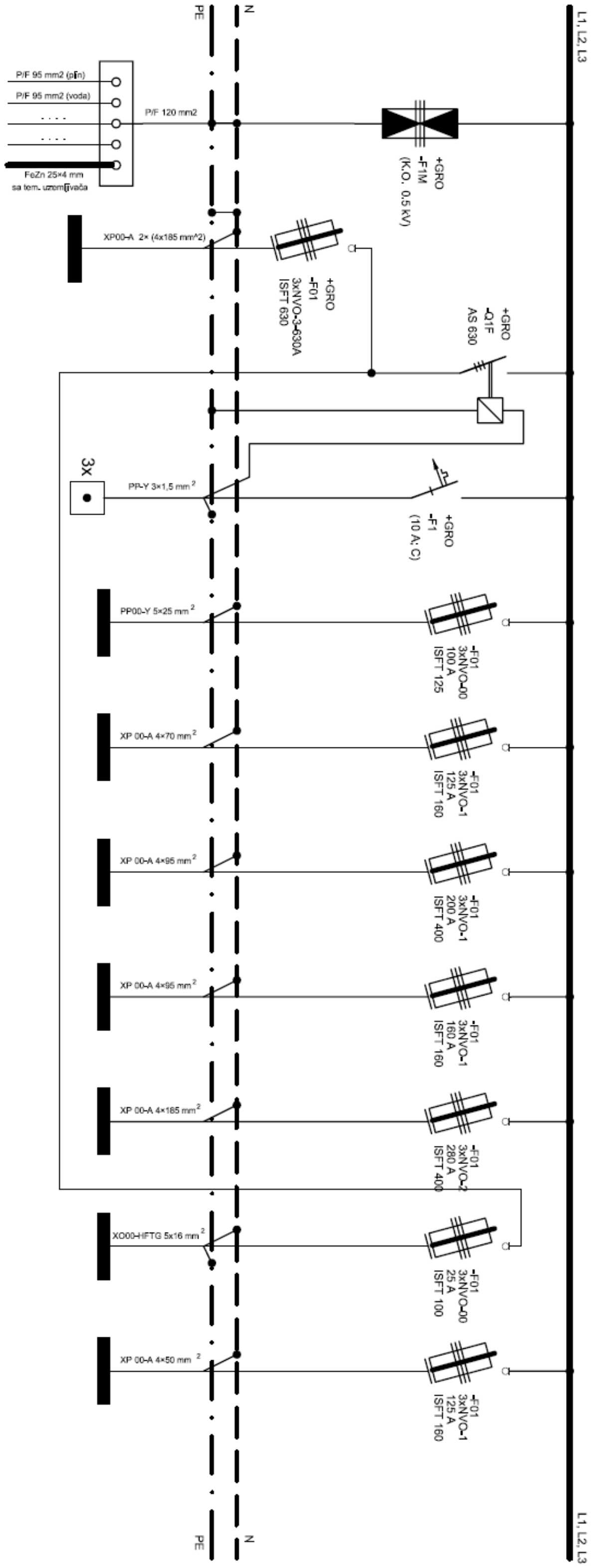



Figure 4.6 *Single line diagram of the power supply of building in Cara Hadrijana street.*

## 4.1.3. Description and classification of the consumers in the objects

In the analyzed objects, various rooms are located with different types of electrical consumers. In this section typical consumer types are described and the lighting system, as the most common consumer, is described in the separate section. It is important to emphasize that similar consumers are used in both faculty buildings therefore, consumer will not be analyzed separately for each building.

One of the most important types of electrical consumers are computers, computer servers and other computer's additional devices, shown in Figure 4.7. Computers are usually placed in computer laboratories and employee's offices. There are over 200 computers located in both buildings.

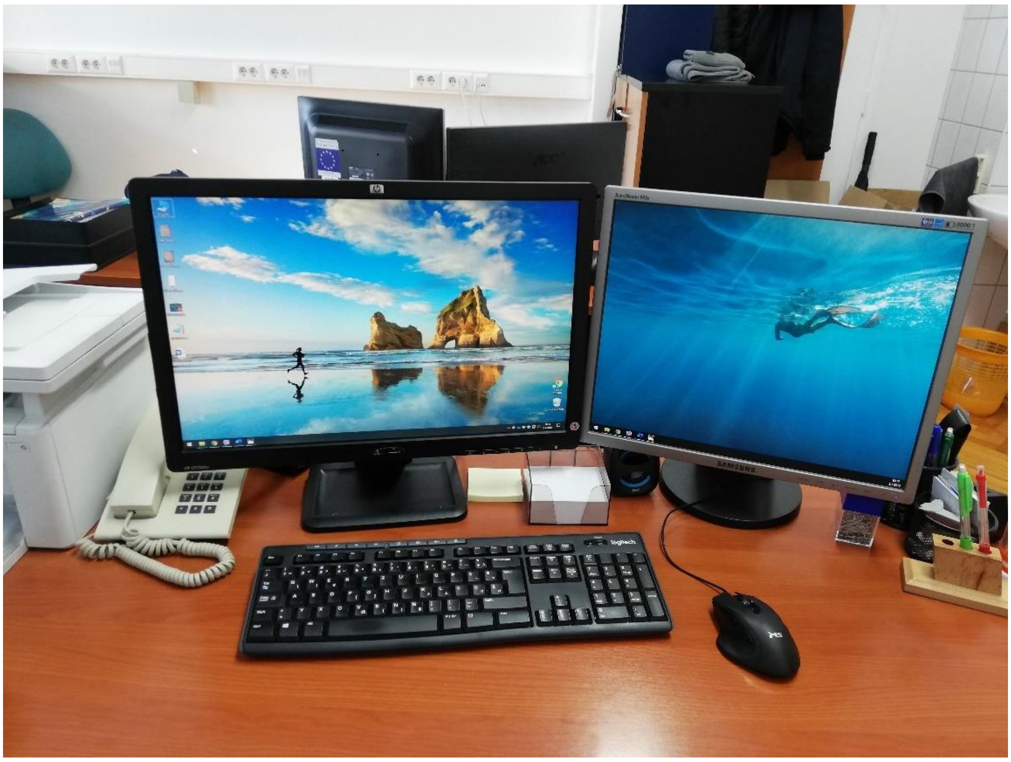


Figure 4.7 *Typical computer from the employee's office.*

For the temperature control and ventilation of the rooms, air conditioning systems are usually used. These systems can use a significant amount of power, especially when the climate conditions imply long times of active work. In the exemplary facilities, there are over 50 air-conditioning units, with the various individual capacity and electric power ratings. Figure 4.8 shows one classroom air-conditioning device while Figure 4.9 shows one office air-conditioning device in the building in Cara Hadrijana street.

Figure 4.8 *Indoor and outdoor unit of the air-conditioning system for classrooms.*

Figure 4.9 *Indoor and outdoor unit of the air-conditioning system in office.*

Furthermore, in the laboratories, there are different devices and equipment dedicated to practical teaching and research activities. Bellow some of the most important devices will be described.

One of the laboratories in the exemplary object in Trpimirova street is the Electric machines laboratory. The experimental setup for the electric machine experiments is depicted in Figure 4.10. This setup is used in the practical courses for students and research activities.

In the Power electronics laboratory, photovoltaic system emulator which consists of two 5 kW programmable DC power supplies and 10 kW photovoltaic inverter depicted in Figure 4.11 is used for practical courses and research activities.


Figure 4.10 *Laboratory setup for electric machines experiments in Electric machines laboratory in building in Trpimirova street.*


Figure 4.11 *Photovoltaic system emulator in Power electronics laboratory in building in Trpimirova street.*

Part of the Laboratory for renewable energy sources is artificial light source rated at 5 kW supplied with three-phase 5 kW autotransformer depicted in Figure 4.12.

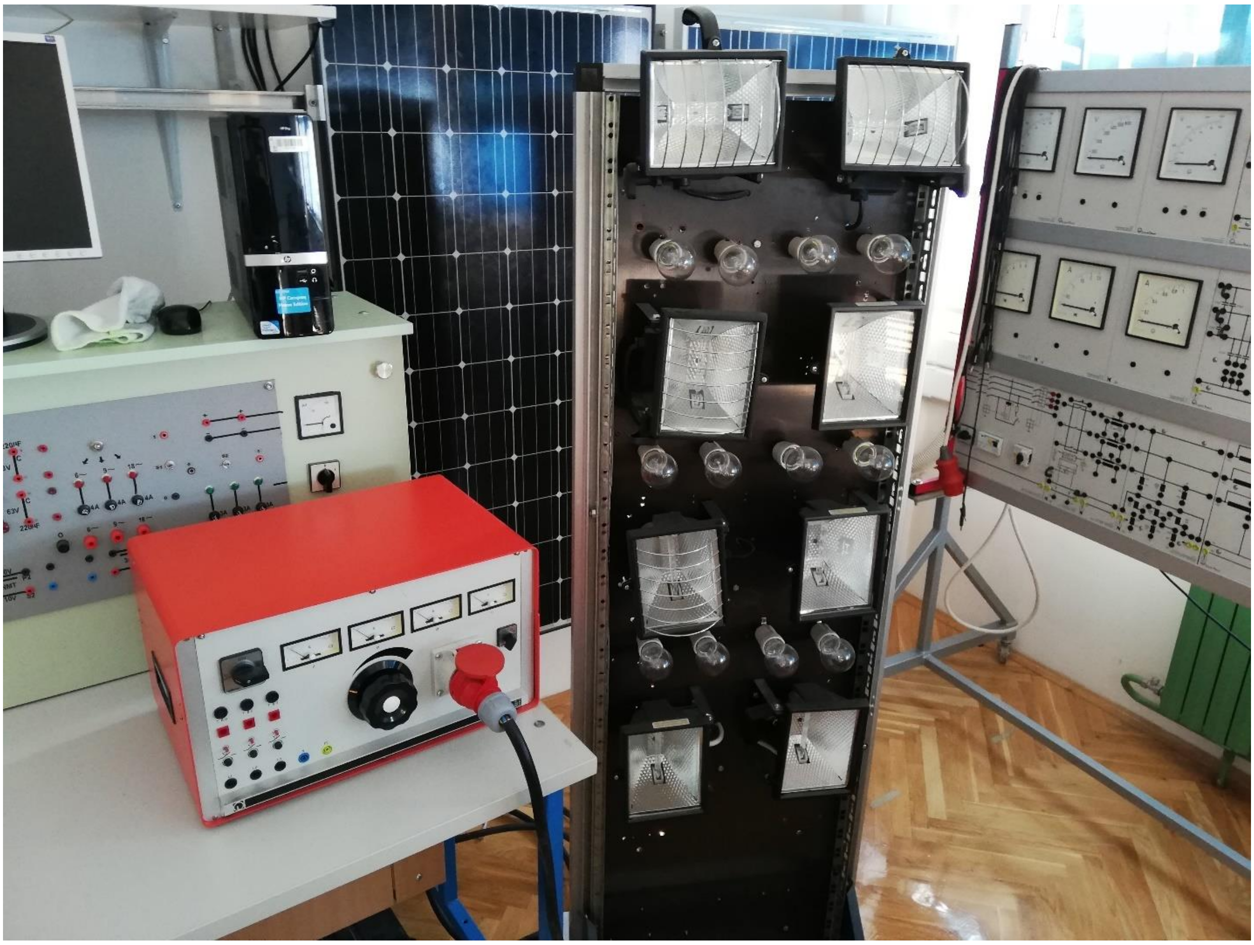


Figure 4.12 *Artificial light source in the Laboratory for renewable energy sources in building in Trpimirova street.*

