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 5: Mechanical Engineering Faculty, Slavonski Brod public building

Slavonski Brod
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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 Technical Sciences public building. 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.

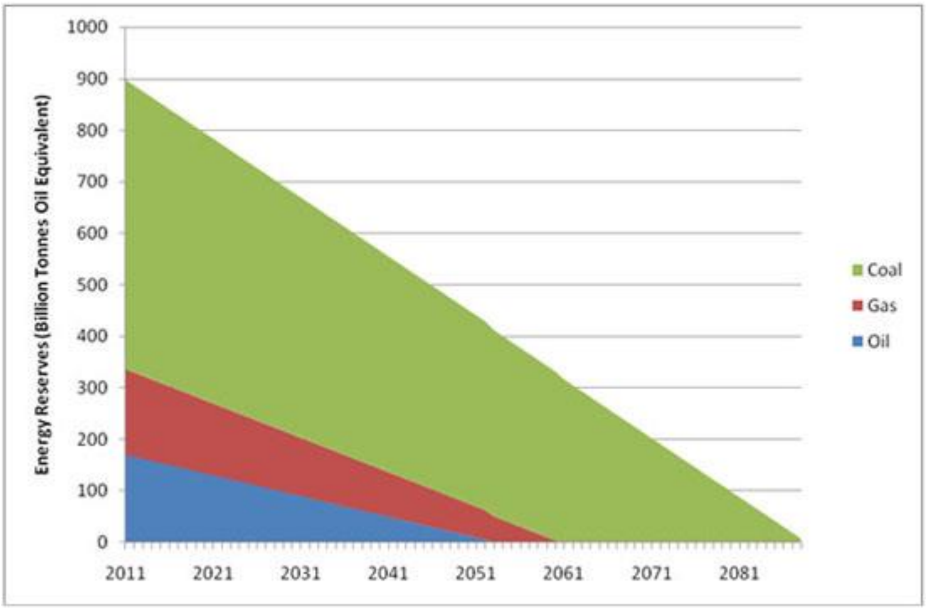


Figure 1.1 The prediction of fossil fuel energy reserves [1].

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.

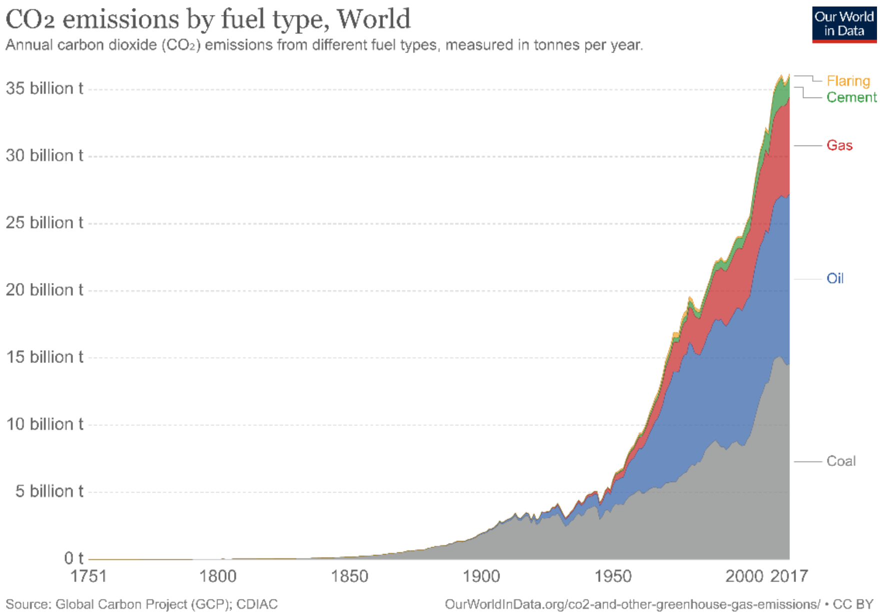


Figure 1.2 Carbon dioxide (CO_2) emission by a specific type of fossil fuel [2].

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.

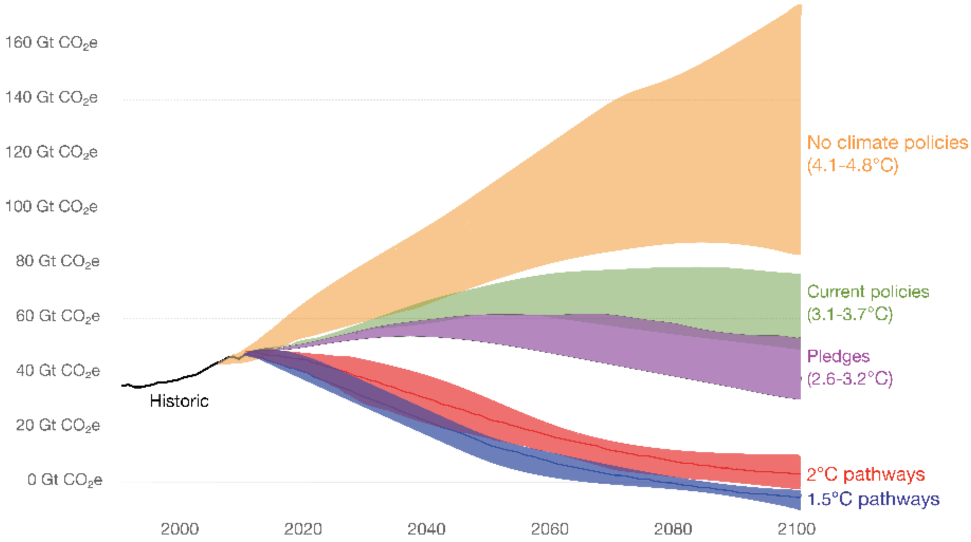


Figure 1.3 The prediction of the CO_2 emission based on different scenarios [2].

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 centers 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].

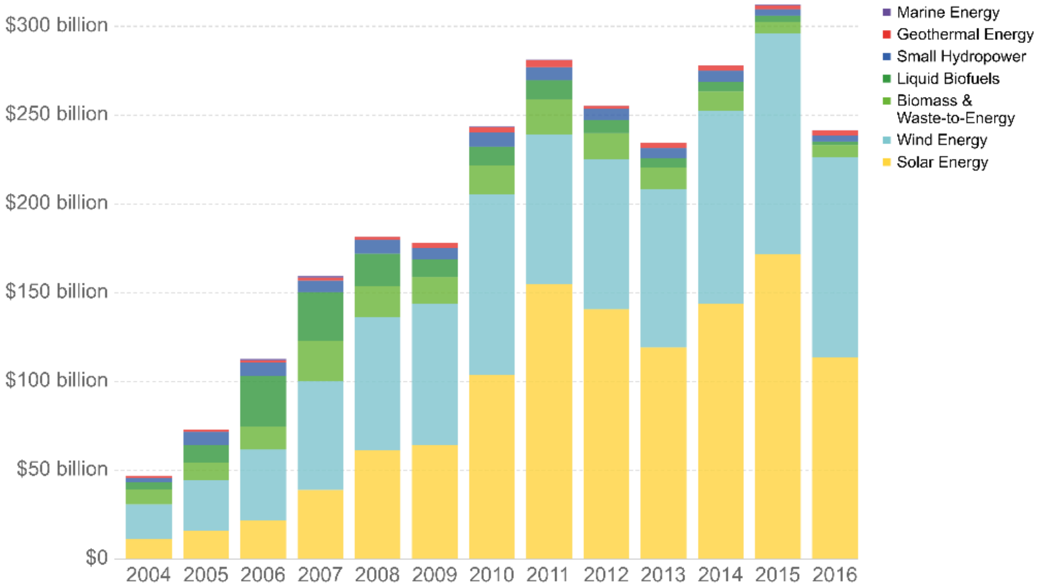


Figure 1.4 Investment in different renewable energy technologies [6].

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].

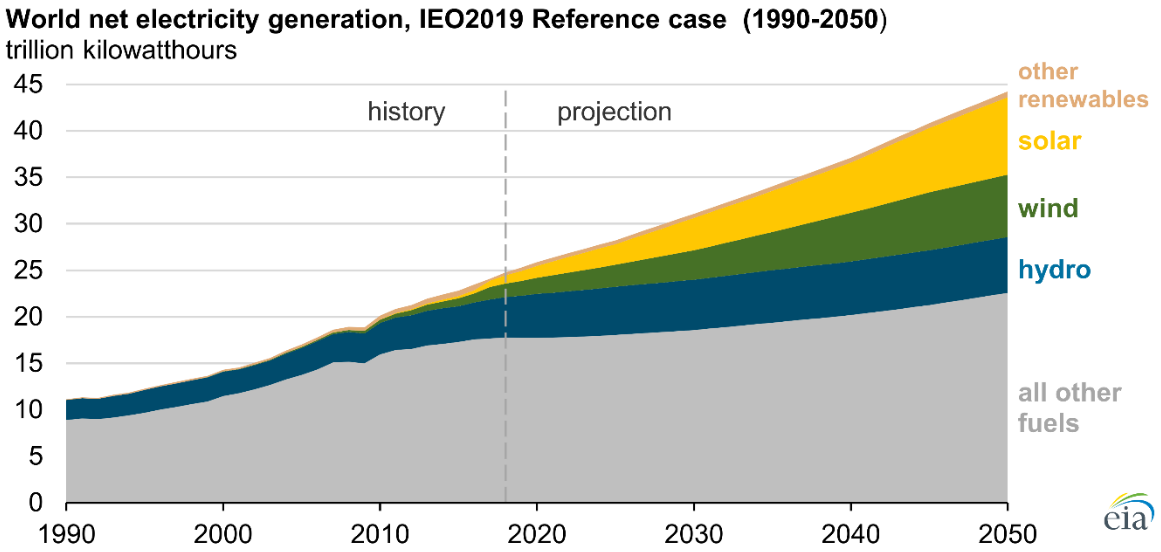


Figure 1.5 World net electricity generation [8].

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 in both Croatia and Serbia.

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 analyze 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 [9]. 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 Fig. 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 [10].

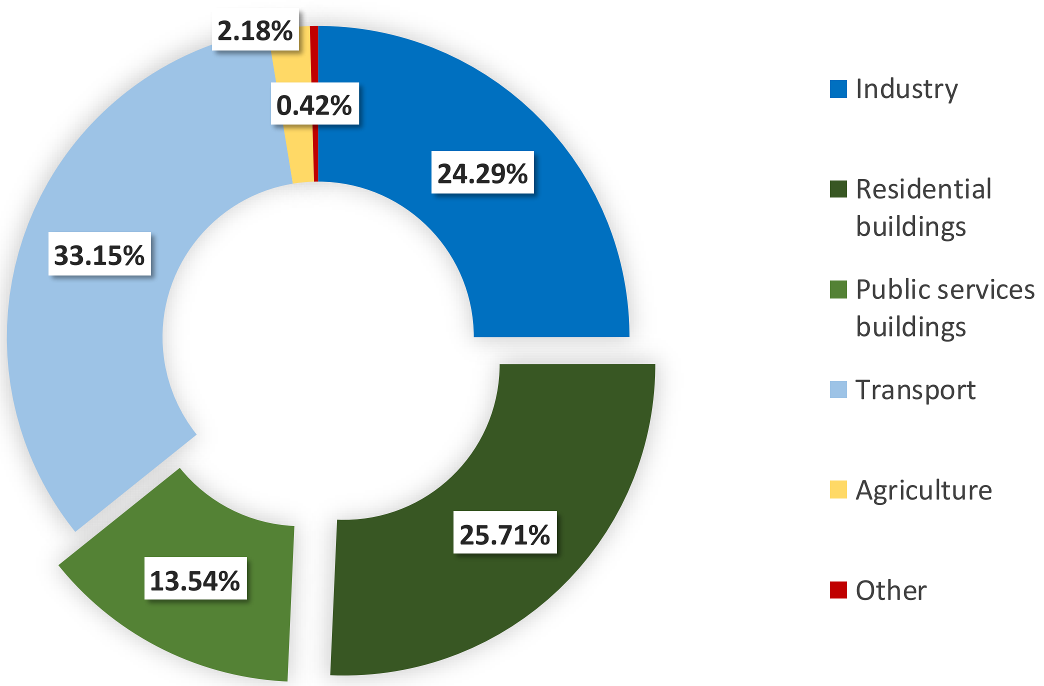


Figure 2.1 Energy consumption by sector in the EU [11].

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 each year, several million deaths are caused by air pollution, 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 [12].

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 [13]. 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 [14]. 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 decarbonisation, 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 behavioural 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 mobilising 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."

Reffering 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 mobilising 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% [11].

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 than 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) [12], 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 optimising 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 [15]. Among others, directive statest that the monitoring and automation of buildings have proben 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 decarbonised 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 [16]. 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 [17]. The amending directive (2018/2002) [18] 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.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 location and the building for the exemplary facility

The Mechanical Engineering Faculty in Slavonski Brod is a part of the Josip Juraj Strossmayer University in Osijek. The Faculty is located at the Brodsko-Posavska County which is one of 20 counties in Croatia. Brodsko-Posavska County is located in the South of Slavonija Region which is one (East) of 5 Croatia's Non-Administrative regions. The facility II of Mechanical Engineering Faculty in Slavonski Brod is a second of the two Faculty buildings. The facility II of Faculty is located at Ivan Gundulić Street No. 20a. The geographical coordinates of the facility II are north latitude 45° 9' 18.73" and east longitude 18° 1' 19.54", as shown in Figure 3.1 (*source: google.com/maps*).

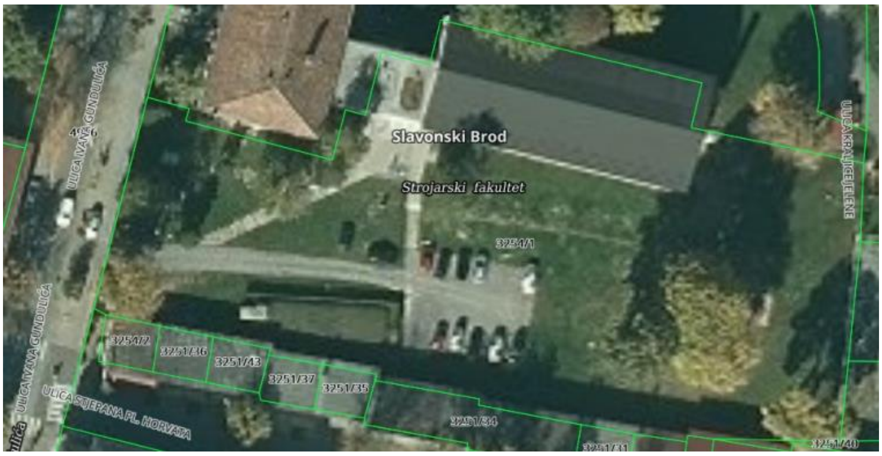


Figure 3.1 – Location of the Mechanical Engineering Faculty facility II.

The facility II of Faculty is located at k.p. 3254/1, K.O. Slavonski Brod, as shown in the situational plan given in Figure 3.2 (*source: geoportal.dgu.hr*). Near the facility II is a facility of Pedagogical Faculty in Slavonski Brod.

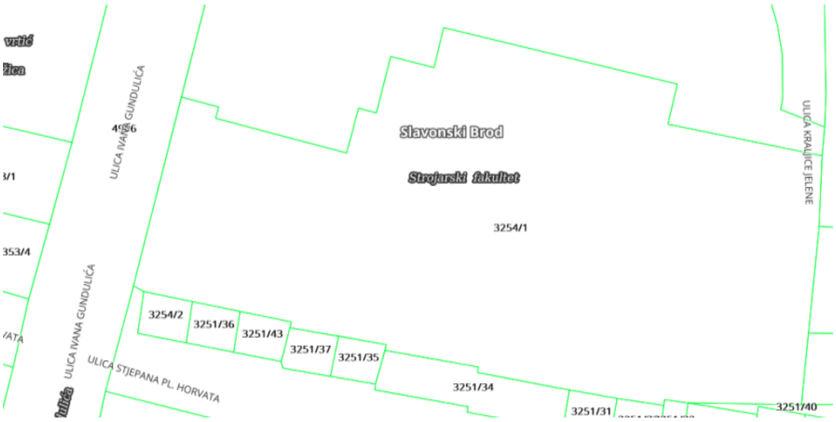


Figure 3.2 – Situational plan of the Mechanical Engineering Faculty facility II.

The facility II of Faculty is equipped with laboratories, with a total area of 1404 m^2. The facility is divided into 22 offices, 4 laboratories, 4 computer laboratories and 2 classrooms.

The main entrance to the building, part of the building with laboratories and classrooms, as well as the roof of the Mechanical Engineering Faculty facility II, where the photovoltaic power plant is located, are given in the figures below (Figure 3.3, Figure 3.4 and Figure 3.5).

Figure 3.3 – The main entrance to facility II of Mechanical Engineering Faculty

Figure 3.4 – Part of Mechanical Engineering Faculty with parking area.

Figure 3.5 – Part of Mechanical Engineering Faculty with classrooms and offices where the thermal solar system and photovoltaic power plant will be installed.

The facility II of Mechanical Engineering Faculty class is defined according to HRN HD 60364-5-51:2010/A12:2017 standard:

Environmental conditions:

AA Ambient temperature:	AA5
AB Atmospheric humidity:	AB5
AC Altitude:	AC1
AD Water presence:	AD1 (AD3 toilets)
AE Presence of foreign solids:	AE2
AF Presence of corrosive substances or contaminants:	AF3
AG Mechanical stresses - Impact:	AG2
AH Mechanical stresses - Vibrations:	AH2
AK Flora presence and/or mold:	AK1
AL Fauna presence:	AL1
AM Electromagnetic, electrostatic or ionizing effects:	AM1
AN Solar radiation:	AN1
AP Seismic Impact:	AP1
AQ Atmospheric Discharge:	AQ1
AR Air movement:	AR1
AS Wind:	AS1

– Usage

BA People Qualification:	BA4
BC People contact with land potential:	BC2
BD Emergency evacuation conditions:	BD3
BE The nature of the processed or stored materials:	BE1

– Building construction

CA Construction materials:	CA1
CB Object structure:	CB1

The beginnings of higher education in the field of technical sciences in Eastern Croatia date back to 1962, when the Technical College in Zagreb established the Centre for Part-time Study in Engineering in Slavonski Brod, in a city with well-known factory Đuro Đaković, established in 1921. The Centre for Part-time Study in Engineering was active for 17 years, being supported by today's Faculty of Mechanical Engineering and Naval Architecture of the University of Zagreb. In 1979, there are conditions achieved for establishment of the Mechanical Engineering Faculty in Slavonski Brod, as an independent legal entity within Josip Juraj Strossmayer University of Osijek.

Being one of the University of Osijek's constituents, the Faculty operates by its clear vision of development. During the Homeland War, the Faculty faced difficulties in organising the classes, but today the Faculty is systematically performing its main activities: education of students, scientific research and international cooperation, as well as cooperation with the economy sector, all with the aim to fulfil its social role in the community in which it operates.

The number of students and employees has grown constantly. With the increase in the number of people, the need for space grew, which affected the redevelopment of the original facility. Thus, a number of modern laboratories and classrooms have been made, through several adaptations of the facility. In this way, the number of rooms required for teaching and research work has been increased.

The energy efficiency assessment covers the parts of a facility owned by the Mechanical Engineering Faculty, which are in the function of maintaining all teaching activities for students, spaces for scientific research, entrance halls and rooms for general and legal affairs.

Most of the time, especially while performing general tasks, employees and faculty members work in offices. An example of an office is given in Figure 3.6. 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 3 workplaces, usually 2.

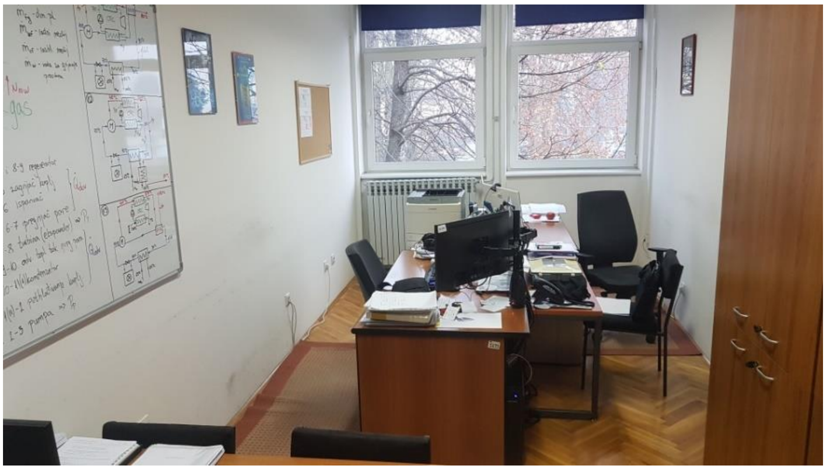


Figure 3.6 – Office with one workplace.

In addition, most teaching activities are performed in classrooms. An example of one classroom with 112 students and 1 teaching position is given in Figure 3.7. The number of student places in classrooms varies between 28 and 112 places with 1 teaching position. All classrooms contain computers and projectors.

Figure 3.7 – Classroom with 24 students and 1 teaching position.

Figure 3.8 shows an example of a computer lab classroom. The classroom is used to teach and to test student's knowledge using appropriate software. The computer lab classrooms have 10 or 15 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 3.8 – Example of one computer lab classroom.

Figure 3.9 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 located 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. With the exception of specific consumers, neither lighting nor a certain number of computer sites should be neglected.

Figure 3.9 – An example of a laboratory for Laboratory for Computer Aided Process Planning (CAPP) and Computer Aided Design (CAD)

Figure 3.10 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 3.10 – General purpose rooms.

3.1. 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 [19].

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 [19].

Crucial source of information for Croatia's wind energy potential estimation is the wind atlas. Maps given in Figure 3.11 and Figure 3.12 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 [20].

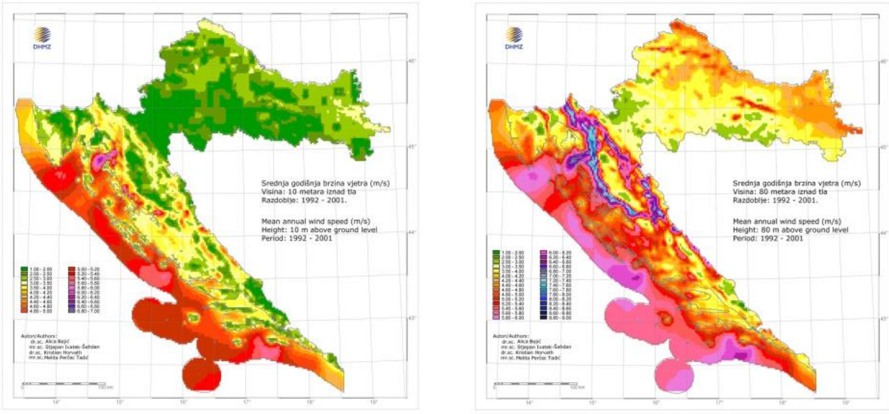


Figure 3.11 – Mean annual wind speed (m/s)

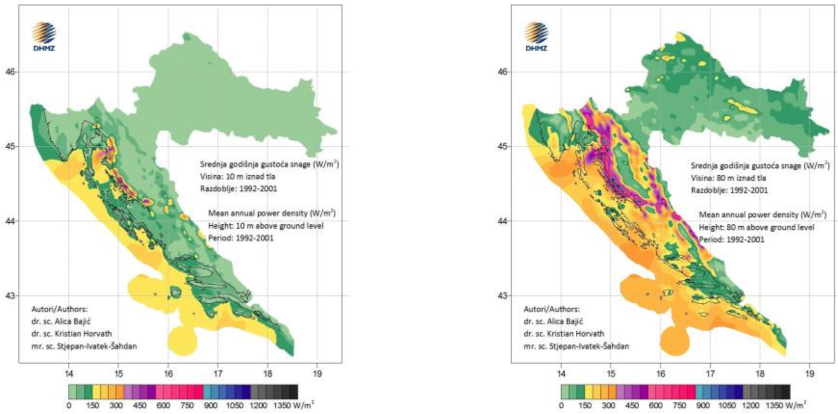


Figure 3.12 Mean annual power density (W/m^2)

Figure 3.13 shows the daily mean air temperature up to 18.12. 2019. Comparison to the average for the 1963 – 2018 period in Slavonski Brod (according to data of the Croatian Meteorological and Hydrological Service). The average values of climatic parameters, climate normals, give an insight into the climatic characteristics of the area. By comparing climatic parameters for different 30-year periods, one can gain insight into the climatic conditions of an area or their variability can be an indication of climate change. In 0 are shown average values of climatic parameters.

Table 3.1 – Average values of climatic parameters for Slavonski Brod

1961–1990	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Z/W	P/Sp	LJ/Su	J/A	Veg	G/An
Temperatura zraka Air temperature																		
t (°C)	-1.1	1.7	6.1	11.1	15.8	19.0	20.6	19.9	16.1	10.7	5.4	0.7	0.5	11.0	19.8	10.7	17.1	10.5
T_{max} (°C)	18.7	21.9	27.4	31.4	35.2	37.0	39.2	38.8	34.5	30.2	25.2	23.0	23.0	35.2	39.2	34.5	39.2	39.2
T_{min} (°C)	-27.8	-23.0	-14.0	-4.5	-1.7	1.7	6.1	4.7	-3.1	-5.8	-13.7	-22.0	-27.8	-14.0	1.7	-13.7	-4.5	-27.8
t_{max} (°C)	2.5	6.2	11.9	17.2	22.0	25.0	27.1	26.7	23.3	17.3	10.0	4.2	4.3	17.0	26.3	16.9	23.6	16.1
t_{min} (°C)	-4.8	-2.4	0.8	5.0	9.3	12.5	13.6	13.2	9.9	5.3	1.3	-2.6	-3.2	5.0	13.1	5.5	10.6	5.1
$t_{min\ 5cm}$ (°C)	-5.6	-3.9	-1.3	2.7	7.0	10.6	11.7	10.8	8.0	3.5	-0.1	-3.7	-4.4	2.8	11.1	3.8	8.5	3.3
$t_{min\ 5cm}$ min (°C)	-28.6	-26.0	-19.0	-8.5	-5.0	-1.7	0.6	3.0	-7.0	-9.8	-18.5	-23.3	-28.6	-19.0	-1.7	-18.5	-8.5	-28.6
t_{more} / t_{sea} (°C)																		
t_{min} ≤-10°C (d)	4.6	1.8	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	2.1	8.5	0.6	0.0	0.3	0.0	9.4
t_{max}<0°C (d)	9.8	3.4	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	6.0	19.1	0.8	0.0	0.4	0.0	20.4
t_{min}<0°C (d)	26.1	19.3	12.0	2.2	0.2	0.0	0.0	0.0	0.2	3.3	10.8	22.5	67.1	14.4	0.0	14.2	2.6	96.5
t_{max}≥25°C (d)	0.0	0.0	0.3	2.0	8.9	16.1	21.8	20.9	11.2	2.5	0.1	0.0	0.0	11.2	58.9	13.8	81.0	83.8
t_{max}≥30°C (d)	0.0	0.0	0.0	0.1	0.8	3.5	8.2	7.5	2.1	0.0	0.0	0.0	0.0	0.9	19.2	2.2	22.2	22.3
t_{min}≥20°C (d)	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.4	0.4
$t_{min\ 5cm}$<0°C (d)	26.5	21.3	17.6	8.0	1.2	0.1	0.0	0.0	0.7	7.4	13.6	23.5	70.5	26.7	0.1	21.7	10.0	119.9
Temperaturni zbroj iznad pragova 5°C i 10°C Temperature sum above the thresholds 5°C and 10°C																		
$t_{5°C}$ (°C)	4.1	17.5	80.0	184.1	328.6	411.2	474.9	461.9	346.3	198.1	63.0	12.0	33.6	592.7	1348.0	607.4	2207.0	2581.7
$t_{5°C}$ max (°C)	22.7	91.4	147.4	258.6	411.4	491.7	544.3	536.1	451.5	347.3	186.8	65.3	116.0	743.0	1554.2	778.0	2523.1	2979.9
$t_{5°C}$ min (°C)	0.0	0.0	19.5	92.7	253.0	362.6	417.0	370.8	257.0	85.5	3.2	0.0	3.1	411.1	1209.4	468.8	1966.2	2251.7
$t_{10°C}$ (°C)	0.1	1.7	13.7	62.8	176.2	261.2	319.9	306.9	197.3	72.5	10.8	1.2	3.0	252.7	888.0	280.6	1324.3	1424.3
$t_{10°C}$ max (°C)	2.5	14.2	38.9	125.5	258.2	341.7	389.3	380.1	301.6	199.8	71.1	22.1	33.2	378.2	1094.2	429.8	1630.7	1762.0
$t_{10°C}$ min (°C)	0.0	0.0	0.0	17.4	101.4	212.6	261.9	215.8	109.7	5.3	0.0	0.0	0.0	127.0	749.4	157.5	1085.8	1157.4
Temperatura tla Soil temperature																		
t_{5cm} (°C)	0.3	2.0	6.0	11.7	17.2	21.2	22.9	22.0	18.1	12.4	6.4	2.0	1.4	11.7	22.0	12.3	18.8	11.8
t_{5cm} max (°C)	3.5	6.0	9.3	17.8	21.2	24.0	26.2	23.7	21.3	16.4	9.4	4.2	6.0	21.2	26.2	21.3	26.2	26.2
t_{5cm} min (°C)	-6.1	-3.4	2.2	8.7	14.1	19.1	20.1	19.3	15.6	9.2	2.6	-2.9	-6.1	2.2	19.1	2.6	8.7	-6.1
t_{20cm} (°C)	1.4	2.6	5.8	11.3	16.2	20.1	22.0	21.8	18.5	13.3	7.6	3.2	2.4	11.1	21.3	13.1	18.3	12.0
t_{20cm} max (°C)	3.7	5.7	9.0	14.2	19.0	22.7	24.5	23.3	21.0	16.9	11.0	5.4	5.7	19.0	24.5	21.0	24.5	24.5
t_{20cm} min (°C)	-4.4	-0.8	1.6	8.7	13.8	18.4	19.8	19.4	16.3	10.8	4.5	-0.9	-4.4	1.6	18.4	4.5	8.7	-4.4
Oborina Precipitation																		
R (mm)	48.9	42.7	50.8	59.4	73.3	84.6	82.5	69.1	59.1	52.0	63.6	57.5	148.7	183.5	236.2	174.8	428.1	743.6
Rmax (mm)	120.7	119.4	118.0	114.9	179.5	142.6	262.2	168.7	171.6	155.0	127.7	123.3	308.5	292.1	462.2	271.5	621.4	928.2
Rmin (mm)	4.8	6.4	4.8	21.0	9.7	25.8	25.5	4.6	9.5	0.1	10.5	3.9	43.6	94.0	107.9	79.0	299.1	540.7
Rd_{max} (mm)	28.4	25.5	29.8	42.5	65.5	52.4	76.8	51.0	64.0	58.6	38.3	35.8	35.8	65.5	76.8	64.0	76.8	76.8
Rd≥0.1mm (d)	13.3	12.1	13.0	13.4	13.3	14.1	10.2	10.4	9.4	9.6	12.7	14.8	40.0	39.6	34.7	31.7	70.7	146.1
Rd≥1mm (d)	7.8	7.8	8.6	9.2	9.7	10.3	7.8	7.1	6.7	6.5	9.3	9.9	25.4	27.5	25.1	22.5	50.7	100.6
Rd≥5mm (d)	3.5	3.1	3.3	3.9	4.7	5.2	4.5	4.1	3.7	3.3	4.3	3.9	10.6	11.9	13.9	11.3	26.2	47.5
Rd≥10mm (d)	1.3	1.3	1.5	1.9	2.3	2.7	2.7	2.6	2.1	1.7	1.9	1.4	4.0	5.6	7.9	5.6	14.1	23.2
Rd≥20mm (d)	0.2	0.1	0.3	0.4	0.6	1.2	1.2	0.9	0.6	0.4	0.5	0.3	0.6	1.4	3.3	1.5	4.9	6.8
Rd≥50mm (d)	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.2	0.1	0.2	0.3
S≥1cm (d)	14.2	8.5	2.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	2.2	8.5	31.1	2.8	0.0	2.2	0.1	36.3
S≥10cm (d)	7.1	4.4	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	3.8	15.3	0.6	0.0	0.5	0.0	16.4
S≥30cm (d)	2.3	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	3.7	0.0	0.0	0.0	0.0	3.7
S≥50cm (d)	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.0	0.0	0.0	0.0	0.3
S_{max} (cm)	47	55	24	4	0	0	0	0	0	0	15	68	68	24	0	15	4	68
Isparavanje Evaporation																		
EV (mm)																		
EVmax (mm)																		
EVmin (mm)																		
PET (mm)	10	17	31	52	77	99	115	104	70	40	21	12	39	160	318	131	517	648
ET (mm)	10	17	31	52	77	96	109	94	64	39	21	12	39	160	299	124	492	622