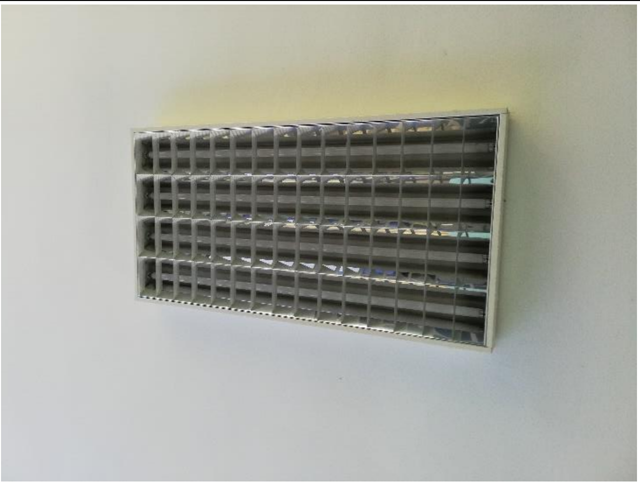
Furthermore, in the Laboratory for process automation and robotics in building in Cara Hadrijana street, robot arm depicted in Figure 4.13 is used for practical courses and research activities.

Figure 4.13 *Robot arm in Laboratory for process automation and robotics in building in Cara Hadrijana street*

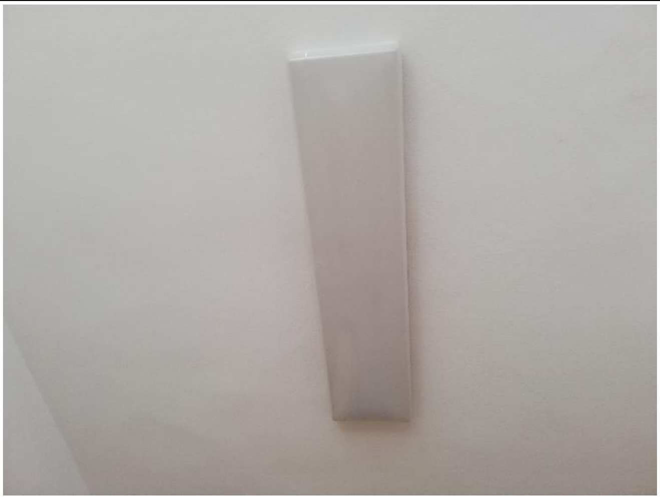
## 4.1.4. Lighting system

Visual inspection of the objects has been done in order to analyze what kind of lighting is used in the exemplary objects. Analysis shown that lighting system in the exemplary objects are based on the incandescent (metal-halogen) and fluorescent light bulbs. A brief description of most frequently used types of lights is given in 0.

*Table 4.1 Description of different types of light.*

| Light type | Description | Appearance |
|---|---|---|
| Type 1 | – Installation type: Ceiling light<br>– Optics: Aluminum raster<br>– Light sources: 4 fluo TL-D sources 36 W<br>– Electromagnetic ballast |  |
| Type 2 | – Installation type: Ceiling light<br>– Optics: Aluminum raster<br>– Light sources: 4 fluo TL-D sources 36 W<br>– Electromagnetic ballast |  |
| Type 3 | – Installation type: Ceiling light<br>– Optics: Diffuse plastic<br>– Light sources: 1 fluo TL-D sources 18 W<br>– Electromagnetic ballast |  |

| Light type | Description | Appearance |
|---|---|---|
| Type 4 | – Installation type: Ceiling light<br>– Optics:<br>– Diffuse plastic<br>– Light sources: 1 fluo TL-D sources 18 W<br>– Electromagnetic ballast |  |
| Type 5 | – Installation type: Ceiling light<br>– Optics: Safety glass<br>– Light sources: 1 metal-halogen source 40 W |  |

| Light type | Description | Appearance |
|---|---|---|
| Type 6 | – Installation type: Ceiling light<br>– Optics: Aluminium raster<br>– Light sources: 2 fluo TL-D sources 36 W |  |
| Type 7 | – Installation type: Ceiling light<br>– Optics: Diffuse plastic<br>– Light sources: 2 fluo TL-D sources 36 W |  |

| Light type | Description | Appearance |
| --- | --- | --- |
| Type 8 | – Installation type: Outdoor light<br>– Optics: Aluminum raster<br>– Light sources: 1 metal-halogen source 100 W<br>– Electromagnetic ballast<br>– Total number: 9 |  |

### 4.1.5. Analysis of the energy consumption of the buildings

In order to establish appropriate measures for the enhancement of energy efficiency, it is necessary to analyze the energy consumption in the exemplary objects. A detailed analysis is given for the period from January 2018. to December 2018. This period is chosen as a reference since it covers the entire student year, calendar year and all seasons. During the analysis, all relevant parameters for the energy consumption were taken from the electricity bills for the exemplary object.

Figure 4.14 depicts parameters of electricity consumption in October 2019 from electricity meters on two measurement devices (two objects of the Faculty of Electrical Engineering, Computer Science and Information Technology Osijek).

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Datum računa: 31.10.2019
Mjesto izdavanja: ZAGREB
Datum dospijeća: 09.12.2019
R-1

Podaci o kupcu:
Šifra kupca: 10002919
Kupac: FAKULTET ELEKTROTEHNIKE, RAČUN
Ulica i kbr.: KNEZA TRPIMIRA 2 /B
Mjesto: OSIJEK
OIB: 95494259952

Broj obračuna po mjernim mjestima: 2

FAKULTET ELEKTROTEHNIKE, RAČUNARSTVA I INFORMACIJSKIH TEHNOL
KNEZA TRPIMIRA 2 /B
31000 OSIJEK

**Račun: 0010002919-191020-6 za opskrbu i korištenje mreže, razdoblje 10/2019**

| Opis | Jed.mjere | Količina | Jed.cijena | Iznos kn |
|---|---|---|---|---|
| **P PRO** | | | | |
| Radna energija po višoj dnevnoj tarifi | kWh | 21359 | 0,4481 | 9.570,96 |
| Radna energija po nižoj dnevnoj tarifi | kWh | 9155 | 0,2466 | 2.257,62 |
| Naknada za poticanje proizvodnje iz obnovljivih izvora | kWh | 30514 | 0,1050 | 3.203,98 |
| Trošarine za neposlovnu uporabu električne energije | kWh | 30514 | 0,00750 | 228,86 |
| Opskrbna naknada | mjesec | 1 | 35,00 | 35,00 |
| UKUPAN IZNOS ZA KORIŠTENJE MREŽE I USLUGA | | | | 9.768,84 |
| UKUPAN IZNOS ZA OPSKRBU | | | | 15.296,42 |
| Porezna osnovica | | | | 25.065,26 |
| PDV 13% | | | | 3.258,48 |
| **UKUPAN IZNOS RAČUNA** | | | | **28.323,74** |

Isporučena električna energija je 100% iz obnovljivih izvora
Registrirajte se na aplikaciju "Moj račun" i pregledajte svoje račune, uplate i promet - www.hep.hr/opskrba

Figure 4.14 *The electricity bill for two objects of the Faculty of Electrical Engineering, Computer Science and Information Technology Osijek (summarized bill for electricity consumption) for October 2019.*

One electricity bill with the most important parameters is given in Figure 4.15. The bill is split into several segments. The red squared segment shows the total parameters taken from the two electricity meters of Faculty of Electrical Engineering, Computer Science and Information Technology Osijek buildings in Trpimirova and Cara Hadrijana street. It is clear that the metering is double tariff for active power (RVT and RNT items). In the electricity bill, there are calculated active power consumption for the month, considering the consumption in the lower and higher tariff, expressed in kWh, as well as the equivalent cost for the power usage expressed in kunas (HRK). It can be seen that the electricity contract price for the higher tariff is 0.4481 HRK/kWh and for the lower tariff is 0.2466 HRK/kWh. For the reactive power, although double-tariff metering is shown, the reactive power energy consumption is charged as it is a single rate tariff. Lower tariff is charged in the period 10 pm to 8 am during the summertime or between 9 pm until 7 am during the wintertime, while the higher tariff is charged in the remaining period. Regarding the purpose of the object, the highest consumption is during the higher tariff

period. Also, cost of the incentives for the renewable energy sources (to cover feed-in tariffs) of 0.105 HRK/kWh and cost for non-business usage of electricity: 0.0075 HRK/kWh are presented.

The blue squared segment of the bill is dedicated to the costs for the connection to the transmission and distribution power network, charged active power in both tariffs (RVT and RNT), charged reactive power (JEN), charged exceeding reactive power and monthly cost for measurement registration and calculation of the bill 41.30 HRK. The electricity contract price for the higher tariff is 0.21 HRK/kWh and for the lower tariff is 0.10 HRK/kWh. Furthermore, the contracted power, the amount of 44.50 HRK per kW of the active power has to be additionally paid.