1971–2000	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Z/W	P/Sp	LJ/Su	J/A	Veg	G/An
Temperatura zraka Air temperature																		
t (°C)	-0.2	1.9	6.5	11.0	16.1	19.3	21.0	20.4	16.1	10.6	5.0	1.1	0.9	11.2	20.2	10.6	17.3	10.7
T_{max} (°C)	18.7	21.9	27.4	29.0	34.6	35.1	38.6	39.6	34.5	30.2	25.6	23.0	23.0	34.6	39.6	34.5	39.6	39.6
T_{min} (°C)	-26.1	-23.0	-12.9	-5.5	-0.8	1.7	6.0	4.7	-3.0	-7.4	-13.7	-20.5	-26.1	-12.9	1.7	-13.7	-5.5	-26.1
t_{max} (°C)	3.5	6.9	12.5	17.1	22.2	25.2	27.4	27.2	23.1	17.0	9.5	4.8	5.0	17.3	26.6	16.5	23.7	16.4
t_{min} (°C)	-3.8	-2.6	0.9	4.9	9.4	12.7	14.0	13.7	9.9	5.4	1.0	-2.4	-3.0	5.0	13.4	5.5	10.8	5.2
$t_{min\ 5cm}$ (°C)	-4.8	-4.4	-1.4	2.3	6.9	10.6	11.8	11.1	7.9	3.7	-0.4	-3.5	-4.2	2.6	11.2	3.7	8.4	3.3
$t_{min\ 5cm}$ min (°C)	-27.5	-26.0	-16.5	-8.5	-5.0	-1.7	0.6	3.0	-7.0	-9.8	-18.5	-21.5	-27.5	-16.5	-1.7	-18.5	-8.5	-27.5
t_{more} / t_{sea} (°C)																		
t_{min} ≤-10°C (d)	2.9	1.9	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2.2	7.0	0.5	0.0	0.2	0.0	7.7
t_{max}<0°C (d)	7.9	3.1	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	4.8	15.9	0.6	0.0	0.8	0.0	17.2
t_{min}<0°C (d)	25.4	19.8	12.1	2.6	0.1	0.0	0.0	0.0	0.1	3.6	11.5	21.8	67.4	14.8	0.0	15.2	2.8	97.0
t_{max}≥25°C (d)	0.0	0.0	0.4	2.1	9.6	16.5	22.6	22.1	11.1	2.2	0.0	0.0	0.0	12.1	61.2	13.4	84.0	86.6
t_{max}≥30°C (d)	0.0	0.0	0.0	0.0	0.8	4.0	8.8	8.7	1.7	0.0	0.0	0.0	0.0	0.8	21.5	1.8	24.0	24.1
t_{min}≥20°C (d)	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.9	0.9
$t_{min\ 5cm}$<0°C (d)	26.4	21.8	18.0	9.0	1.1	0.1	0.0	0.0	0.6	7.2	14.3	22.9	71.4	28.0	0.1	21.9	10.7	121.1
Temperaturni zbroj iznad pragova 5°C i 10°C Temperature sum above the thresholds 5°C and 10°C																		
$t_{5°C}$ (°C)	5.8	19.4	85.2	181.3	332.8	418.4	485.7	478.7	345.0	197.1	58.9	13.4	38.7	599.2	1382.8	601.0	2241.9	2621.8
$t_{5°C}$ max (°C)	22.7	69.0	160.0	275.6	424.8	484.3	566.4	640.1	451.5	284.3	169.3	65.3	116.0	734.8	1670.7	799.3	2553.4	3060.4
$t_{5°C}$ min (°C)	0.0	0.0	19.5	92.7	225.3	362.6	417.0	370.8	257.0	85.5	3.2	0.0	3.5	411.1	1209.4	468.8	1966.2	2251.7
$t_{10°C}$ (°C)	0.1	1.4	15.8	61.5	181.4	268.4	330.7	323.7	195.8	74.9	9.7	1.5	3.0	258.7	922.8	280.4	1361.5	1464.8
$t_{10°C}$ max (°C)	2.5	11.1	38.9	139.9	269.9	334.2	411.4	485.1	301.6	141.1	44.5	22.1	33.2	387.4	1210.6	407.8	1688.1	1794.7
$t_{10°C}$ min (°C)	0.0	0.0	0.0	17.4	81.1	212.6	261.9	215.8	108.7	5.3	0.0	0.0	0.0	127.0	749.4	157.5	1085.8	1157.4
Temperatura tla Soil temperature																		
t_{5cm} (°C)	0.9	2.4	6.6	11.7	17.8	21.5	23.3	22.7	18.2	12.4	6.3	2.2	1.8	12.0	22.5	12.3	19.2	12.2
t_{5cm} max (°C)	3.5	6.0	10.1	14.5	21.2	24.0	26.2	27.5	21.3	14.8	10.0	4.2	6.0	21.2	27.5	21.3	27.5	27.5
t_{5cm} min (°C)	-1.2	-0.7	2.2	8.6	13.9	19.5	21.5	19.3	15.6	9.2	2.6	-0.8	-1.2	2.2	19.3	2.6	8.6	-1.2
t_{20cm} (°C)	1.7	2.5	6.2	11.1	16.8	20.5	22.6	22.5	18.5	13.3	7.6	3.4	2.5	11.4	21.8	13.2	18.7	12.2
t_{20cm} max (°C)	4.2	5.7	9.8	13.9	19.7	23.8	25.4	26.4	21.0	16.2	10.8	5.6	5.7	19.7	26.4	21.0	26.4	26.4
t_{20cm} min (°C)	-1.7	-0.5	2.5	8.3	13.2	18.6	20.8	19.4	16.2	10.3	4.5	1.2	-1.7	2.5	18.6	4.5	8.3	-1.7
Oborina Precipitation																		
R (mm)	47.3	38.5	45.8	55.9	69.4	82.4	87.8	67.9	62.9	68.3	68.4	53.4	137.9	171.1	238.1	199.6	426.3	748.1
Rmax (mm)	111.7	83.6	98.8	101.8	179.5	164.5	262.2	141.2	173.8	183.4	127.7	113.3	223.5	292.1	462.2	358.2	621.4	992.2
Rmin (mm)	12.4	3.3	10.5	23.8	9.7	25.3	6.4	10.9	9.5	4.1	10.5	3.9	43.6	94.0	123.8	79.0	250.9	511.3
Rd_{max} (mm)	36.8	29.6	30.4	28.1	45.0	64.2	76.8	48.4	42.4	58.6	36.0	34.3	36.8	45.0	76.8	58.6	76.8	76.8
Rd≥0.1mm (d)	12.0	11.1	12.1	13.4	12.5	13.8	10.4	10.1	9.7	11.0	12.4	13.7	36.8	37.9	34.4	33.1	70.0	142.2
Rd≥1mm (d)	7.3	7.2	7.8	9.2	9.2	10.4	7.9	7.2	7.4	7.6	8.8	9.0	23.6	26.2	25.4	23.7	51.2	98.8
Rd≥5mm (d)	3.5	2.7	3.0	3.9	4.2	5.3	4.6	4.1	4.2	4.1	4.8	3.6	9.7	11.2	14.0	13.0	26.4	48.0
Rd≥10mm (d)	1.5	1.2	1.4	1.9	2.1	2.5	3.1	2.5	2.2	2.2	2.3	1.3	3.9	5.4	8.1	6.7	14.3	24.2
Rd≥20mm (d)	0.1	0.1	0.2	0.2	0.6	0.9	1.3	0.9	0.6	0.7	0.5	0.3	0.5	1.1	3.2	1.8	4.7	6.6
Rd≥50mm (d)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2
S≥1cm (d)	11.2	7.3	1.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	2.7	7.4	26.3	2.0	0.0	2.7	0.2	30.6
S≥10cm (d)	4.1	3.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.7	9.1	0.3	0.0	0.4	0.0	9.5
S≥30cm (d)	0.3	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.9	0.0	0.0	0.0	0.0	0.9
S≥50cm (d)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S_{max} (cm)	34	51	24	4	0	0	0	0	0	0	15	36	51	24	0	15	4	51
Isparavanje Evaporation																		
EV (mm)																		
EVmax (mm)																		
EVmin (mm)																		
PET (mm)	11	18	33	51	79	101	117	109	69	39	20	12	41	163	327	128	526	659
ET (mm)	11	18	33	51	79	98	111	95	63	38	20	12	41	163	304	121	497	629