**FAKULTET ELEKTROTENIKE, RAČUNARSTVA I INFORMACIJSKIH TEHNOLO OSIJEK, KNEZA TRPIMIRA 2/B**
**Broj obračunskog mjesta: 0808003628** **Model: HEP PRO** **Brojilo: 51077197** **Obr.: 1**

| OBRAČUN OPSKRBE | | tar.stavka | | konstanta | potrošak | jed.cijena | iznos kn |
|---|---|---|---|---|---|---|---|
| 01.10.2019 | 01.11.2019 | RVT | Radna energija po višoj dnevnoj tarifi | 40 | 13240 | 0,4481 | 5.932,84 |
| | | RNT | Radna energija po nižoj dnevnoj tarifi | 40 | 4605 | 0,2466 | 1.135,59 |
| | | OIE | Naknada za poticanje proizvodnje iz obnovljivih izvora | | 17845 | 0,1050 | 1.873,73 |
| 01.10.2019 | 01.11.2019 | TRNP | Trošarine za neposlovnu uporabu električne energije | | 17845 | 0,00750 | 133,84 |
| UKUPAN IZNOS OPSKRBE | | | | | | | 9.076,00 |

**Vaša trenutna prosječna cijena iznosi: 0,3961.**
**Podatak se može koristiti u svrhu izračuna otkupne cijene električne energije koju je kupac s vlastitom proizvodnjom isporučio u mrežu ili za izračun i kontrolu otkupne cijene kod samoizdanog računa.**

| OBRAČUN ZA KORIŠTENJE MREŽE | | brojilo | tar.stavka | | stanje od | stanje do | konstanta | potrošak | jed.cijena | iznos kn |
|---|---|---|---|---|---|---|---|---|---|---|
| 01.10.2019 | 01.11.2019 | 51077197 | RVT | R1 | 4660.449 | 4991.448 | 40 | 13240 | 0,21 | 2.780,40 |
| | | | RNT | R2 | 5747.630 | 5862.746 | 40 | 4605 | 0,10 | 460,50 |
| | | | JEN | J1 | 3463.607 | 3562.303 | 40 | 3948 | | |
| | | | JEN | J2 | 1369.229 | 1405.887 | 40 | 1466 | | |
| | | | SVT | S1 | 1.661 | | 40 | 66,45 | | |
| angažirana snaga u doba više tarife | | | | | | | | 66,00 | 38,50 | 2.541,00 |
| naknada za mjernu uslugu (broj mjeseci) | | | | | | | | 1,00 | 41,30 | 41,30 |
| ƐUPAN IZNOS ZA KORIŠTENJE MREŽE PRIJENOSA I DISTRIBUCIJE | | | | | | | | | | 5.823,20 |
| UKUPAN IZNOS OPSKRBA I MREŽA | | | | | | | | | | 14.899,20 |

**FAKULTET ELEKTROTENIKE, RAČUNARSTVA I INFORMACIJSKIH TEHNOLO OSIJEK, CARA HADRIJANA 10/B**
**Broj obračunskog mjesta: 0808606425** **Model: HEP PRO** **Brojilo: 99652575** **Obr.: 2**

| OBRAČUN OPSKRBE | | tar.stavka | | konstanta | potrošak | jed.cijena | iznos kn |
|---|---|---|---|---|---|---|---|
| 01.10.2019 | 01.11.2019 | RVT | Radna energija po višoj dnevnoj tarifi | 80 | 8119 | 0,4481 | 3.638,12 |
| | | RNT | Radna energija po nižoj dnevnoj tarifi | 80 | 4550 | 0,2466 | 1.122,03 |
| | | OIE | Naknada za poticanje proizvodnje iz obnovljivih izvora | | 12669 | 0,1050 | 1.330,25 |
| 01.10.2019 | 01.11.2019 | TRNP | Trošarine za neposlovnu uporabu električne energije | | 12669 | 0,00750 | 95,02 |
| UKUPAN IZNOS OPSKRBE | | | | | | | 6.185,42 |

| OBRAČUN ZA KORIŠTENJE MREŽE | | brojilo | tar.stavka | | stanje od | stanje do | konstanta | potrošak | jed.cijena | iznos kn |
|---|---|---|---|---|---|---|---|---|---|---|
| 01.10.2019 | 01.11.2019 | 99652575 | RVT | R1 | 07748.299 | 07849.792 | 80 | 8119 | 0,21 | 1.704,99 |
| | | | RNT | R2 | 04794.792 | 04851.669 | 80 | 4550 | 0,10 | 455,00 |
| | | | JEN | J1 | 00002.477 | 00002.477 | 80 | 0 | | |
| | | | JEN | J2 | 03554.775 | 03627.273 | 80 | 5800 | | |
| | | | SVT | S1 | 0.484 | | 80 | 38,74 | | |
| angažirana snaga u doba više tarife | | | | | | | | 39,00 | 38,50 | 1.501,50 |
| ~rekomjerno preuzeta jalova energija | | | | | | | | 1.619,00 | 0,15 | 242,85 |
| ~knada za mjernu uslugu (broj mjeseci) | | | | | | | | 1,00 | 41,30 | 41,30 |
| UKUPAN IZNOS ZA KORIŠTENJE MREŽE PRIJENOSA I DISTRIBUCIJE | | | | | | | | | | 3.945,64 |
| UKUPAN IZNOS OPSKRBA I MREŽA | | | | | | | | | | 10.131,06 |

Figure 4.15 *The electricity bill for the exemplary objects in Trpimirova and Cara Hadrijana street for October 2019.*

Table 4.2 shows an overview of the electricity consumption and electricity cost from January to December 2018 for both buildings. Net electricity consumption of the building in Trpimirova street is resulting from total building consumption reduced by electricity production from 10 kW photovoltaic system on the roof of the building in Trpimirova street. Building in Cara Hadrijana street is represented by total consumption only.

*Table 4.2 – Electrical energy consumption of the buildings during 2018.*

| | **Building in Trpimirova street** | | **Building in Cara Hadrijana street** | |
|---|---|---|---|---|
| | **Net consumption [MWh]** | **Total cost [HRK]** | **Total consumption [MWh]** | **Total cost [HRK]** |
| **Jan 2018** | 19.416 | 17,846.00 | 6.577 | 6,068.00 |
| **Feb 2018** | 18.248 | 16,743.00 | 6.517 | 5,890.00 |
| **Mar 2018** | 19.693 | 19,278.00 | 8.605 | 7,375.00 |
| **Apr 2018** | 17.751 | 17,763.00 | 7.769 | 7,062.00 |
| **May 2018** | 20.389 | 20,642.00 | 8.031 | 7,250.00 |
| **Jun 2018** | 20.554 | 21,985.00 | 6.976 | 6,626.00 |
| **Jul 2018** | 18.024 | 18,413.00 | 7.011 | 6,259.00 |
| **Aug 2018** | 15.49 | 15,436.00 | 6.185 | 5,915.00 |
| **Sep 2018** | 17.056 | 17,094.00 | 7.534 | 7,032.00 |
| **Oct 2018** | 20.388 | 20,635.00 | 8.964 | 8,054.00 |
| **Nov 2018** | 21.16 | 21,249.00 | 9.45 | 8,264.00 |
| **Dec 2018** | 19.161 | 18,865.00 | 9.333 | 8,259.00 |
| **Total** | 227.33 | 225,949.40 | 92.953 | 84,055.58 |

Table 4.2 shows the relatively constant electricity consumption during the year for building in Trpimirova street while the electricity consumption of building in Cara Hadrijana street has variability during the year. Slight consumption decline is visible during the August and September during the examination and vacation period when no teaching and exams are arranged. From the October to December, electricity consumption in building in Cara Hadrijana street is higher. Analyzing the annual electricity bills, total electricity consumption of both buildings was 320,283.43 kWh with the total cost of 310,004.98 HRK.

Graphical interpretation of the electricity consumption is depicted in Figure 4.16 and Figure 4.17 which show energy consumption per month, expressed in MWh, in the period from January to December 2018 for buildings in Trpimirova and Cara Hadrijana street, respectively.

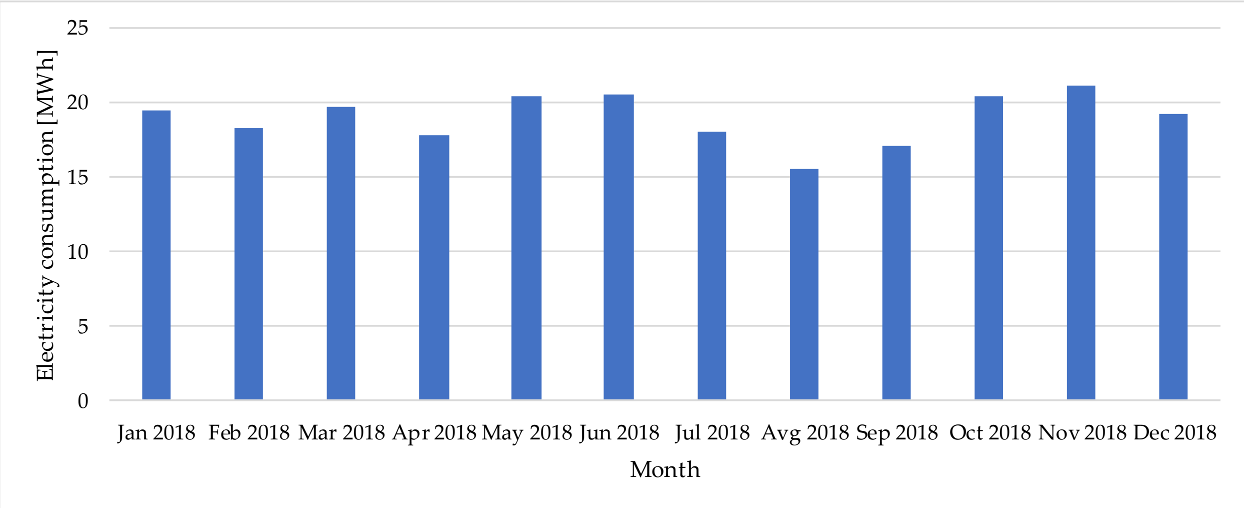


Figure 4.16 *Electricity consumption per month of the building in Trpimirova street during 2018.*

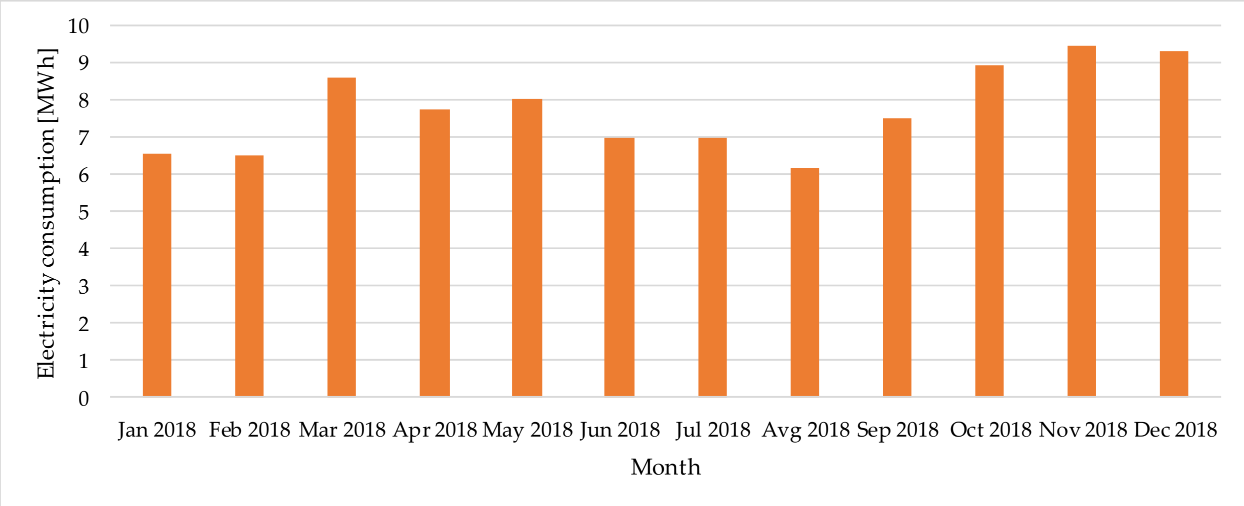


Figure 4.17 *Electricity consumption per month of the building in Cara Hadrijana street during 2018.*

# 5. The overview of the potential for the available renewable energy resources

## 5.1. Solar energy

Because of its favourable geographical location, Republic of Croatia has large solar energy potential. Annual global solar irradiation on horizontal surface is given in Figure 5.1. Global irradiation and solar electricity potential for the optimally inclined photovoltaic modules of the Republic of Croatia are shown in Figure 5.2. It is visible that continental areas have slightly lower annual solar irradiated energy. Nevertheless, continental part, in which Osijek is situated has great solar energy potential.

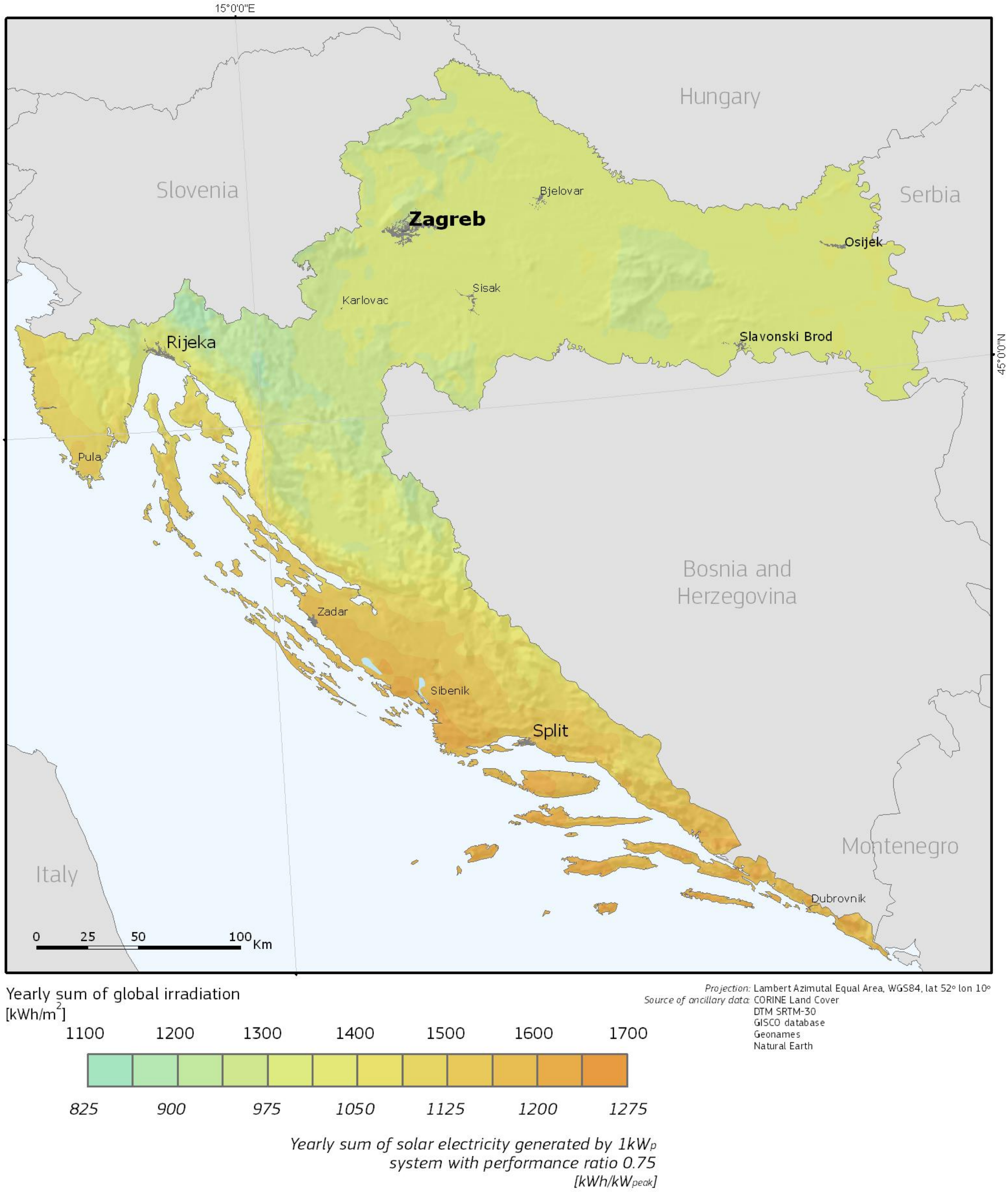


Figure 5.1 – *Annual global solar irradiation on horizontal surface in Republic of Croatia [24].*

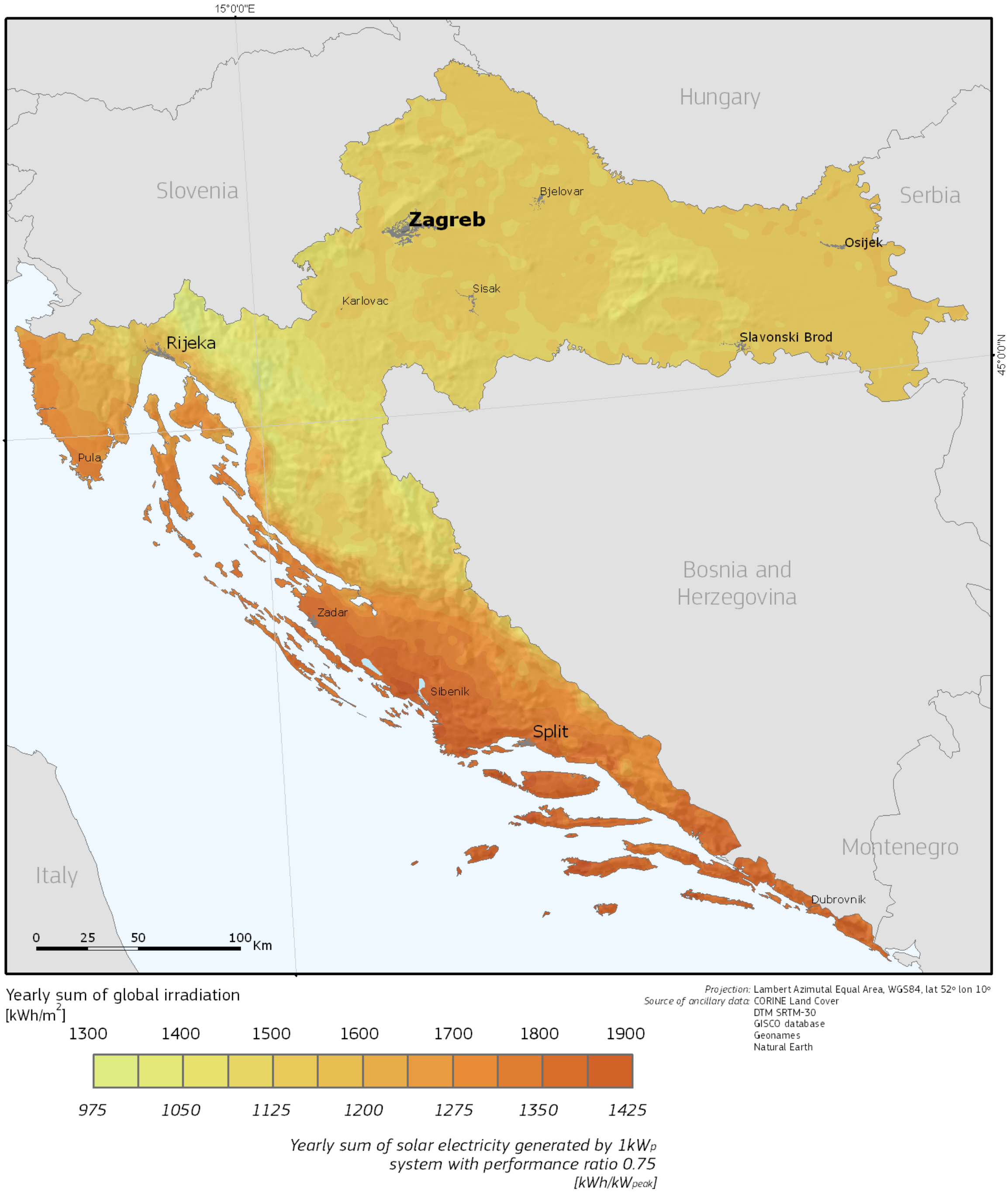


Figure 5.2 – *Annual global solar irradiation on optimally inclined surface in Republic of Croatia [24].*

Average annual solar irradiation on horizontal plane in Osijek region is around 1282 kWh/m2 while annual optimal inclination angle of photovoltaic modules and solar thermal collectors is 34° [24]. Highest solar irradiation occurs in summer months (June – August) while the lowest occur in winter months (November - January). Distribution of global solar irradiation for every month and annual solar irradiation for Osijek is given in Table 5.1.

*Table 5.1 – Global monthly and annual solar irradiation for Osijek [24].*

| Month | Global |
|---|---|
| | kWh/m² |
| January | 40.8 |
| February | 41.78 |
| March | 90.86 |
| April | 133.58 |
| Max | 172.2 |
| June | 198.09 |
| July | 187.46 |
| August | 138.18 |
| September | 116.22 |
| October | 92.04 |
| November | 42.67 |
| December | 28.21 |
| Total | 1,282.09 |

Due to changes in the elevation angle of the Sun during the day, month and year, the value of the radiated energy that reaches the surface changes. More energy is received only by the surface at which the angle changes and adjusts to the position of the Sun each month, or even more if the receiving surface follows the Sun's trajectory daily. Nevertheless, the optimal slope of the collector should be 30-40°. The optimum slope for the summer period is 20-30° and for winter is about 60°.