1961–1990	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Z/W	P/Sp	LJ/Su	J/A	Veg	G/An
Vlažnost zraka Air humidity																		
U (%)	87.0	81.7	74.5	71.5	73.7	74.7	73.4	75.7	79.1	81.7	86.1	88.2	85.6	73.2	74.6	82.3	74.7	78.9
Umin (%)	31.0	13.0	5.0	6.0	18.0	23.0	24.0	21.0	16.0	15.0	28.0	31.0	13.0	5.0	21.0	15.0	6.0	5.0
U>80% (d)	16.5	8.9	5.1	4.4	3.5	3.0	2.3	2.5	3.1	6.0	13.4	17.8	43.2	13.0	7.8	22.5	18.8	86.5
U≤30% (d)	0.0	0.3	3.0	3.8	1.4	0.7	0.7	1.0	1.3	0.8	0.1	0.0	0.3	8.2	2.4	2.2	8.9	13.1
e (hPa)	5.2	5.9	7.0	9.3	13.1	16.4	17.6	17.3	14.4	10.7	8.0	6.0	5.7	9.8	17.1	11.0	14.7	10.9
Sunčevo zračenje Solar radiation (1961-1980)																		
$G_{0°}$ (MJm^{-2})	128	192	346	474	609	633	653	571	427	278	134	90	410	1429	1857	838	3367	4535
$G_{45°S}$ (MJm^{-2})	200	271	414	482	550	542	573	555	496	389	199	132	603	1446	1669	1084	3197	4802
Trajanje sijanja Sunca Insolation duration																		
SS (h)	1.6	2.7	4.3	5.7	7.0	7.6	8.6	8.1	6.4	4.4	2.2	1.4	1.9	5.6	8.1	4.3	7.2	5.0
SS_{rel} (%)																		
SS_{max} (h)	3.2	6.0	6.5	8.0	8.7	9.1	10.6	10.2	9.0	6.7	3.7	2.9	3.1	6.8	9.1	5.3	8.0	5.7
SS_{min} (h)	0.5	0.6	2.2	3.8	4.5	5.9	6.1	6.2	4.5	2.7	0.1	0.5	0.9	4.1	6.8	3.1	6.2	4.4
Naoblaka Cloudiness																		
N (10/10)	7.8	7.3	6.8	6.5	6.2	6.0	4.8	4.6	5.2	6.1	7.6	8.1	7.7	6.5	5.1	6.3	5.5	6.4
N_{max} (10/10)	9.4	9.3	8.5	7.8	7.7	7.2	7.5	6.5	6.8	8.0	9.6	9.7	8.8	7.6	6.2	7.4	6.6	7.0
N_{min} (10/10)	5.9	4.3	4.7	4.9	4.8	5.0	3.3	2.6	2.3	3.8	5.9	6.1	6.1	5.4	4.2	5.3	4.8	5.7
N<2/10	1.6	1.9	3.1	3.4	3.3	3.1	7.0	8.7	6.5	3.8	1.7	1.2	4.7	9.7	18.8	12.0	32.0	45.2
N<2/10 max	5	8	9	11	10	7	13	18	19	10	5	4	16	22	32	24	51	71
N<2/10 min	0	0	0	0	0	0	1	0	0	0	0	0	0	2	11	3	16	23
N>8/10	18.0	14.9	13.3	11.0	9.7	8.4	5.7	5.8	7.6	10.3	16.7	19.6	52.5	34.1	19.8	34.6	48.2	141.1
N>8/10 max	29	24	24	18	18	15	15	11	13	19	27	28	68	50	31	49	66	178
N>8/10 min	9	3	3	4	3	2	2	0	1	2	9	10	37	21	11	24	31	107
Meteorološke pojave Weather phenomena																		
magla/fog	15.6	10.6	6.1	3.6	5.4	7.0	8.0	10.4	15.3	17.5	15.1	15.4	41.7	15.1	25.4	47.9	49.6	130.1
magla/fog max	26	21	20	11	13	18	20	23	27	27	24	26	65	43	53	77	103	232
magla/fog min	7	3	0	0	0	0	0	0	2	5	0	5	16	0	3	15	10	47
tuča/hail	0.0	0.0	0.0	0.1	0.3	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.4	0.5	0.1	1.0	1.0
tuča/hail max	0	0	1	1	1	1	1	1	1	0	0	1	1	2	2	1	2	3
tuča/hail min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
grm/thun	0.1	0.1	0.4	2.3	5.8	7.6	6.9	6.7	2.0	0.7	0.4	0.2	0.4	8.5	21.3	3.1	31.3	33.3
grm/thun max	1	1	2	8	12	14	14	13	6	4	2	2	2	15	30	7	45	48
grm/thun min	0	0	0	0	1	3	2	2	0	0	0	0	0	1	14	0	18	20
rosa/dew	1.4	3.0	11.3	18.9	22.2	22.2	25.1	25.9	24.5	22.8	11.6	3.4	7.9	52.4	73.2	58.9	138.7	192.3
rosa/dew max	21	19	25	26	30	28	31	31	30	31	25	20	34	71	87	81	164	247
rosa/dew min	0	0	0	10	13	13	8	19	16	11	2	0	0	26	50	33	98	126
mraz/frost	11.1	10.2	10.0	3.6	0.3	0.0	0.0	0.0	0.3	4.9	9.3	11.5	32.8	13.9	0.0	14.6	4.2	61.2
mraz/frost max	26	22	17	11	3	0	0	0	2	17	22	23	63	24	0	30	14	108
mraz/frost min	0	0	3	0	0	0	0	0	0	0	1	0	8	3	0	2	0	14
inje/rime	5.6	1.7	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.3	3.5	10.8	0.3	0.0	1.4	0.0	12.5
inje/rime max	20	7	3	0	0	0	0	0	0	3	7	10	28	3	0	8	0	31
inje/rime min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tlak zraka Air pressure																		
p (hPa)	1009.1	1006.8	1005.6	1002.7	1004.0	1004.4	1005.2	1005.2	1007.5	1009.0	1007.7	1008.2	1008.0	1004.1	1004.9	1008.1	1004.8	1006.3
p max (hPa)	1033.2	1030.7	1030.3	1023.4	1018.6	1018.2	1018.0	1016.1	1023.8	1026.0	1029.4	1035.8	1035.8	1030.3	1018.2	1029.4	1023.8	1035.8
p min (hPa)	975.7	964.7	977.0	976.1	981.2	989.2	965.2	987.0	984.6	976.8	977.7	960.5	960.5	976.1	965.2	976.8	965.2	960.5
Vjetar Wind																		
v_h (ms^{-1})	1.8	2.0	2.4	2.4	2.0	1.9	1.7	1.7	1.5	1.6	1.7	1.9	1.9	2.3	1.7	1.6	1.9	1.9
v_h max (ms^{-1})	15.4	13.1	12.5	13.5	12.0	12.0	16.8	12.0	12.0	12.0	13.0	13.1	15.4	13.5	16.8	13.0	16.8	16.8
v_{max} (ms^{-1})	30.0	25.4	23.3	29.7	25.1	23.1	31.1	29.6	28.0	23.0	25.6	27.7	30.0	29.7	31.1	28.0	31.1	31.1
Osjet ugode Thermal sensation																		
$PhET_{7h}$ (°C)	-8.7	-8.4	-2.5	4.9	12.5	17.1	18.3	15.4	9.3	3.0	-2.1	-6.2	-7.8	5.0	16.9	3.4	12.9	4.4
$PhET_{14h}$ (°C)	-1.8	-0.6	9.3	15.8	23.2	27.7	31.1	30.2	25.0	16.1	6.3	-0.2	-0.9	16.1	29.7	15.8	25.5	15.2
$PhET_{21h}$ (°C)	-7.4	-6.8	0.0	4.9	10.2	13.7	15.3	14.5	10.7	5.0	-0.6	-5.1	-6.4	5.1	14.5	5.1	11.6	4.5

1971–2000	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Z/W	P/Sp	LJ/Su	J/A	Veg	G/An
Vlažnost zraka Air humidity																		
U (%)	87.1	80.9	73.1	72.0	73.6	74.7	73.7	75.6	79.6	82.4	86.3	88.6	85.5	72.9	74.7	82.8	74.9	79.0
Umin (%)	31.0	13.0	5.0	6.0	18.0	23.0	25.0	21.0	18.0	15.0	28.0	31.0	13.0	5.0	21.0	15.0	6.0	5.0
U>80% (d)	16.5	7.9	4.9	4.5	3.8	3.4	2.6	2.8	3.2	7.4	13.3	17.3	41.7	13.1	8.8	23.9	20.3	87.5
U≤30% (d)	0.0	0.4	2.9	3.3	1.7	0.6	0.7	1.3	0.7	0.8	0.1	0.0	0.4	7.9	2.7	1.6	8.4	12.5
e (hPa)	5.5	5.9	7.0	9.2	13.3	16.6	18.1	17.8	14.5	10.8	7.8	6.1	5.9	9.9	17.5	11.0	14.9	11.1
Sunčevo zračenje Solar radiation																		
$G_{0°}$ (MJm^{-2})																		
G45°S (MJm^{-2})																		
Trajanje sijanja Sunca Insolation duration																		
SS (h)	1.8	3.2	4.6	5.8	7.2	7.9	8.7	8.2	6.3	4.2	2.2	1.6	2.2	5.9	8.3	4.3	7.4	5.2
SS_{rel} (%)																		
SS_{max} (h)	3.8	6.0	6.3	7.3	9.3	11.4	10.6	11.0	9.0	6.1	3.9	2.9	3.7	7.3	10.6	5.3	8.9	6.3
SS_{min} (h)	0.5	0.6	2.6	3.8	4.5	5.9	6.1	6.2	4.5	2.7	0.1	0.6	0.9	4.1	6.8	3.1	6.2	4.4
Naoblaka Cloudiness																		
N (10/10)	7.6	6.7	6.3	6.3	5.8	5.6	4.7	4.4	5.1	6.1	7.4	7.6	7.3	6.1	4.9	6.2	5.3	6.1
N_{max} (10/10)	9.4	9.3	8.2	7.8	7.7	7.2	7.5	6.5	7.2	8.0	9.6	9.5	8.5	7.3	6.2	7.4	6.6	7.0
N_{min} (10/10)	4.5	4.1	4.7	4.9	4.1	2.6	3.3	1.8	2.3	4.3	5.9	5.8	5.3	4.9	3.0	5.2	4.0	5.1
N<2/10	2.0	3.3	3.6	3.3	3.8	3.6	7.1	8.8	5.8	3.5	1.9	1.9	7.2	10.6	19.5	11.2	32.4	48.5
N<2/10 max	10	12	9	11	10	13	13	21	17	10	5	7	22	22	38	22	56	82
N<2/10 min	0	0	0	0	0	0	1	0	0	0	0	0	0	3	9	3	16	23
N>8/10	17.6	13.1	11.0	10.2	8.3	7.0	5.2	4.9	6.9	10.7	15.9	17.6	48.3	29.6	17.1	33.5	42.6	128.5
N>8/10 max	29	24	21	18	18	15	15	10	14	19	27	28	68	47	31	49	66	178
N>8/10 min	6	3	3	4	2	0	2	0	0	4	7	10	26	12	2	21	17	72
Meteorološke pojave Weather phenomena																		
magla/fog	15.4	10.6	6.2	4.7	6.1	7.7	9.1	11.2	16.2	17.4	15.2	15.8	41.8	16.9	28.1	48.7	55.0	135.5
magla/fog max	26	21	20	11	13	18	20	23	27	27	24	26	65	43	53	77	103	232
magla/fog min	5	2	0	0	1	1	0	0	0	8	7	3	17	4	3	18	7	44
tuča/hail	0.0	0.0	0.1	0.0	0.2	0.2	0.3	0.2	0.1	0.1	0.0	0.0	0.1	0.3	0.7	0.2	1.0	1.2
tuča/hail max	1	0	1	1	1	1	1	2	1	1	0	1	1	2	2	1	3	3
tuča/hail min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
grm/thun	0.1	0.1	0.5	1.9	5.1	6.8	6.3	6.1	2.1	1.0	0.3	0.2	0.5	7.5	19.2	3.5	28.3	30.7
grm/thun max	1	1	2	6	10	16	14	12	6	5	2	2	2	15	30	8	43	47
grm/thun min	0	0	0	0	1	2	2	1	0	0	0	0	0	1	9	0	18	20
rosa/dew	2.9	4.8	12.8	18.8	23.0	22.1	25.8	25.9	24.5	23.4	12.9	4.8	12.5	54.5	73.8	60.9	140.1	201.8
rosa/dew max	21	19	25	26	30	28	31	31	30	30	25	20	34	71	87	81	164	247
rosa/dew min	0	0	0	7	6	2	8	3	13	7	3	0	0	14	13	25	39	54
mraz/frost	14.8	13.7	11.2	3.9	0.2	0.0	0.0	0.0	0.3	5.1	10.0	13.8	42.3	15.3	0.0	15.4	4.4	73.0
mraz/frost max	26	24	17	11	1	0	0	0	2	12	22	28	71	26	0	30	14	108
mraz/frost min	3	3	3	0	0	0	0	0	0	0	0	0	19	5	0	2	0	51
inje/rime	4.8	1.8	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.3	3.3	9.9	0.3	0.0	1.5	0.0	11.7
inje/rime max	18	7	3	0	0	0	0	0	0	3	7	10	28	3	0	8	0	31
inje/rime min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tlak zraka Air pressure																		
p (hPa)	1010.4	1008.4	1006.3	1002.7	1004.2	1004.5	1004.9	1005.4	1007.0	1008.7	1008.4	1009.3	1009.3	1004.4	1004.9	1008.0	1004.8	1006.7
p max (hPa)	1034.0	1031.1	1030.3	1023.5	1018.8	1019.0	1018.0	1016.1	1023.6	1026.3	1029.4	1032.1	1034.0	1030.3	1019.0	1029.4	1023.6	1034.0
p min (hPa)	975.7	964.7	977.0	978.3	981.2	988.8	965.2	987.6	982.5	977.8	977.7	960.5	960.5	977.0	965.2	977.7	965.2	960.5
Vjetar Wind																		
v_h (ms^{-1})	2.0	2.2	2.6	2.6	2.2	2.1	1.9	1.8	1.7	1.8	1.9	2.0	2.1	2.5	1.9	1.8	2.1	2.1
v_h max (ms^{-1})	15.4	16.9	18.4	20.3	14.3	14.2	16.8	14.2	15.9	16.9	18.5	13.6	16.9	20.3	16.8	18.5	20.3	20.3
v_{max} (ms^{-1})	30.0	26.0	25.7	29.7	25.6	26.1	38.3	29.6	28.0	27.0	27.2	27.7	30.0	29.7	38.3	28.0	38.3	38.3
Osjet ugode Thermal sensation																		
$PhET_{7h}$ (°C)	-7.6	-7.4	-2.5	4.4	12.5	16.9	18.2	15.7	9.2	3.4	-2.1	-6.0	-7.0	4.8	16.9	3.5	12.8	4.6
$PhET_{14h}$ (°C)	-0.9	0.9	9.6	15.9	23.2	28.0	31.2	31.2	24.8	15.9	6.1	0.3	0.1	16.3	30.1	15.6	25.7	15.5
$PhET_{21h}$ (°C)	-6.3	-5.6	0.1	4.9	10.4	14.1	15.8	15.3	10.9	5.4	-0.6	-4.8	-5.5	5.2	15.0	5.2	11.9	5.0

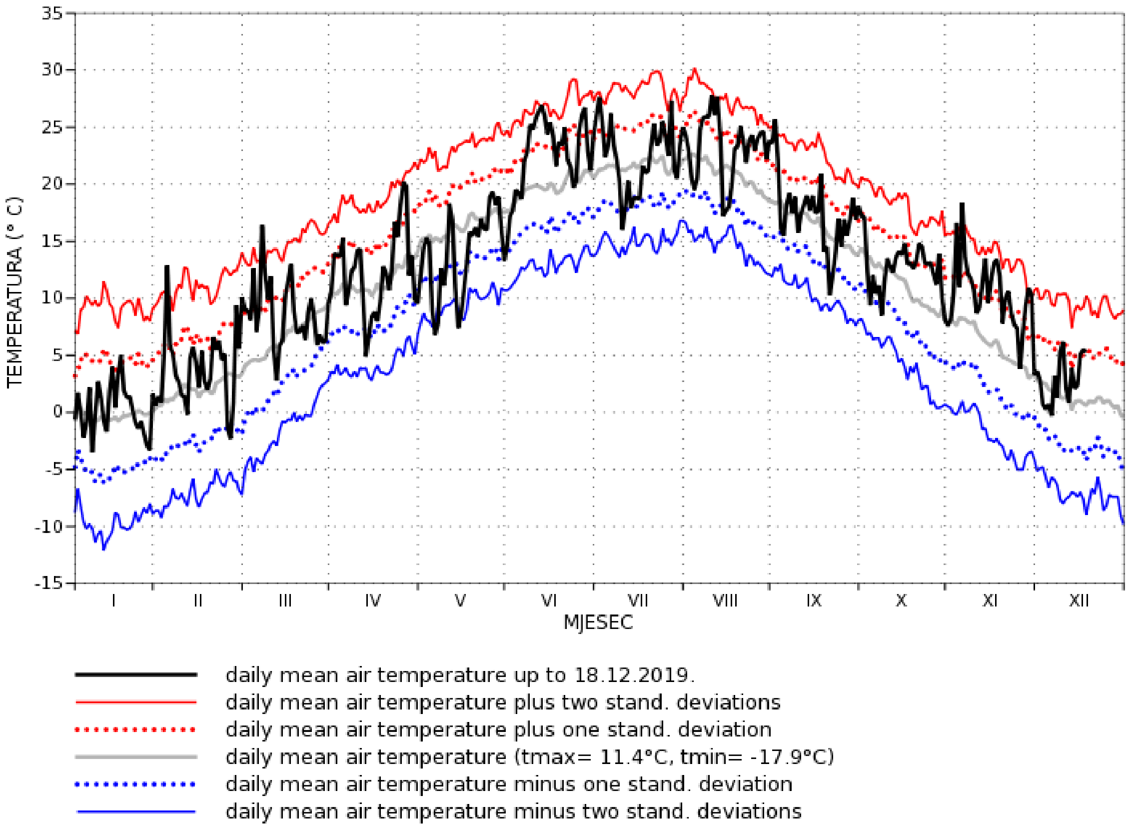
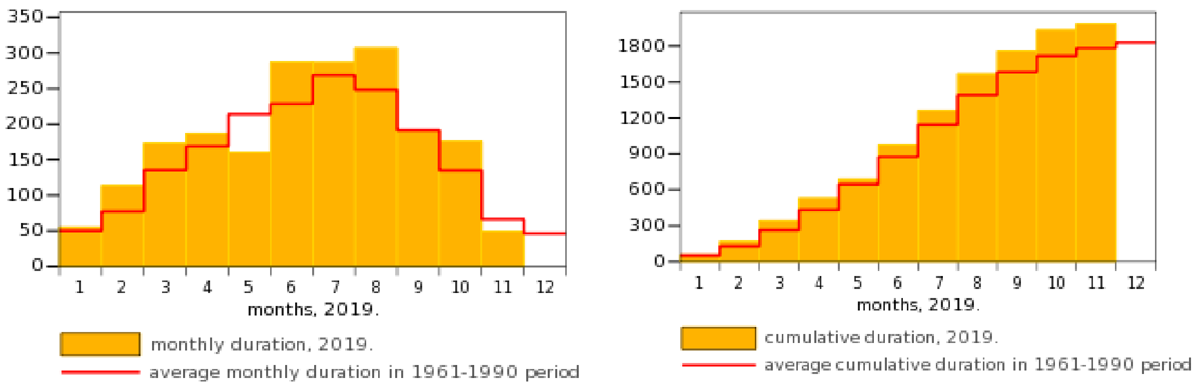