## 5.2. Wind energy

In order to harness wind energy, one of the important factors is the existing road and railway structure and the accessibility of the terrain on which wind farms are planned. Also important is the existence and coverage of the territory with medium and high voltage power grid. Such infrastructure factors, necessary for successful connection of wind power plants, include the existence of suitable transformer stations and the possibility of connection to them. The most significant parameters for wind turbine performance are speed and direction of the wind at the site. Therefore, wind energy potential will be analysed with two separate measurements, first from weather station of Croatian Meteorological and Hydrological Service located in village Čepin near Osijek and second located at the roof of the building in Trpimirova street.

Measurements of wind speed in 2015, taken by weather station in Čepin near Osijek, are given in Figure 5.3. It can be seen that highest mean wind speed occur in March and April while the lowest in December.

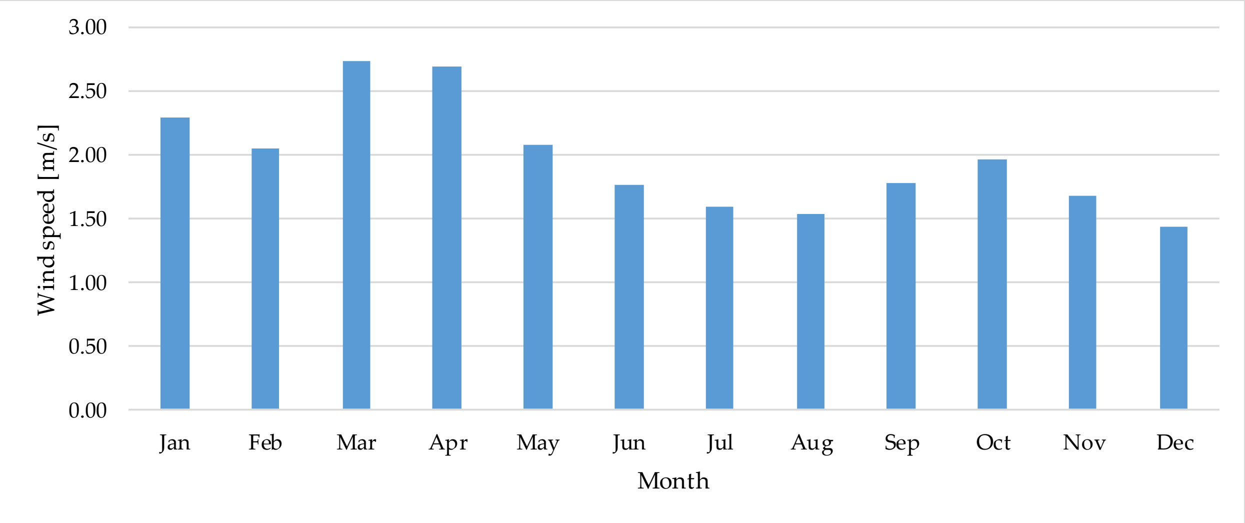


Figure 5.3 *Monthly mean values of wind speed for 2015 at the weather station in Čepin near Osijek.*

In order to asses wind energy potential for certain region or microlocation, wind speed measurements in surrounding area are needed. For this purpose, measurements taken by weather station located on the roof of the faculty building in Trpimirova street are also analysed. Figure 5.4 shows frequency distribution of wind speed based on 1-hour average values in 2018. It is visible from the figure that the highest frequency of wind speed occurs from 0 to 1 m/s.

Furthermore, to analyse the direction of the wind on the microlocation, rose of winds is constructed (Figure 5.5). It is visible that the most frequent wind speed direction is between East and South while the most frequent is South-East.

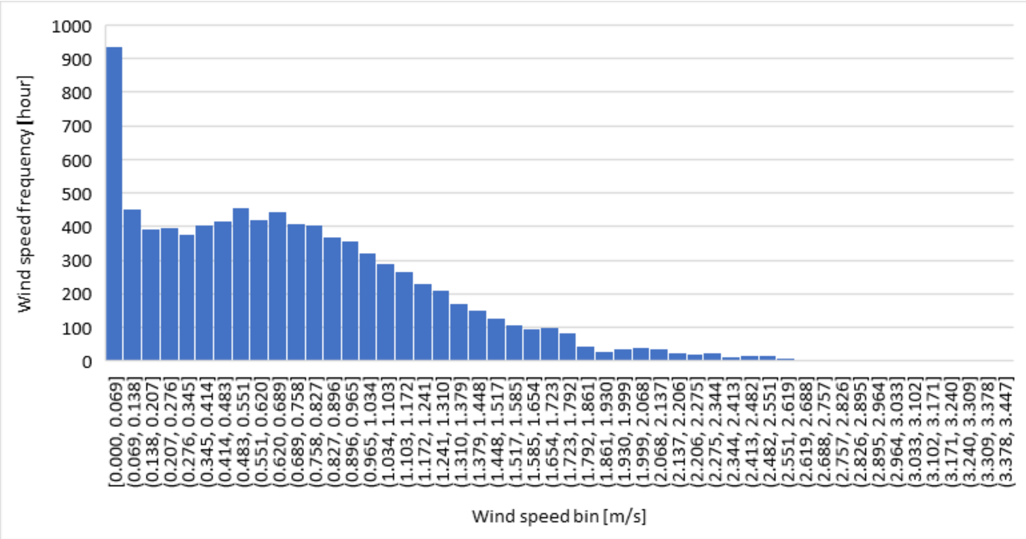


Figure 5.4 – *Wind speed frequency at the microlocation of FERIT building in Trpimirova street*

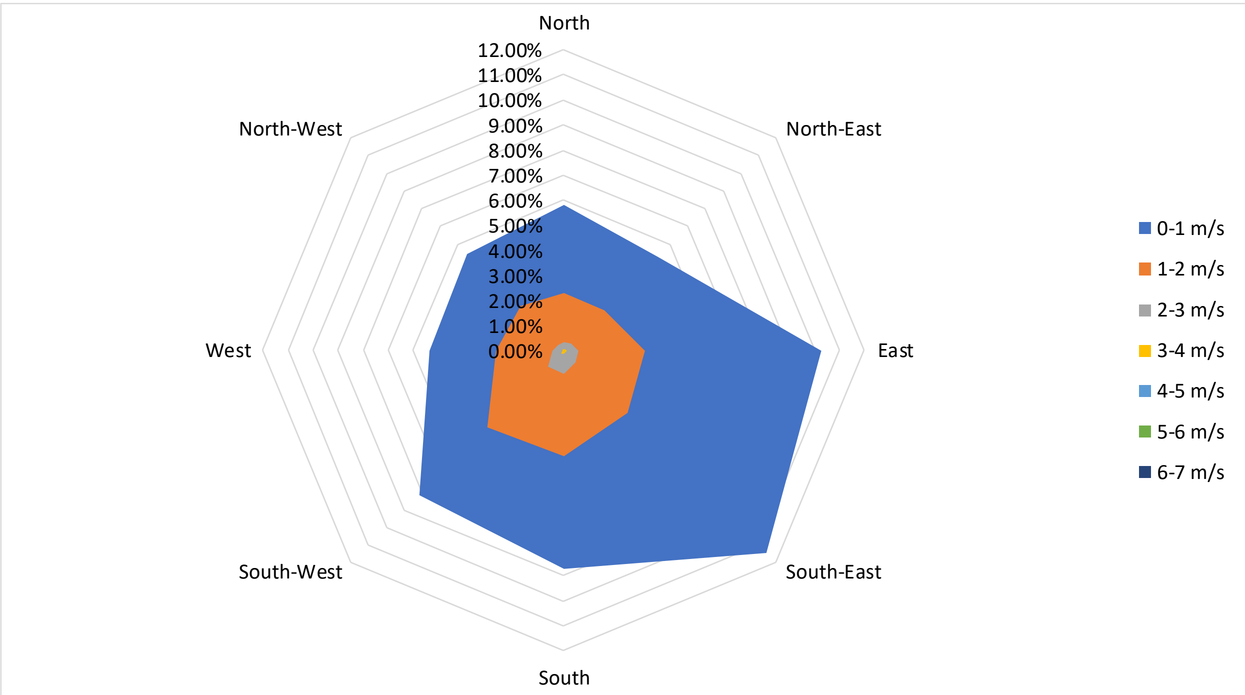


Figure 5.5 – *Rose of winds for the microlocation of FERIT building in Trpimirova street*

# 6. The optimal renewable energy system topology and building energy management system for the exemplary facilities

In this section, regarding the features of the location and building for the exemplary objects and considering conducted analysis of the energy demand and potential for renewable energy sources, the recommendation for the optimal renewable energy system, as well as topology of the smart building energy system are proposed. This system would improve the energy efficiency of the exemplary object and provide higher reliability and better performance on the energy flow control.

## 6.1. Optimal configuration of a renewable energy system

One of the possible strategies for the increase in energy efficiency is to incorporate renewable energy sources into traditional power systems. If the power is partially produced by the renewables, the power share coming from the fossil fuels is decreased and thus greenhouse gas emission reduced. Furthermore, the reduction in the energy provided by the power grid would leave to significant money savings. Also, reduced risk of loss from grid blackouts is another benefit regarding less dependence of the object on the energy coming from the grid. This concept provides sustainable renewable energy to the grid and reduces the need for grid expansion.

According to the analysis of the renewables potential of the exemplary objects of the FERIT, following systems are going to be constituted:

- 80 kW photovoltaic (PV) systems in Trpimirova street consisting of 75 kW PV system on the roof/wall of building and 5 kW PV based e-bike charging station in the yard
- 40 kW PV systems in Cara Hadrijana street consisting of 35 kW PV system on the roof/wall of building and 5 kW PV based e-bike charging station in the yard
- Minimally 20 kW renewable energy storage/supply system in building in Trpimirova street;
- 6 kW wind energy system in building yard in Trpimirova street;

### 6.1.1. Photovoltaic systems on the buildings roofs

PV systems utilize solar irradiation for direct conversion of solar energy into electricity. There are two basic elements of PV systems, PV array and inverter on which PV modules are connected.

PV array consists of series-parallel connected PV modules which topology depends on the size of the array and inverter characteristics. Since output of the PV modules is DC electricity, in order to integrate PV systems into AC power grid, converter unit is necessary. This unit is called inverter which is power electronics device that converts DC electricity into AC electricity suitable for the power grid. The DC cables that connect PV strings with the inverters are planned for external mounting. Other electrical equipment such as protective and switching devices are placed inside the distribution board. The point between the board and the distribution power grid is called the point of common coupling (PCC) and the voltage level in the PCC is 0.4 kV.

Proposed PV systems for FERIT project partner have nominal power of 120 kW. This power will be distributed on two FERIT buildings roofs located in Trpimirova and Cara Hadrijana street. Preliminary design of the systems proposed that system with nominal power of around 80 kW will be installed on building in Trpimirova street and around 40 kW on building in Cara Hadrijana.

***80 kW PV systems in Trpimirova street***

75 kW PV system is planned to be installed on South-oriented roof/wall surfaces on different angles, depending on the roof/wall section. Azimuth of the building is 0 ° (South is reference). Tilt angle of the roof section on which PV modules will be installed varies from 20 ° to 30°. Block diagram of 75 kW PV system is given in Figure 6.1 while 3D model of the system is given in Figure 6.2.

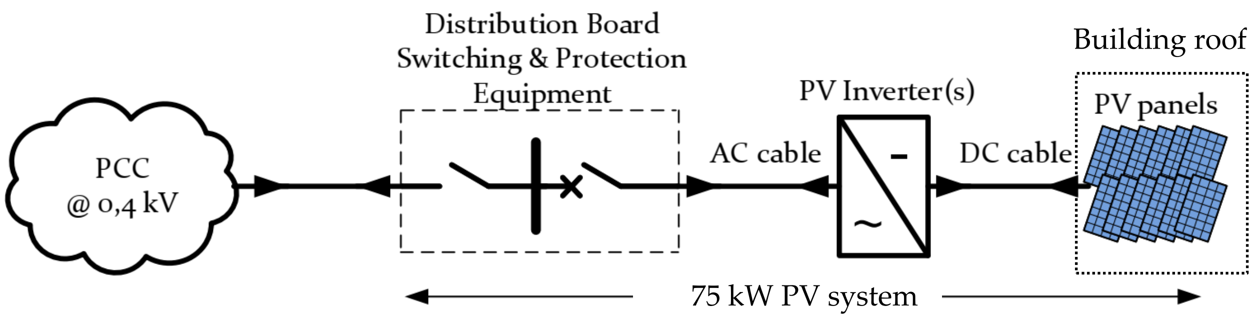


Figure 6.1 *Block diagram of 75 kW PV system on building in Trpimirova street*

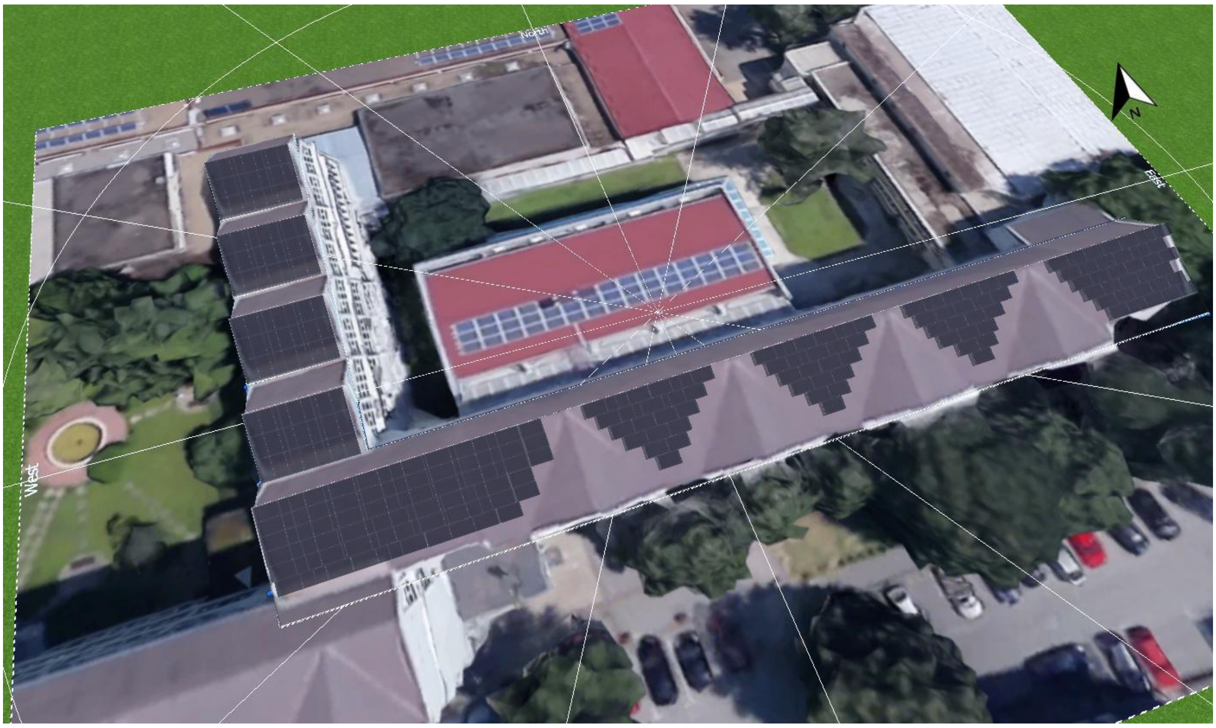

Figure 6.2 – *Preliminary 3D model of 75 kW PV system on building roof in Trpimirova street (with possible wall-mounted modules depending on roof shading)*

The global e-bike market is expected to grow at a CAGR of 6.39%, during the forecast period, i.e. 2019-2024, according to [25]. Apart from the growing consumer preference toward recreational and adventure activities, the adoption of e-bike applications in several sectors, like logistics and e-bike rental services, is expected to drive the market studied during the forecast period. This is affordable and efficient transportation to the masses. Assuming that the number of electric bicycles is going to grow and considering that there is a large number of students and employees at the Faculty that may use this attractive technology, electric bike and assistive device (such as mobile phone) charging station is going to be constructed. This charging station is powered with solar energy and eco-friendly.

The e-bike charging station is going to be a part of 80 kW PV system located at the building in Trpimirova street. PV panels are going to be placed on a charging station roof since it is aesthetically attractive, enhances the landscape and architecture and yet behaves as a functional power generator.

The installed power of the PV based e-bike charging station is 5 kW and will be mounted on PV trackers in order to maximize PV electricity production during working hours. The block diagram of this system is depicted in Figure 6.3.

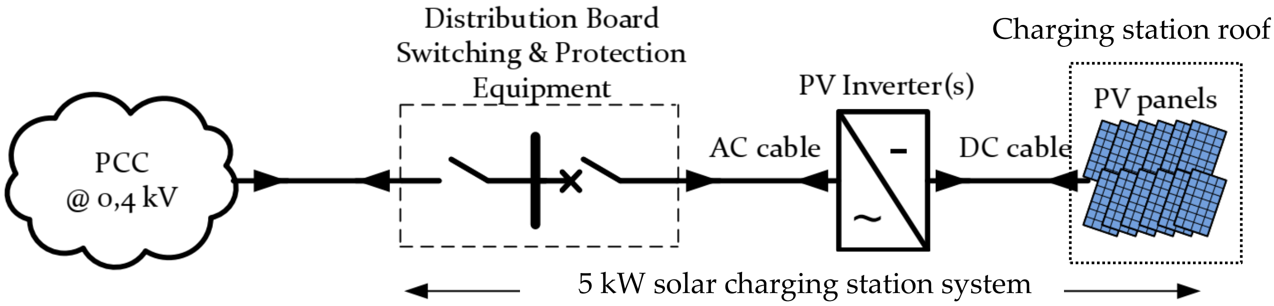


Figure 6.3 *Block diagram of 5 kW PV based e-bike charging station.*

The PV system is directly connected to the inverter unit that transforms the DC voltage from the output of PV panels placed on the solar tree to AC voltage. Electrical equipment such as protective and switching devices are placed inside the distribution board. The voltage level in the PCC is 0.4 kV.

If we assume to use monocrystalline silicon modules SUNCECO SEM 300W-HE, which technical characteristics are given in Table 6.1., for the PV modules of the system, PV array will consists of around 267 PV modules with nominal power of 300 W which results in total output power of 80.1 kW at the DC side of the system.

*Table 6.1 – Technical characteristics of PV modules [26].*

| SUNCECO SEM 300W-HE | | | |
|---|---|---|---|
| Nominal power | $P_{max}$ | 300 | W |
| Maximum power point voltage | $U_{MPP}$ | 32.9 | V |
| Maximum power point current | $U_{MPP}$ | 9.12 | A |
| Short-circuit current | $U_{OC}$ | 9.58 | A |
| Open-circuit voltage | $I_{SC}$ | 39.7 | V |
| Efficiency | $\eta$ | 18.3 | % |
| Maximum system voltage | | 1000 | V |
| Dimensions | | 1650 x 992 x 35 | mm |
| Weight | | 18,5 | kg |
| Operating temperature | | -40 do +85 | °C |
| Number of cells | | 60 | pcs. |

Based on Solar energy potential described in section 5.1. for Osijek, monthly forecast of electricity production for 80 kW (75 kW + 5 kW) PV systems is determined using PVSOL Premium software package and given in Figure 6.4. Total annual production of the PV system is around 95 MWh.

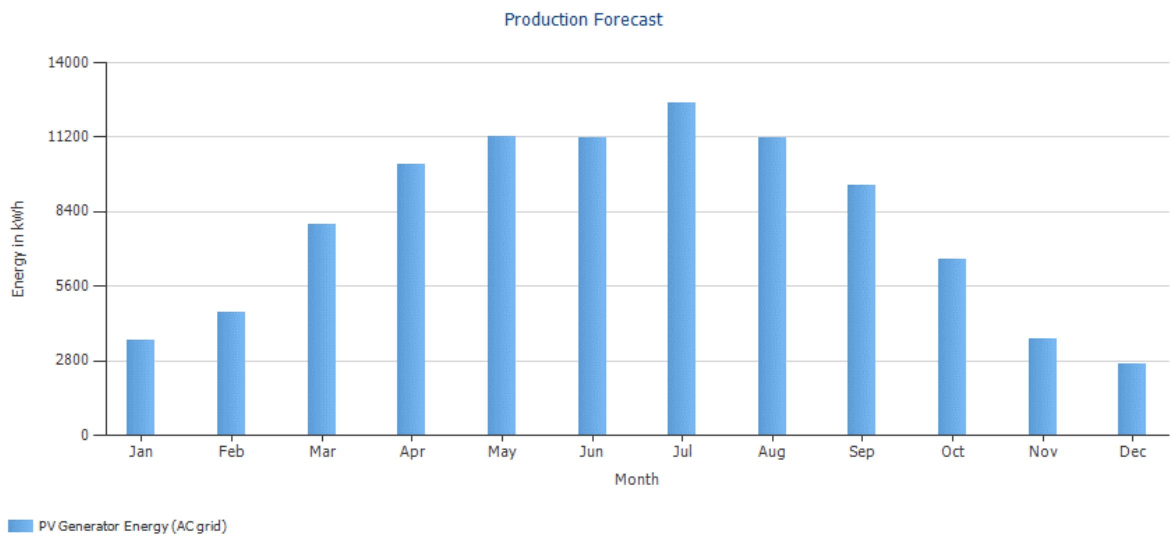


Figure 6.4 – *Estimated electricity production of 80 kW PV systems on building in Trpimirova street*

***40 kW PV system on building in Cara Hadrijana street***

35 kW PV system is planned to be installed on South-oriented roof surfaces on different angles, depending on the roof section. Azimuth of the building is 19 ° to West (South is reference). Tilt angle of the roof section on which PV modules will be installed varies from 0 ° to 20°. Block diagram of 35 kW PV system is given in Figure 6.5 while 3D model of the system is given in Figure 6.6.