Figure 3.13 – Comparison to the average for the 1963 – 2018 period in Slavonski Brod

Figure 3.14 show months insolation duration (h) for last 4 years comparison with average monthly duration in 1961. – 1990. period for Slavonski Brod.



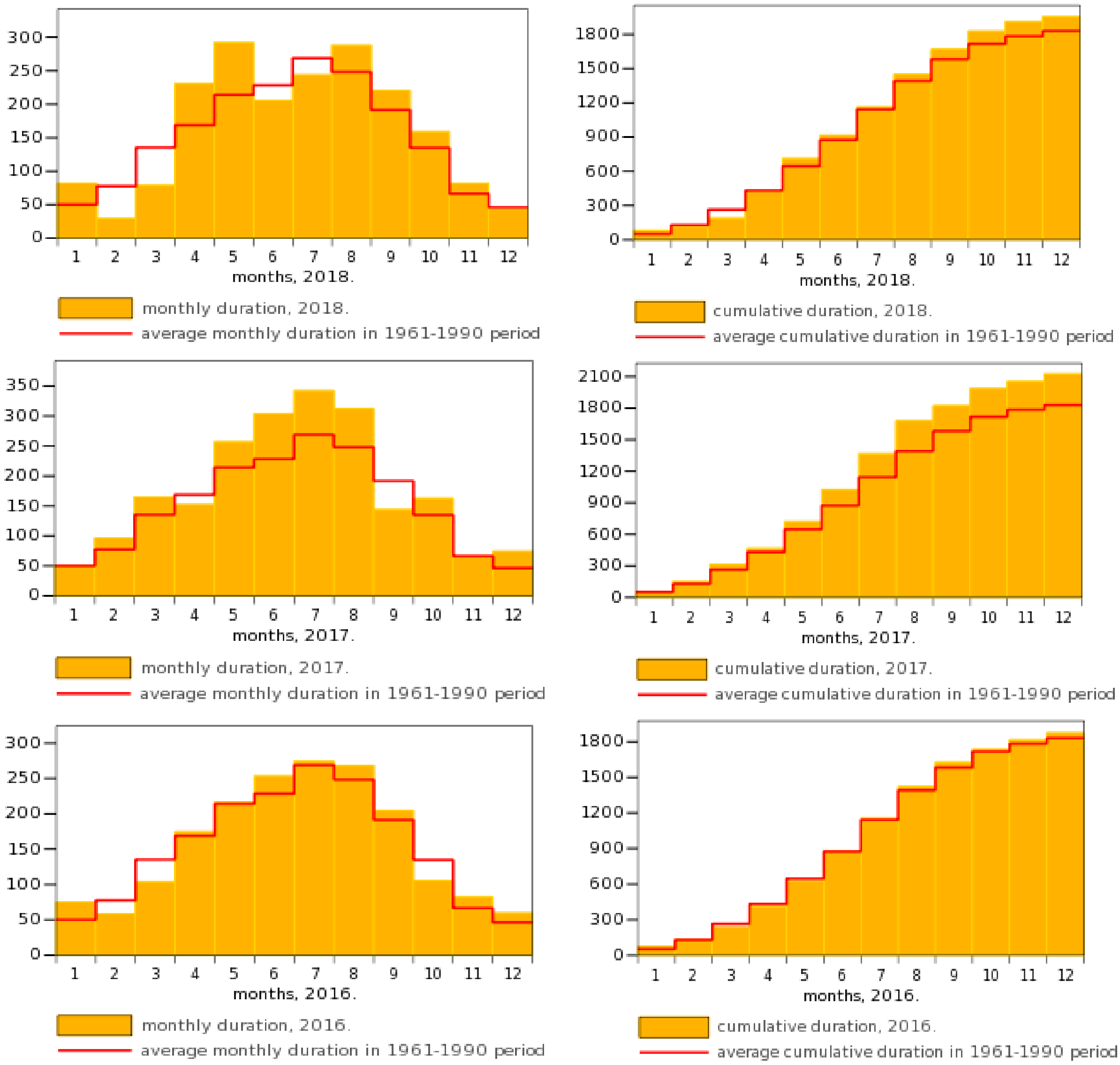


Figure 3.14 – Insolation duration (h) in Slavonski Brod

3.2. Description of construction characteristics of the facility

The building of the Mechanical Engineering Faculty was upgraded project on the existing building of Pedagogical High School for needs of the Pedagogical Academy. Since then it has been renovated several times (1996-1997, 2002-2003, 2005-2006), and heating methods have been improved in two occasions (1994 introduction of central heating with fuel oil, 2001 transition to heating) natural gas). It consists of the ground floor and first floor that can be seen in Figure 3.15.

Figure 3.15 – Mechanical Engineering Faculty – Building 2 (I. Gundulića 20A)

The structure of the building is reinforced concrete (AB) - skeletal (columns, beams, ceilings), with masonry walls. Sewerage was carried vertically through the building and below the ground floor. The facade was damaged several times, which required subsequent renovation on several occasions. The current damage can be seen in Figure 3.16. Exterior walls are made of multi-layer: 25 cm brick plastered on both sides or 15 cm concrete, plastered on both sides.

Figure 3.16 – Manifestation of facade damage and wall rupture at joints.

The windows are mostly PVC joinery with two exceptions, which makes a large area and a thermal bridge. The profiles used in these cases are made of aluminium and wood as seen in Figure 3.17. Joinery also contains PVC, wooden or aluminium frame with transparent glass 4 + 12 + 4 (air).

Figure 3.17 – Appearance of used joinery made of aluminums and wooden profiles.

The climatic data relevant to the study and the location of the facility at the microsite are given in Table 3.2.

Table 3.2 – The climatic data for analysis and the location of the facility.

The climatic data	
Location	Slavonski Brod
Number of Heating Degree Day *HDD*	3197
Number of days of heating season *HD*	231
Mean heating period temperature $\vartheta_{H,mn}$ [°C]	6.16
Internal temperature for winter period $\vartheta_{H,I}$ [°C]	20
Wind effect	
Position (wind exposure)	Slightly sheltered
Number of facades exposed to the wind	More than two facade

3.2.1. Comfort conditions

Thermal comfort is ensured by thermal zoning of the building, as urban conditions and design have allowed at the time of construction. External design temperatures for Slavonski Brod were used in the calculations.

The air comfort in the building is provided by natural ventilation and floor height. Since the windows are mostly PVC with occasionally aluminium and wood, without thermal break, the sealing is good.

Light comfort in the building is ensured by the introduction of natural light through large transparent surfaces as well as the use of artificial lighting.

Sound comfort is ensured by the application of rubberized floor coverings.

3.2.2. Thermal characteristics of the facility

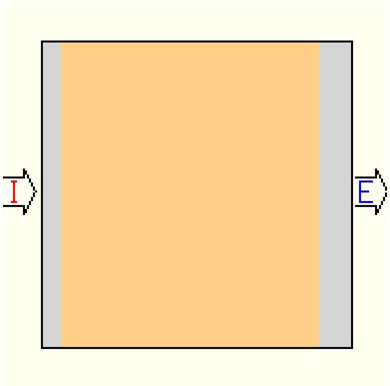
According to the design characteristics, the heat transfer coefficients are shown in Table 3.3.

Table 3.3 – Heat transfer coefficients per building component

Name of building part	Area [m^2]	U [W/m^{2}K]
Outside wall	444.14	1.89
Floor, hallway	292.93	2.03
Floor, office	409.60	1.63
Ceiling - attic	701.26	1.40
Ceiling - outdoor space	73.89	1.29
Flat roof	80.62	1.95
Brick wall	63.63	2.79

The thermal characteristics of the materials and calculation of the heat transfer coefficients are shown in the following figures.

Outside wall



Outside wall

Area: 444.14 m^2

Internal temperature: 20.00 °C

Outside temperature: -1.10 °C

Defined layers of building parts

Layer	Material	d [cm]	λ [W/mK]	ρ [kg/m³]
1	Lime-cement plaster	2.00	1.00	1800
2	Solid clay brick	25.00	0.81	1800
3	Lime-cement plaster	3.00	1.00	1800

Definirani udjeli u ploštini građevnog dijela prema orijentacijama

The total area of the building part is 444.14 m^2, of which it is oriented
to the east: 116.73 m^2
to the west: 43.68 m^2
to the north: 196.45 m^2
to the south: 87.28 m^2

Results of heat transfer coefficient calculation

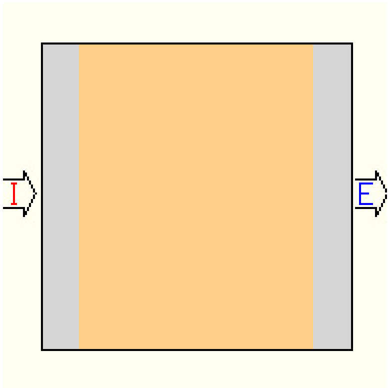
Layer	Material	λ [W/mK]	d [cm]	R [m²K/W]
1	Lime-cement plaster	1	2.00	0.020
2	Solid clay brick	0.81	25.00	0.309
3	Lime-cement plaster	1	3.00	0.030
			R_{si} =	**0.130**
			R_{se} =	**0.040**
			R_T =	**0.529**

Regarding the minimum thermal protection and the maximum allowable value of the heat transfer coefficient U (W/m^2K) (Technical regulation on the rational use of energy and thermal protection in buildings), the construction part:

Does not satisfy

$U = 1.89$ [W/m²K] > $U_{max} = 0.45$ [W/m²K]

Brick wall



Brick wall

Area: 63.63 m²
Internal temperature: 20.00 °C
Outside temperature: -1.10 °C

Defined layers of building parts

Layer	Material	d [cm]	λ [W/mK]	ρ [kg/m³]
1	Lime-cement plaster	2.00	1.00	1800
2	Solid clay brick	12.00	0.81	1800
3	Lime-cement plaster	3.00	1.00	1800

Definirani udjeli u ploštini građevnog dijela prema orijentacijama

The total area of the building part is 63.63 m^2, of which it is oriented to the west: 63.63 m^2

Results of heat transfer coefficient calculation

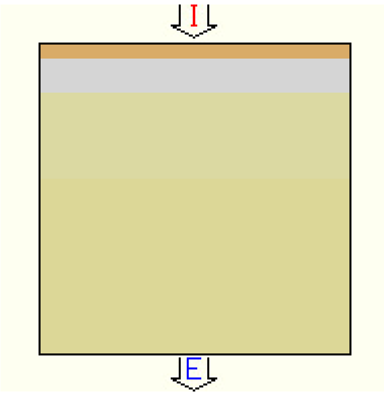
Layer	Material	λ [W/mK]	d [cm]	R [m²K/W]
1	Lime-cement plaster	1	2.00	0.020
2	Solid clay brick	0.81	12.00	0.148
3	Lime-cement plaster	1	3.00	0.030
			R_{si} =	**0.130**
			R_{se} =	**0.040**
			R_T =	**0.358**

Regarding the minimum thermal protection and the maximum allowable value of the heat transfer coefficient U (W/m^{2}K) (Technical regulation on the rational use of energy and thermal protection in buildings), the construction part:

Does not satisfy

$U = 2.79$ [W/m^{2}K] > $U_{max} = 0.45$ [W/m^{2}K]

Floor, hallway



Floor, hallway

Area: 292.93 m^2
Internal temperature: 20.00 °C
Outside temperature: 10.50 °C

Defined layers of building parts

Layer	Material	d [cm]	λ [W/mK]	ρ [kg/m³]
1	Stone slabs	2.00	2.80	2500
2	Cement mortar	4.00	1.60	2000
3	Concrete	10.00	2.50	2400
4	Sand, gravel, crushed stone	20.00	0.81	1700

Results of heat transfer coefficient calculation

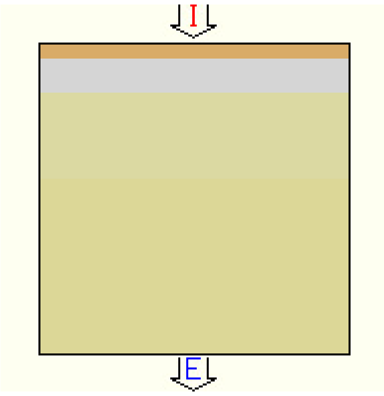
Layer	Material	λ [W/mK]	d [cm]	R [m²K/W]
1	Stone slabs	2.80	2.00	0.010
2	Cement mortar	1.60	4.00	0.025
3	Concrete	2.50	10.00	0.040
4	Sand, gravel, crushed stone	0.81	20.00	0.247
			R_{si} =	**0.170**
			R_{se} =	**0.000**
			R_T =	**0.492**

Regarding the minimum thermal protection and the maximum allowable value of the heat transfer coefficient U (W/m^2K) (Technical regulation on the rational use of energy and thermal protection in buildings), the construction part:

Does not satisfy

$U = 2.03$ [W/m^2K] $> U_{max} = 0.50$ [W/m^2K]

Floor, office



Floor, office

Area: 409.60 m^2
Internal temperature: 20.00 °C
Outside temperature: 10.50 °C

Defined layers of building parts

Layer	Material	d [cm]	λ [W/mK]	ρ [kg/m³]
1	Wood	2.00	0.15	550
2	Cement mortar	4.00	1.60	2000
3	Concrete	10.00	2.50	2400
4	Sand, gravel, crushed stone	20.00	0.81	1700

Results of heat transfer coefficient calculation

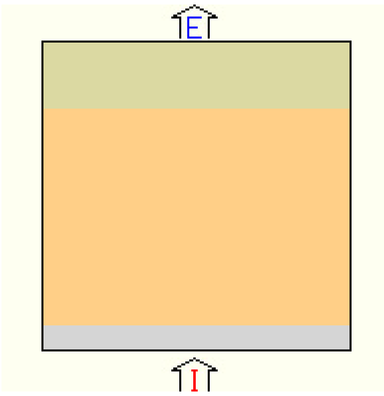
Layer	Material	λ [W/mK]	d [cm]	R [m²K/W]
1	Wood	0.15	2.00	0.133
2	Cement mortar	1.60	4.00	0.025
3	Concrete	2.50	10.00	0.040
4	Sand, gravel, crushed stone	0.81	20.00	0.247
			R_{si} =	**0.170**
			R_{se} =	**0.000**
			R_T =	**0.615**

Regarding the minimum thermal protection and the maximum allowable value of the heat transfer coefficient U (W/m²K) (Technical regulation on the rational use of energy and thermal protection in buildings), the construction part:

Does not satisfy

$U = 1.63$ [W/m²K] > $U_{max} = 0.50$ [W/m²K]

Ceiling - attic



Ceiling – attic

Area: 701.26 m^2
Internal temperature: 20.00 °C
Outside temperature: -1.10 °C

Defined layers of building parts

Layer	Material	d [cm]	λ [W/mK]	ρ [kg/m³]
1	Lime-cement plaster	2.00	1.00	1800
2	Hollow clay blocks	16.00	0.48	1100
3	Concrete	5.00	2.50	2400

Defined roof cover (HRN EN ISO 6946)

Plate cover, cover with roofing board, formwork panels or similar cover.

Results of heat transfer coefficient calculation

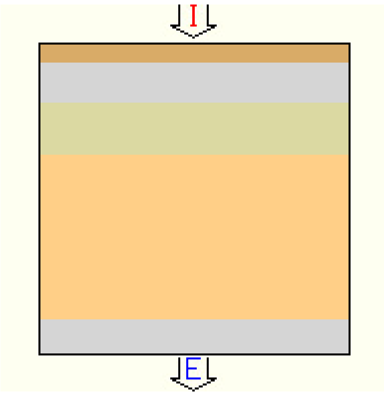
Layer	Material	λ [W/mK]	d [cm]	R [m²K/W]
1	Lime-cement plaster	1.00	2.00	0.020
2	Hollow clay blocks	0.48	16.00	0.333
3	Concrete	2.50	5.00	0.020
			R_{si} =	**0.100**
			R_{se} =	**0.040**
			R_U =	**0.200**
			R_T =	**0.713**

Regarding the minimum thermal protection and the maximum allowable value of the heat transfer coefficient U (W/m^{2}K) (Technical regulation on the rational use of energy and thermal protection in buildings), the construction part:

Does not satisfy

$U = 1.40$ [W/m^{2}K] $> U_{max} = 0.30$ [W/m^{2}K]

Ceiling - outdoor space



Ceiling - outdoor space

Area: 73.89 m^2
Internal temperature: 20.00 °C
Outside temperature: -1.10 °C

Defined layers of building parts

Layer	Material	d [cm]	λ [W/mK]	ρ [kg/m³]
1	Wood	2.00	0.15	550
2	Cement screed	4.00	1.60	2000
3	Concrete	5.00	2.50	2400
4	Hollow clay blocks	16.00	0.45	1000
5	Lime-cement plaster	3.00	1.00	1800

Results of heat transfer coefficient calculation

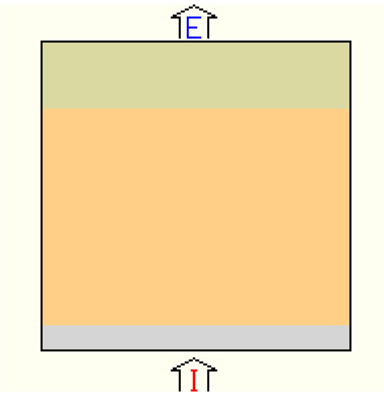
Layer	Material	λ [W/mK]	d [cm]	R [m²K/W]
1	Wood	0.15	2.00	0.133
2	Cement screed	1.60	4.00	0.025
3	Concrete	2.50	5.00	0.020
4	Hollow clay blocks	0.45	16.00	0.356
5	Lime-cement plaster	1.00	3.00	0.030
			R_{si} =	**0.170**
			R_{se} =	**0.040**
			R_T =	**0.774**

Regarding the minimum thermal protection and the maximum allowable value of the heat transfer coefficient U (W/m^{2}K) (Technical regulation on the rational use of energy and thermal protection in buildings), the construction part:

Does not satisfy

$U = 1.29$ [W/m^{2}K] > $U_{max} = 0.30$ [W/m^{2}K]

Flat roof



Flat roof

Area: 80.62 m^2
Internal temperature: 20.00 °C
Outside temperature: -1.10 °C

Defined layers of building parts

Layer	Material	d [cm]	λ [W/mK]	ρ [kg/m³]
1	Lime-cement plaster	2.00	1.00	1800
2	Hollow clay blocks	16.00	0.48	1100
5	Concrete	5.00	2.50	2400

Results of heat transfer coefficient calculation

Layer	Material	λ [W/mK]	d [cm]	R [m²K/W]
1	Lime-cement plaster	1.00	2.00	0.020
2	Hollow clay blocks	0.48	16.00	0.333
5	Concrete	2.50	5.00	0.020
			R_{si} =	**0.100**
			R_{se} =	**0.040**
			R_T =	**0.513**

Regarding the minimum thermal protection and the maximum allowable value of the heat transfer coefficient U (W/m^2K) (Technical regulation on the rational use of energy and thermal protection in buildings), the construction part:

Does not satisfy

U = 1.29 [W/m^2K] > U_{max} = 0.30 [W/m^2K]

3.2.3. Thermal examination of the facility

During the thermal examination of the facility with a thermal camera, a large thermal spill was detected. Especially through thermal bridges around window frames and at the junction between the ground and first floor. The examination was performed on December, 13. 2019. at an outdoor temperature of 10°C. Figure 3.18 show thermal breakthroughs in those zones.

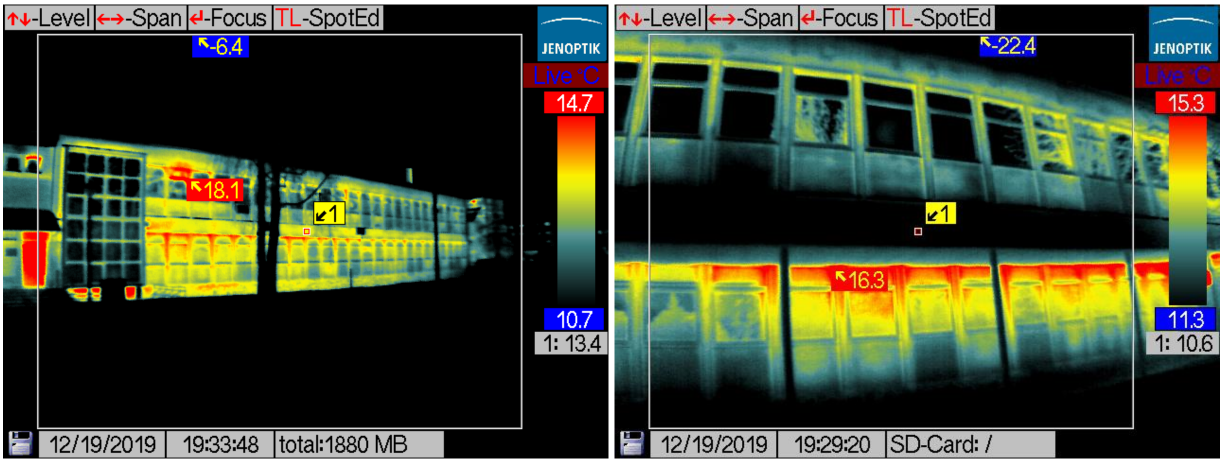


Figure 3.18 – Thermal bridges around windows on south and north side of the building and junction between floors on the north side of the building

The thermal examination also showed a weak area, high heat transfer coefficient in zones where PVC joinery is not used, but aluminium and wood frames are used.

Figure 3.19 – Zone with a high heat transfer coefficient

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, "Strojarski fakultet u Slavonskom Brodu, building in Ivan Gundulić Street 20a", as a part of the building complex of the Mechanical Engineering Faculty in Slavonski Brod, will be referred to as exemplary object.

4.1.1. The power supply of the "Strojarski fakultet u Slavonskom Brodu, building in Ivan Gundulić Street 20a"

This building is supplied from the public transformer station located within the yard of the object, ownership of the HEP group – Croatian Electricity Board. The transformer station is located outside near the main entrance where there is also freestanding distribution cabinet with meter for recording electricity consumption of the object (approved peak power of 29.9 kW). The transformer station is called "TS Gundulić Street" and a three-phase oil transformer with a nominal power of 1000 kVA, a turn ratio of 10/0.4 kV and a Dyn5 transformer connection was used for the object power supply. In Figure 4.1, the transformer station is depicted.

Figure 4.1 – Transformer station "TS 10/0.4 kV No. 128, Gundulić Street" and freestanding electric cabinet in the yard of the analyzed building.

Aluminum cable 3 x (XHE 49A 1x150 mm^2) was used as a high-voltage cable. On the low-voltage side copper busbar 3x(2x80x5) + 1x(80x5) mm^2 was used. The main circuit breaker is set to the nominal value of the 1600 A. Single line diagram of the transformer station is illustrated in Figure 4.2.

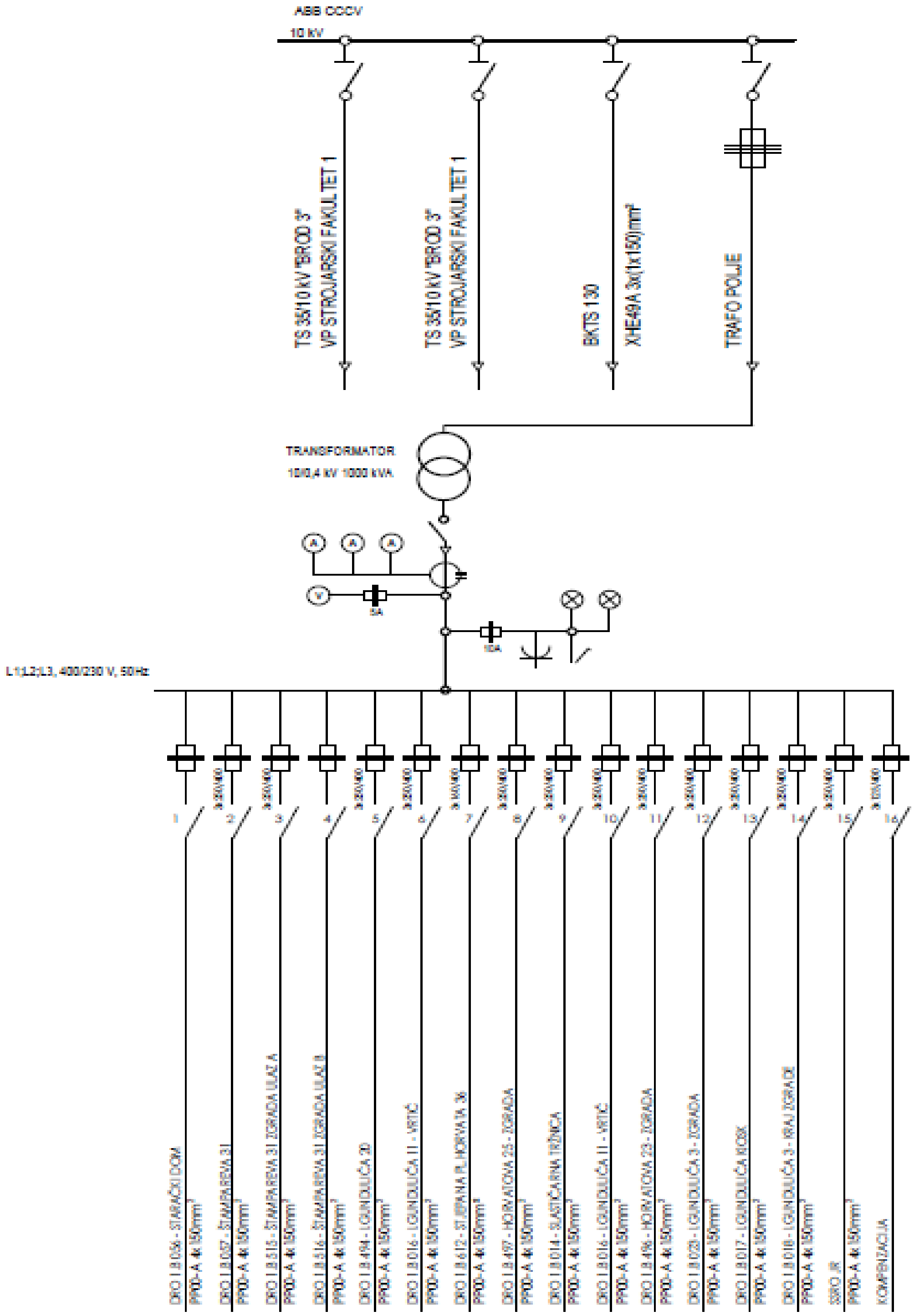


Figure 4.2 – Transformer station single line diagram.

Figure 4.2 shows all outgoing feeders on the low-voltage side of the transformer, together with the cross-sections of the cable lines. Feeder 5 is used to supply building of Strojarski fakultet, Ivan Gundulić Street 20a. The low-voltage block of the transformer station is protected by the main circuit breaker with the nominal current 1600 A. Low-voltage block has 15 low voltage feeders (+compensation). Low voltage block feeder 5 is power supply of the freestanding electric cabinet in the south-west part of the yard of the analyzed building, connected to group of objects (including analyzed object) by cable type PP00-Y 4x150 mm^2. It is protected by fuse with nominal current 250 A and gG characteristics. A cable, type XP00-A 4 x 50 mm^2 makes electric connection between freestanding electric cabinet to main distribution cabinet of the building located in the hallway of the building, directly at the entrance to the building (fuse 63 A, gG). That main electric cabinet houses the main fuses of the building, electric installation of the building busbars and fuses.