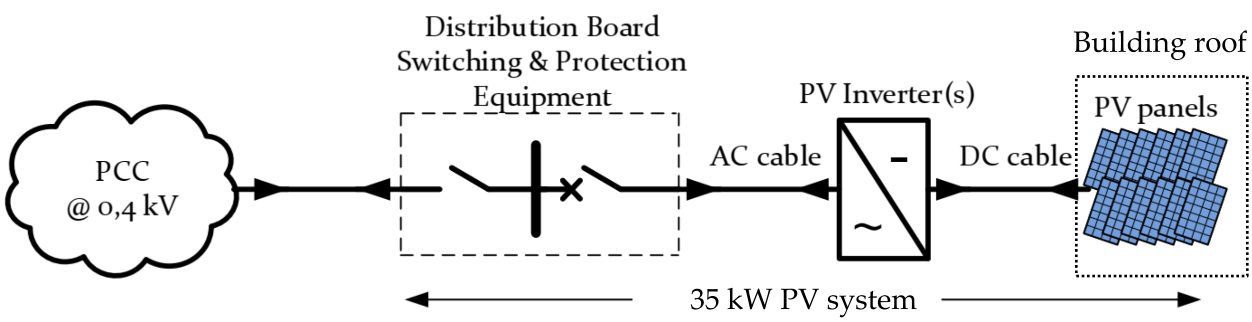


Figure 6.5 *Block diagram of 35 kW PV system on building in Cara Hadrijana street*


Figure 6.6 – *Prelimibary 3D model of 35 kW PV system on building roof in Cara Hadrijana street*

Similar to PV system in Trpimirova street, the e-bike charging station is going to be a part of 40 kW PV system located at the building in Cara Hadrijana street. PV panels are going to be placed on a charging station roof since it is aesthetically attractive, enhances the landscape and architecture and yet behaves as a functional power generator.

The installed power of the PV based e-bike charging station is 5 kW and will be mounted on PV trackers in order to maximize PV electricity production during working hours. The block diagram of this system is depicted in Figure 6.3.

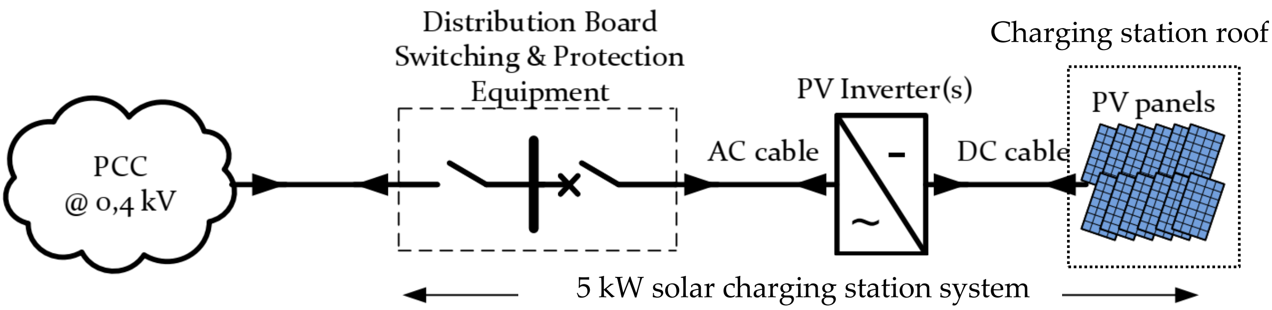


Figure 6.7 *Block diagram of 5 kW PV based e-bike charging station.*

The PV system is directly connected to the inverter unit that transforms the DC voltage from the output of PV panels placed on the solar tree to AC voltage. Electrical equipment such as protective and switching devices are placed inside the distribution board. The voltage level in the PCC is 0.4 kV.

If we assume to use monocrystalline silicon modules SUNCECO SEM 300W-HE, which technical characteristics are given in Table 6.1., for the PV modules of the system, PV array will consists of around 134 PV modules with nominal power of 300 W which results in total output power of 40.2 kW at the DC side of the system.

Based on Solar energy potential described in section 5.1. for Osijek, monthly forecast of electricity production for the proposed 40 kW (35 kW + 5 kW) PV systems is determined using PVSOL Premium software package and given in Figure 6.8. Total annual production of the PV system is around 40 MWh.

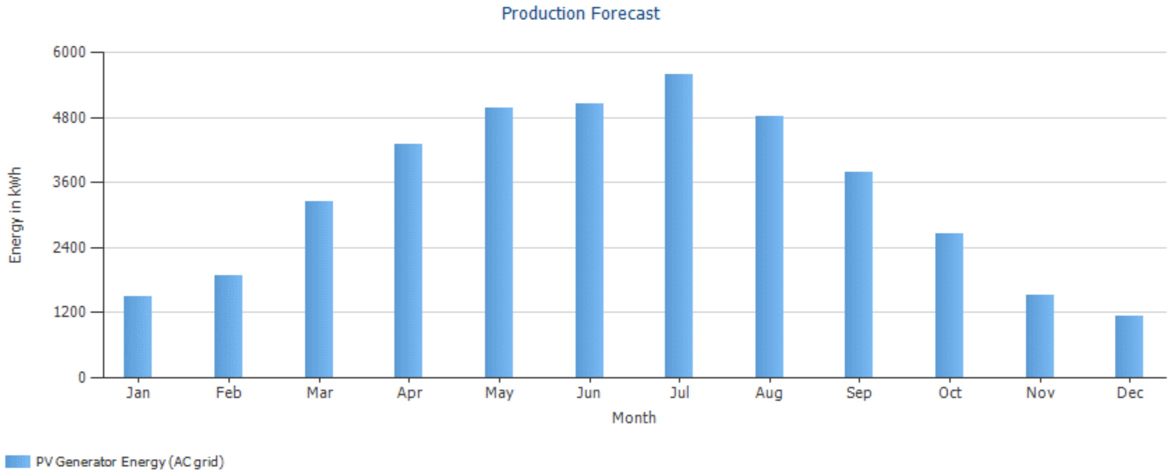


Figure 6.8 – *Estimated electricity production of 40 kW PV systems on building in Cara Hadrijana street*

## 6.1.2. Renewable energy storage/supply system

Energy storage/supply technologies are used in modern grids in order to enhance the reliability of renewable energy sources, improve the resilience of the grid and resolve its issues, as well as realize the benefits of smart grids and optimizing generation to suit demand. They are usually accompanied by renewable energy sources. Due to the highly intermittent nature of the renewables, sometimes it is possible that consumers do not need all the energy produced by the source or there is not enough energy as required. Therefore, energy storage/supply systems can be used to store energy when the amount generated exceeds the demand and inject power into the system during shortages. Furthermore, they can be used for the peak shaving application, i.e. to cover the peak load.

Therefore, a renewable energy storage/supply system is going to be installed at the exemplary object in Trpimirova street in order to provide stabilizing the power output while also enhancing the reliability of the system. The block diagram of the energy storage/supply system is given in Figure 6.9. The bi-directional power converter is used as an interface between the storage/supply system and the grid. Switching and protection equipment is placed in the distribution board.  The installed power of the bi-directional converter used in the system is minimum 20 kW, depending on financial resources of the project. The storage/supply comprises the battery storage system, as well as the supercapacitor system. Batteries present an advanced technique for storing electrical energy in electrochemical form and have a wide range of use. Supercapacitors have a high energy storage capacity due to their high-power ability and since the stored energy has to be used very quickly, they are able to provide peak shaving and thus improve the power profile.

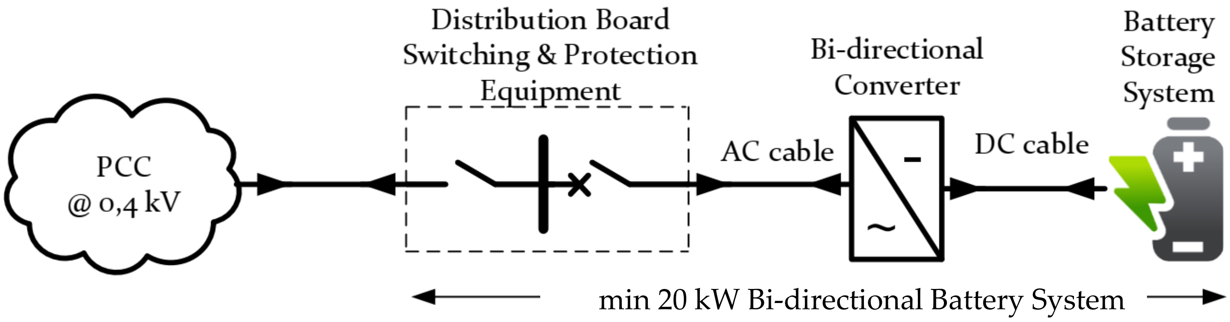


Figure 6.9 *Block diagram of the energy storage/supply system.*

The battery of the electric vehicles can also be used as a storage/supply unit and can enable different grid support functionalities. This is a state-of-art concept that is very interesting to the researches and certainly could become a new tool for electric utilities in the next decade.

### 6.1.3. Wind energy system

The exemplary public building is in the region with moderate potential for wind energy development, especially in higher height levels. However, since the area is urbanized, there are limited options when it comes to wind energy due to the surrounding buildings, trees and other obstacles. Another important issue is the size of the wind turbine. Wind turbines can be noisy and require consistent, non-turbulent winds of certain speeds that are uncharacteristic of urban environments. However, due to the technology improvements wind turbines should be self-starting, ultra-quiet, provide smooth torque, and be highly efficient so usable energy can be delivered at modest wind speeds.

Therefore, a small wind power system is planned to be constructed in the yard of the building in Trpimirova street. The installed power of the system is 6 kW. The block diagram of the wind power system is given in Figure 6.10.