Figure 4.3 – Distribution cabinets in the analyzed building.

Considering that the object was connected to the power grid infrastructure during the object construction period (the year 1963.), the document that provides the permission for the object connection was not available for this study at the time of creation.

4.1.2. Description and classification of the consumers in the object

In the analyzed object, 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.

One of the most important types of electrical consumers are computers, computer servers and other computer's additional devices, shown in Figure 4.4. Computers are usually placed in informatics laboratories (three) and professor's and assistance's offices. Approximately 100 computers are located in offices and 3 computer laboratories.

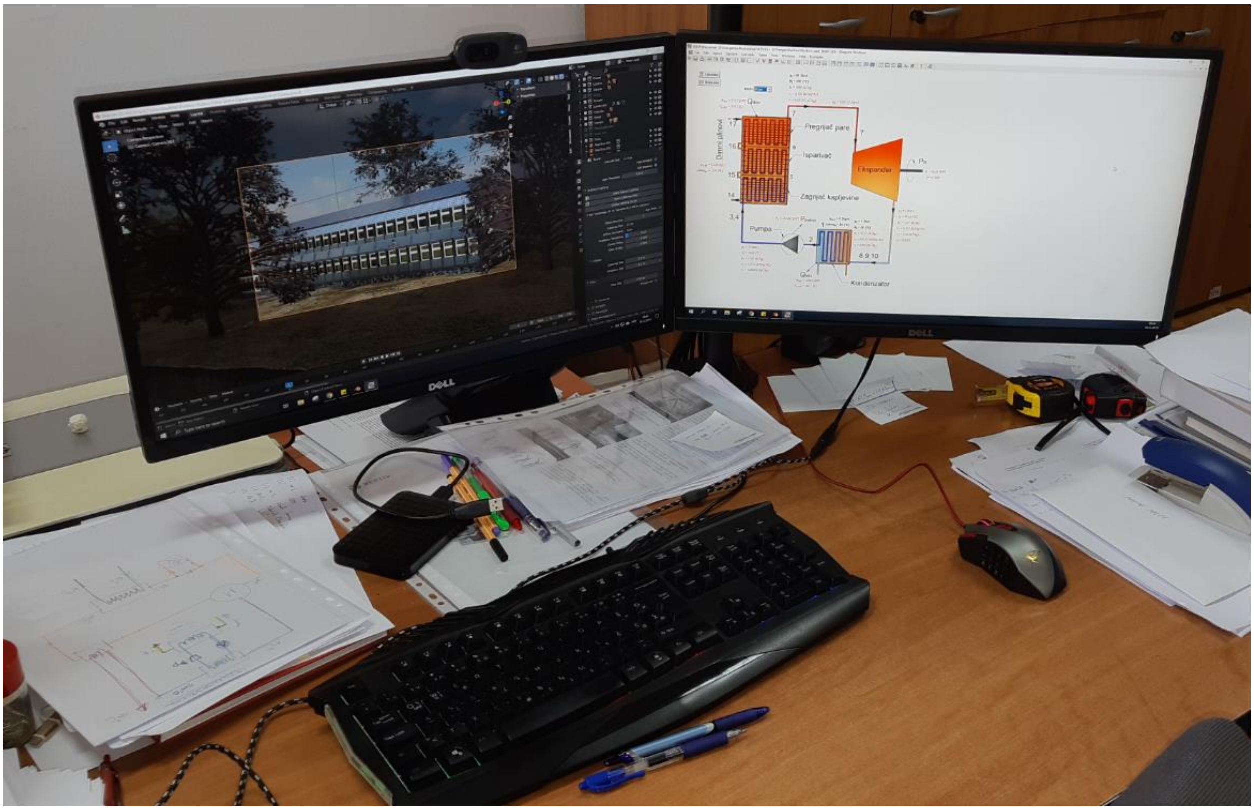


Figure 4.4 – Typical computer from the professor's office.

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 facility, there are 7 air-conditioning units, with the individual capacity of 18000 BTU, electric power 2.55 kW. Figure 4.5 shows one typical air-conditioning device in the exemplary object.

Figure 4.5 – The indoor and outdoor unit of the air-conditioning system.

Further, 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 given.

Figure 4.6 shows the CNC milling cutter device PC Mill 105 with the nominal power of 1.1 kW. This device is located in the Enterprise Resource Planning laboratory and is used for the student training courses.

Figure 4.6 CNC milling cutter device.

Figure 4.7 depicts the turning lathe device COMPACT 5 CNC (0.8 kW), also used for the student training courses and research activities.

Figure 4.7 – Turning lathe device.

A part of the equipment in the analyzed building is shown in Figure 4.8. The power of the educational robotic system SCORBOT depicted in Figure 4.8 is 2.2 kW. There are also several devices of neglected peak power as a part of Production preparation laboratory and computer aided design and Computer lab integrated production and maintenance.

Figure 4.8 – Educational robotic system.

One of the laboratories in the analyzed object is the Laboratory for Rapid Prototyping with experimental equipment and devices such as 3D printer device ZPrinter 310 with peak power of 0.576 kW - depicted in Figure 4.9. This setup is used in the practical courses for students.

Figure 4.9 – 3D printer.

4.1.3. Lighting system

The lighting system in the exemplary object is based on the incandescent and fluorescent light bulbs. During the visual inspection of the object, it is concluded that there are 11 different types of lights. A brief description of the lights used is given in Table 4.1.

Table 4.1 Description of different types of light.

Light type	Description	Appearance
Type 1	– Installation type: Ceiling light – Optics: Aluminum raster – Light sources: 2 fluo TL-D sources 36 W – Electromagnetic ballast – Total number: 120	 
Type 2	– Installation type: Ceiling light – Optics: Aluminum raster – Light sources: 4 fluo TL-D sources 36 W – Electromagnetic ballast – Total number: 7	

Light type	Description	Appearance
Type 3	– Installation type: Ceiling light – Optics: Aluminum raster – Light sources: 4 fluo TL-D sources 18 W – Electromagnetic ballast – Total number: 4	
Type 4	– Installation type: Ceiling light – Optics: – Diffuse plastic – Light sources: 4 fluo TL-D sources 18 W – Electromagnetic ballast – Total number: 1	
Type 5	– Installation type: Wall outdoor reflector – Optics: Safety glass – Light sources: 1 metal-halogen source 150 W – Total number: 3	

Light type	Description	Appearance
Type 6	– Installation type: Ceiling light – Optics: No – Light sources: 1 Fluo bulb 21 W – Total number: 1	
Type 7	– Installation type: Ceiling light – Optics: Glass Opal – Light sources: 1 Fluo bulb 21 W – Total number: 10	

Light type	Description	Appearance
Type 8	– Installation type: Ceiling light – Optics: Aluminum raster – Light sources: 4 fluo TL-D sources 36 W – Electromagnetic ballast – Total number: 9	 
Type 9	– Installation type: Ceiling light – Optics: Clear glass – Light sources: MH 150 W – Total number: 4	
Type 10	– Installation type: Ceiling light – Optics: – Plastic opal – Light sources: LED 26 W – Total number: 2	

Light type	Description	Appearance
Type 11	– Installation type: Outdoor light – Optics: Plastic down – Light sources: LED 21 W – Total number: 5	

4.1.4. Analysis of the energy consumption

In order to establish appropriate measures for the enhancement of energy efficiency, it is necessary to analyze the energy consumption in the exemplary object. 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.

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Datum računa: 30.11.2018
Mjesto izdavanja: ZAGREB
Datum dospijeća: 07.01.2019
R-1

STROJARSKI FAKULTET U SLAVONSKOM BRODU
2178/01-21
11. 12. 2018
03

Podaci o kupcu:
Šifra kupca: 10003033
Kupac: SVEUČILIŠTE JOSIPA JURJA STROS
Ulica i kbr.: TRG IVANE BRLIĆ MAŽURANIĆ 2
Mjesto: SLAVONSKI BROD
OIB: 65410788616

SVEUČILIŠTE JOSIPA JURJA STROSSMAYERA U OSIJEKU, STROJARSKI FAKULTET U SLAVONSKOM BRODU
TRG IVANE BRLIĆ MAŽURANIĆ 2
35000 SLAVONSKI BROD

Broj obračuna po mjernim mjestima: 2

Račun: 0010003033-181120-7 za opskrbu i korištenje mreže, razdoblje 11/2018

Opis	Jed.mjere	Količina	Jed.cijena	Iznos kn
PRO				
Radna energija po višoj dnevnoj tarifi	kWh	8481	0,4481	3.800,34
Radna energija po nižoj dnevnoj tarifi	kWh	2576	0,2466	635,24
Naknada za poticanje proizvodnje iz obnovljivih izvora	kWh	11057	0,1050	1.160,99
Trošarine za neposlovnu uporabu električne energije	kWh	11057	0,00750	82,93
UKUPAN IZNOS ZA KORIŠTENJE MREŽE I USLUGA				4.736,97
UKUPAN IZNOS ZA OPSKRBU				5.679,50
Porezna osnovica				10.416,47
PDV 13%				1.354,15
UKUPAN IZNOS RAČUNA				**11.770,62**

Novi Opći uvjeti opskrbe električnom energijom HEP-Opskrbe d.o.o. za kupce kategorije poduzetništvo stupaju na snagu 29.11.2018. Opći uvjeti objavljeni su 14.11.2018. na web stranici www.hep.hr/opskrba.

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

Temeljem Uredbe o naknadama za poticanje proizvodnje električne energije iz obnovljivih izvora energije i kogeneracije (Narodne novine, broj 128/2013), udio električne energije iz OIEiK, koju smo isporučili krajnjim kupcima, iznosi 14,46 %, pri čemu je ukupna cijena udjela 41.682.285,12 kn (jedinična cijena 0,42 kn/kWh).

Figure 4.10 – The electricity bill for two objects of the Mechanical Faculty in Slavonski Brod (Summarized Bill for electricity consumption).

Figure 4.10 describes parameters of electricity consumption from electricity meters on two measurement devices (two objects of the Mechanical Engineering Faculty in Slavonski Brod - Strojarski fakultet u Slavonskom Brodu).

STROJARSKI FAKULTET SLAVONSKI BROD, IVANA GUNDULIĆA 20/I
Broj obračunskog mjesta: 1008303401 **Model: HEP PRO** **Brojilo: 04150971** **Obr.: 1**

OBRAČUN OPSKRBE	tar.stavka		konstanta	potrošak	jed.cijena	iznos kn
01.11.2018 01.12.2018	RVT	Radna energija po višoj dnevnoj tarifi	1	3121	0,4481	1.398,52
	RNT	Radna energija po nižoj dnevnoj tarifi	1	1150	0,2466	283,59
	OIE	Naknada za poticanje proizvodnje iz obnovljivih izvora		4271	0,1050	448,46
01.11.2018 01.12.2018	TRNP	Trošarine za neposlovnu uporabu električne energije		4271	0,00750	32,03
UKUPAN IZNOS OPSKRBE						**2.162,60**

OBRAČUN ZA KORIŠTENJE MREŽE	brojilo	tar.stavka		stanje od	stanje do	konstanta	potrošak	jed.cijena	iznos kn
01.11.2018 01.12.2018	04150971	RVT	R1	0078565.8	0081686.5	1	3121	0,25	780,25
		RNT	R2	0036421.2	0037571.0	1	1150	0,12	138,00
		JEN	J1	0000190.8	0000190.8	1	0		
		JEN	J2	0023058.7	0024109.7	1	1051		
		SVT	S1	19.3		1	19,30		
angažirana snaga u doba više tarife							19,00	44,50	845,50
naknada za mjernu uslugu (broj mjeseci)							1,00	41,30	41,30
UKUPAN IZNOS ZA KORIŠTENJE MREŽE PRIJENOSA I DISTRIBUCIJE									**1.805,05**
UKUPAN IZNOS OPSKRBA I MREŽA									**3.967,65**

Figure 4.11 – The electricity bill for the exemplary object.

One electricity bill with the most important parameters is given in Figure 4.11. It can be seen that the bill is split into several segments. The first segment shows the total parameters taken from electricity meters of Mechanical Engineering Faculty in Slavonski Brod, I. Gundulić Street - Strojarski fakultet u Slavonskom Brodu, I. Gundulića) – electricity supply. It is clear that the metering is double-tariff for active power. 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 kuna (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 improvement of the Renewable Energy Sources (to cover feeding tariffs): 0.105 HRK/kWh and cost for non-business usage of electricity: 0.0075 HRK/kWh are presented.

The second segment of the bill is dedicated to the costs for the connection to the transmission or distribution power network, charged active power in both tariffs, charged reactive power, charged exceeding reactive power and monthly cost for measurement registration and calculation of the bill 41.30 HRK. It can be seen that the electricity contract price for the higher tariff is 0.25 HRK/kWh and for the lower tariff is 0.12 HRK/kWh.

It can be seen that the maximal approved power, the amount of 44.50 HRK per 1 kW has to be additionally paid.

Table 4.2 shows an overview of the power energy consumption from January 2018. to December 2018.

Table 4.2 – Electrical energy consumption in the "Strojarski fakultet u Slavonskom Brodu, I. Gundulić Street" during 2018.

	Consumption in higher tariff E1 [kWh]	Consumption in lower tariff E2 [kWh]	Total consumption [MWh]	Total energy cost [HRK]	Total cost with VAT taxis [HRK]
January 2018	3363	1324	4687	4359.61	4926.36
February 2018	3060	1254	4314	3900.60	4407.68
Mart 2018	3477	1450	4927	4380.09	4949.50
April 2018	2916	1385	4301	3802.07	4296.34
May 2018	2948	1246	4194	3805.38	4300.08
June 2018	2584	1214	3798	3448.51	3896.81
July 2018	2027	1117	3144	2813.76	3179.55
August 2018	1617	1002	2619	2290.19	2587.92
September 2018	2399	1172	3571	3232.79	3653.05
October 2018	2644	1162	3806	3516.77	3973.95
November 2018	3121	1150	4271	3989.00	4507.57
December 2018	2991	1419	4410	3924.20	4434.34
Total 2018	*33147*	*14895*	*48042*	*43462.96*	*49113.15*

Table 4.2 shows the trend of energy consumption increase, especially during the winter period. Slight consumption decline is visible during the January and February during the examination period when no teaching is arranged and Mart as beginning of the summer semester, while the lowest consumption is in August when there are no activities in the Faculty during the vacation period. In Figure 4.12 energy consumption per month, expressed in kWh is presented in the period from January 2018. to December 2018.