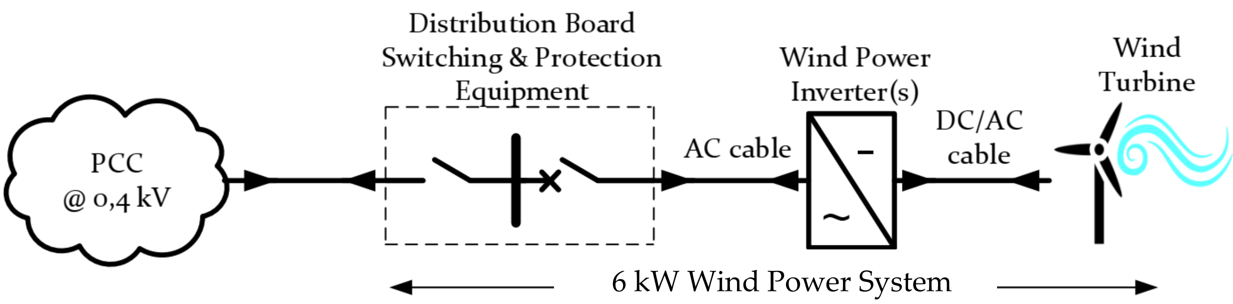


Figure 6.10 *Block diagram of the wind power system.*

The wind turbine(s) is(are) directly connected to the three-phase inverter unit(s) which transforms the DC voltage from the output of wind turbine to AC voltage. Protective and

switching devices are placed inside the distribution board. The voltage level in the PCC is 0.4 kV.

A HOMER Pro software tool [27] is used to estimate the amount of electricity that can be generated by a wind turbine with 6 kW nominal output power and with wind energy potential of Osijek. Monthly forecast of electricity production by such wind energy system is given in Figure 6.11. The prediction is that the energy produced annually is 4.431 MWh.

However, the final decision on number and type of small wind turbine(s) that will be installed with total rated power of 6 kW will be determined depending on market research and availability.

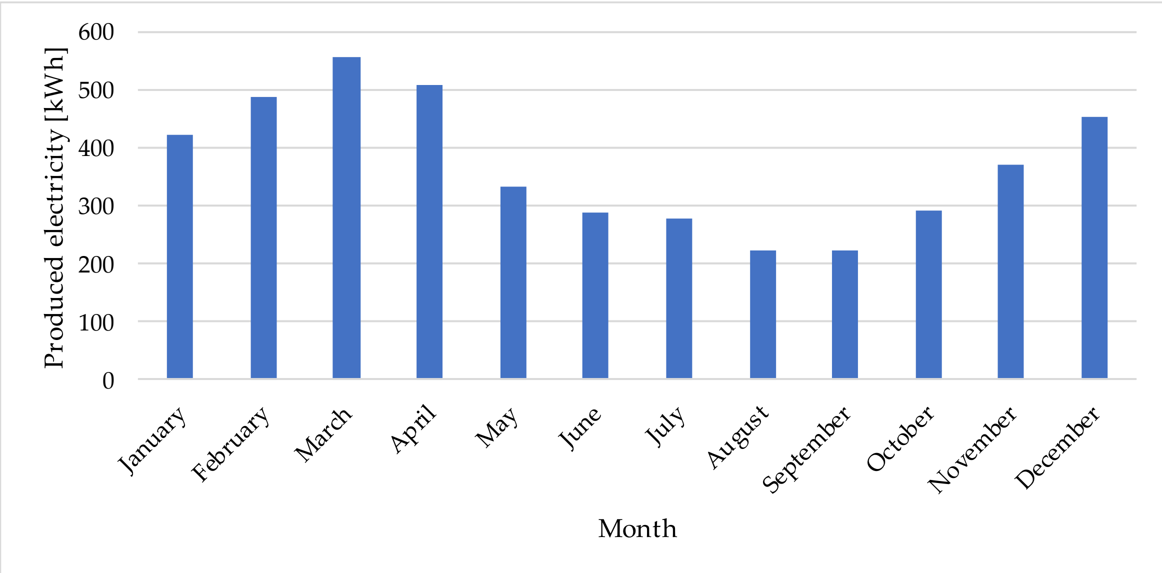


Figure 6.11 *Estimated electricity production of 6 kW wind energy system located at the exemplary object in Trpimirova street.*

## 6.2. Optimal configuration of the smart building energy system

Building energy management system represents superior control and management system for sources of electricity alongside with electric loads into one fully controllable unit. This is realised with Supervisory Control and Data Acquisition System (SCADA) which is computer-based system for control and management of processes. In our case, sources of electricity are renewable energy-based while the electric loads represent building loads. In the area of electrical engineering, this unit represents microgrid which is an emerging concept while its SCADA system represents its superior control and management system.

SCADA system consists of fully coordinated ICT systems that supervise and control every element in the microgrid. Basic block diagram of building energy management system for building in Trpimirova street and its basic elements is given in Figure 6.12.

At the PCC point of all of these systems smart meters will be placed and collect information about electrical quantities and consequently reconstruct the power quality, production and consumption. Sensing devices are going to be placed in all systems to monitor environmental variables such as solar irradiance, temperature, humidity, air speed and direction, etc. This data is sent to the BEMS system and processed. Based on all inputs, BEMS provides outputs – control signals for controllers so that the automation of all ongoing processes is possible regarding the energy efficiency maximization.

In this manner, the maximal energy efficiency should be realized, as well as optimal and coordinate operation of all units.

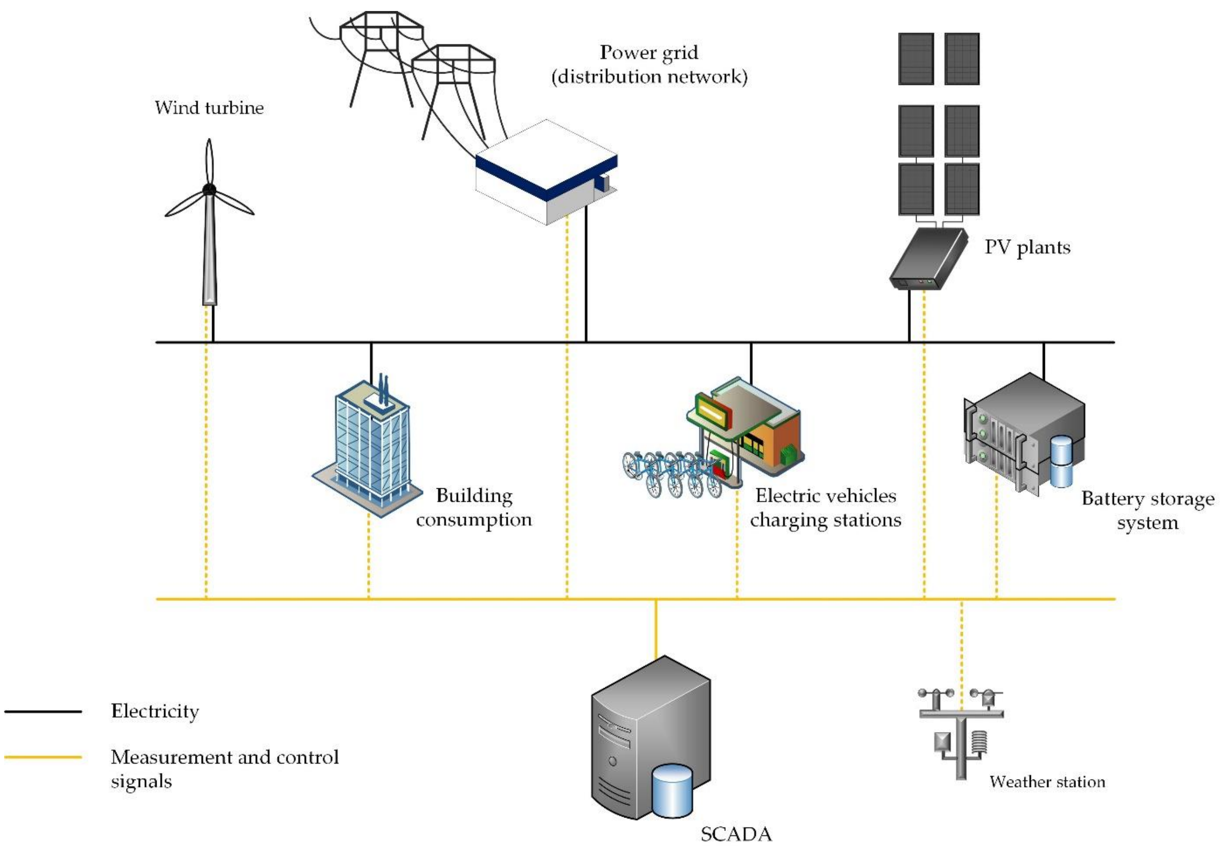


Figure 6.12 – *Basic block diagram of building energy management system for building in Trpimirova street*

# 7. Conclusion

Annual electricity consumption of both buildings of the Faculty of Electrical Engineering, Computer Science and Information Technology is 320,283.43 kWh which results in total cost of 310,004.98 HRK for 2018. Since Osijek, situated in the eastern part of Republic of Croatia, has large solar and moderate wind energy potential, certain part of consumed electricity can be supplied by systems which utilize renewable energy sources. Because of highly intermittent nature of the renewables and non-coincident production and consumption, sometimes it is possible that consumers do not need all the energy produced by the source or there is not enough energy as required. In order to reduce this, energy storage/supply systems can be used to store energy when the amount generated exceeds the demand and inject power into the system during shortages, thus generate additional electricity cost savings.

If we observe each building by itself and only the electricity production systems (excluding renewable energy storage/supply system), that are planned to be installed within the project, building in Trpimirova street will install: 80 kW photovoltaic (PV) systems consisting of 75 kW PV system on the roof/wall of building and 5 kW PV based e-bike charging station in the yard; minimally 20 kW renewable energy storage/supply system; 6 kW wind energy system in building yard.

By comparing electricity production forecast of the systems (80 kW PV systems – 95 MWh and 6 kW wind energy system – 4.431 MWh), and annual electricity consumption of 227.33 MWh, installed systems will participate with around 44 % of the electricity consumption.

If we observe the building in Trpimirova street, annual electricity consumption is 92.953 MWh while 40 kW PV systems consisting of 35 kW PV system on the roof/wall of building and 5 kW PV based e-bike charging station in the yard, that is planned to be installed within the project, will produce around 40 MWh annually. This results in around 43 % of the annual electricity consumption of the building.

Total potential electricity cost saving for both buildings, not including electricity cost savings by utilization of renewable energy storage/supply system, by integration of systems that use renewable energy sources are around 140,750.72 HRK which is around 43.95 % of total electricity cost.

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