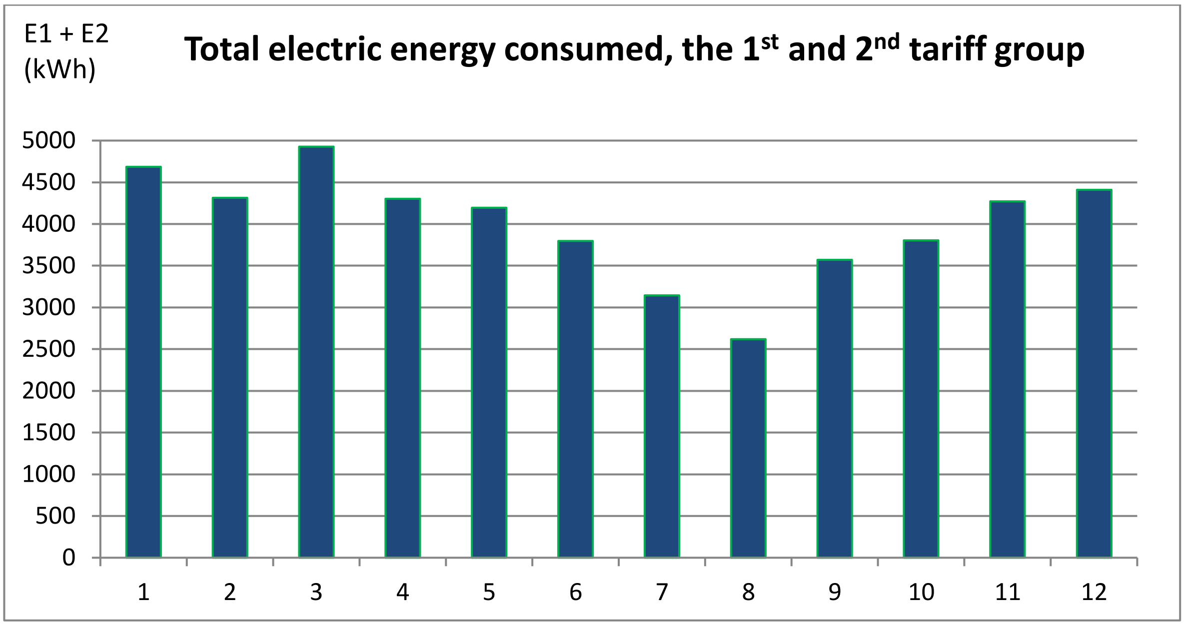

Figure 4.12 – Electrical energy consumption per month in the "Strojarski fakultet u Slavonskom Brodu, I. Gundulić Street" during 2018.

It can be seen that the highest energy consumption was in Mart. During August, the consumption was the lowest since most of the employees take their vacation in this period. During the winter, the highest consumption was in January caused by usage of electrical heating devices (cold walls of the building after winter holidays).

Analyzing the annual electricity bills, it can be seen that electrical energy consumption in higher tariff was 33147 kWh and in lower tariff 14895 kWh, with the total cost of 43462.96 HRK for the active power delivery. The highest consumption was 3477 kWh in the higher tariff and 1450 kWh in the lower tariff, with the total cost of 4380.09 HRK. On the other hand, the lowest consumption was 1617 kWh in the higher tariff and 1002 kWh in the lower tariff, with the total cost of 2290.19 HRK. Therefore, the consumption in the lower tariff is similar, while the consumption in the higher tariff is significantly different. These results are expected considering the habits of the people that use the exemplary object.

During the winter, electric energy consumption increase - the maximum is in January, with 3363 kWh in higher, 1324 kWh in lower tariff and total cost of 4359.61 HRK. Reactive power consumption is neglected for analyzed building. Peak power consumption of the object is in range 10-21 kW, so according the tariff structure cost of peak power is in range 445 – 934.50 HRK.

4.2. The thermal infrastructure of the exemplary object and consumption analysis

The main heating energy source of the Mechanical Engineering Faculty facility II is natural gas and delivered power is charged per kWh. The exemplary object is supplied with one heat station which is depicted in Figure 4.13.

Figure 4.13 – Heat stations in the facility II of Mechanical Engineering Faculty.

In the exemplary object, for the transmission of the heat power and space heating radiators are used. Usually, they are placed beneath the windows. Through the visual inspection of the Mechanical Engineering Faculty, it is concluded that one type of radiators were installed. It is a cast iron radiators.

The height and length of the cast iron radiators vary. This is because there is a different number of tubes that are connected in series. Depending on the room they are built-in, the number of tubes in the cast iron radiators is between 5 and 40.

In their simplest form, the heating fluid (warm water) is circulating through the tubes. The dimensions of the cast iron radiators in the exemplary object vary only in the length – 110 cm, 180 cm, 240 cm or 260 cm. The height of the cast iron radiators is 60 cm or 80 cm while the depth is 10 cm.

This cast iron radiator type is depicted in **Pogreška! Izvor reference nije pronađen.**2, while the panel radiator is shown in **Pogreška! Izvor reference nije pronađen.** (b).

Figure 4.14 – Cast iron of radiators in facility II of Mechanical Engineering Faculty.

In Table 4.3 the number of radiators located in different rooms is presented, together with the total number of radiators.

Table 4.3 The number of radiators according to the room purpose.

Rooms	**Number of radiators**
Cabinets	33
Classrooms	12
Computer classrooms	14
Laboratories	10
Server room	1
Library and Reading room	7
Hallways	7
Toilets	3
Total number	87

4.2.1. The analysis of the heat energy consumption

An analysis of gas consumption for consumers (buildings of Strojarski fakultet) was conducted by the Mechanical Engineering Faculty in Slavonski Brod, specifically for the faculty building at Ivan Gundulić Street 20A, Slavonski Brod for 2018. Figure 4.15 shows the annual states of gas counters for each month in the given period. The gas consumption is multiplied by a correction factor of 1.086893 until August 2018, after which the correction factor 1.125969, and ultimately the consumption is expressed in kWh. During 2018. gas consumption was over 150,000 kWh per year.

Brod-plin d.o.o.

Str. 1
Datum: 23.08.2019

ANALITIKA POTROŠNJE PLINA ZA POTROŠAČA
7450 STROJARSKI FAKULTET SLAVONSKI BROD
GODINA: 2018

Tarifna grupa / model:TG2 Poduzetništvo TM5

Datum očitanja	Brojilo	Staro stanje (m3)	Novo stanje (m3)	Utrošeno (m3)	Faktor korekcije	Utrošeno (m3)	Utrošeno (kWh)
Opskrbljivač:	**87814 MEĐIMURJE-PLIN d.o.o.**						
31.01.2018	288275	85165	87557	2392	1,086893	2600	25180
28.02.2018	288275	87557	90401	2844	1,086893	3091	30083
31.03.2018	288275	90401	92825	2424	1,086893	2635	25574
30.04.2018	288275	92825	93362	537	1,086893	584	5639
31.05.2018	288275	93362	93362	0	1,086893	0	0
30.06.2018	288275	93362	93362	0	1,086893	0	0
31.07.2018	288275	93362	93362	0	1,086893	0	0
31.08.2018	288275	93362	93362	0	1,086893	0	0
30.09.2018	288275	93362	93381	19	1,125969	21	204
31.10.2018	288275	93381	94313	932	1,125969	1049	10121
30.11.2018	288275	94313	96107	1794	1,125969	2020	19578
31.12.2018	288275	96107	99476	3369	1,125969	3793	36712
	Ukupno:			**14311**		**15793**	**153091**

Figure 4.15 – Analysis of gas consumption for faculty building at Ivan Gundulić Street 20A

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

Because of its favourable geographical location, Croatia has large solar energy potential. Annual global solar irradiation on horizontal surface is given in Figure 5.1. It is visible that continental areas have slightly lower annual solar irradiated energy. Nevertheless, continental part, in which Slavonski Brod is situated has great solar energy potential.

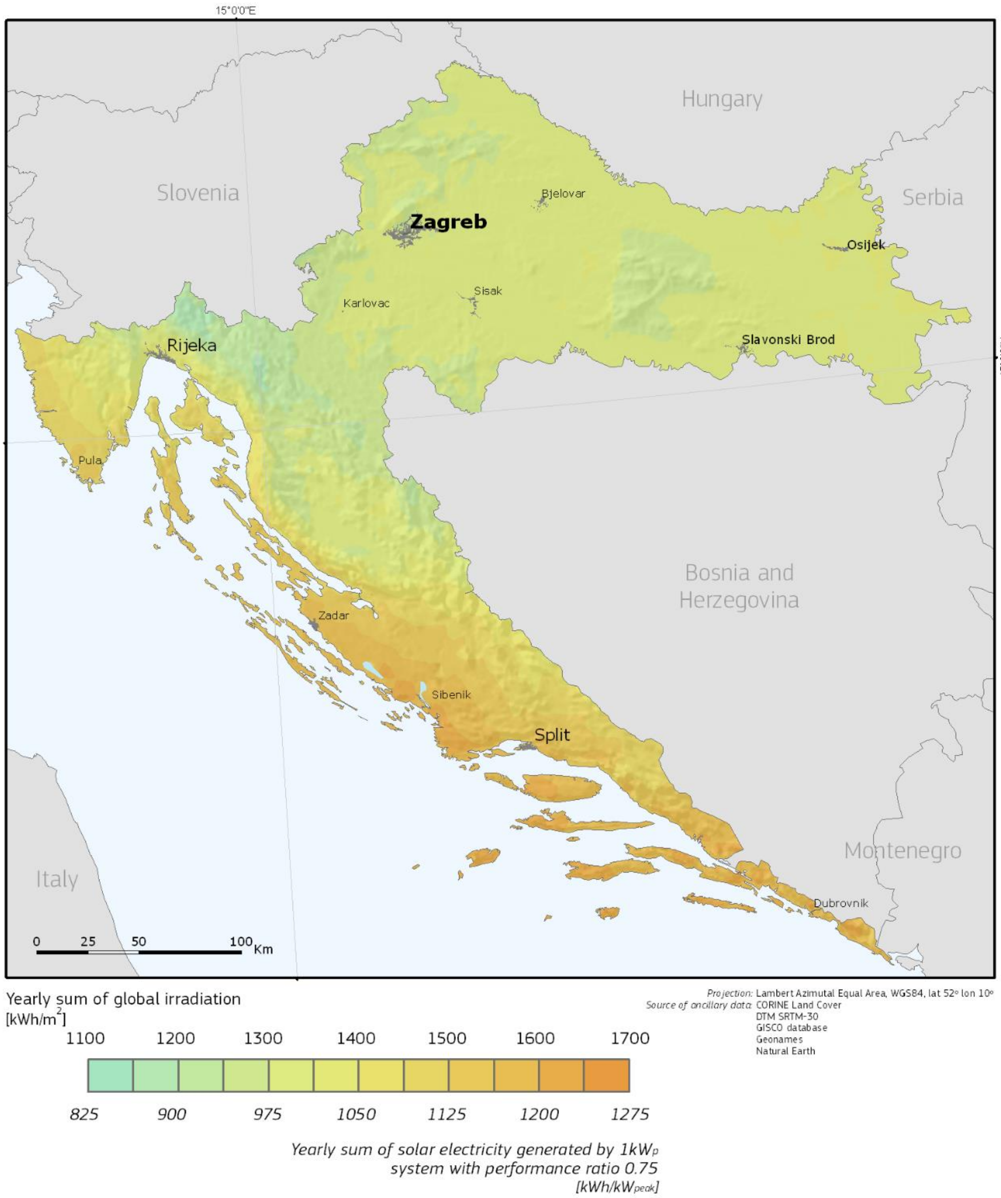

Figure 5.1 – Annual global solar irradiation on horizontal surface in Croatia [Joint Research Centre Institute for Energy and Transport. (2018). Photovoltaic Geographical Information System]

Average annual solar irradiation on horizontal plane in Osijek region is around 1350 kWh/m^2 while annual optimal inclination angle of photovoltaic modules and solar thermal collectors is 34° [Joint Research Centre Institute for Energy and Transport. (2018). Photovoltaic Geographical Information System]. Highest solar irradiation occurs in summer months (June – August) while the lowest occur in winter months (November - January). Distribution of global, direct and diffuse solar irradiation for average day in a month and annual solar irradiation for Osijek is given in Table 5.1.

Table 5.1 – Global, direct and diffuse monthly and annual solar irradiation for Osijek [Joint Research Centre Institute for Energy and Transport. (2018). Photovoltaic Geographical Information System]

Month	Global	Direct	Diffuse
	kWh/m²/day		
Jan	1.1	0.74	0.36
Feb	1.85	1.09	0.76
Mar	3.48	1.81	1.67
Apr	4.84	2.13	2.71
May	5.74	2.41	3.33
Jun	6.27	2.51	3.76
Jul	6.44	2.32	4.12
Aug	5.65	1.86	3.79
Sep	3.9	1.72	2.18
Oct	2.7	1.32	1.38
Nov	1.42	0.82	0.6
Dec	0.87	0.61	0.26
Year	1,350.02	589.08	760.94

Heat energy potentials of the renewable energy sources planned to mount on building of Strojarski fakultet are based on microclimatic conditions (air temperature, relative humidity, wind velocity, sun irradiation) in the area of Slavonski Brod. During the winter and summer time stable functionality of the heat pump provides up to maximum thermal power with high efficiency (COP). Low air temperatures (-7°C to -10°C) occur very rarely and the maximum outdoor air temperature in summer is up to + 33°C / + 35°C. The lowest and highest outside air temperatures have a rare frequency and their cumulative values are in a short period of time. During that period COP decrease, but rated power of heat pump remains constant.

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

Therefore, this section will propose renewable energy systems and building energy management system (BEMS) concept for their integration into one controllable system.

6.1. Solar-Thermal systems

In order to increase energy efficiency through the use of renewable energy sources, the construction of a thermo-technical system from hot-water solar collectors, an air-to-water heat pump and a condensation flow apparatus with natural gas propulsion is envisaged. Electricity supply will be provided through a photovoltaic system by absorbing solar radiation. The customized method of installation on the building and the construction of the installation will retain the external architectural form with optimal year-round utilization of external energy potential (outdoor air, solar insulation). The fan / convector will use heat / cooling energy to heating / cooling certain rooms in the building. The installed thermal power of the solar collectors is 25 kW and the heat pumps total ≥ 60 kW at appropriate external microclimate conditions and solar insulation at the location. The thermotechnical system will be properly dimensioned, thermally and hydraulically balanced with very little heat loss of energy transfer. The maximum hot water temperature will be up to 80° C and the cold water operating mode 7/12°C. Technical connectivity and appropriate drive and control elements and circuits, as well as custom software support, will enable thermo-technical functionality, optimal energy efficiency and monitoring of relevant thermo-technical parameters during use. Consumers' energy needs (thermal / cooling) will be continually adjusted and supplemented according to the available state of the renewable energy source (1. Solar collectors, 2. Heat pump, 3. Gas-fired condensing circulation apparatus), depending on the external microclimatic conditions and solar insolation.

6.2. Photovoltaic systems

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

Photovoltaic array consists of series-parallel connected photovoltaic modules which topology depends on the size of the array and inverter characteristics. Since output of the photovoltaic modules is DC electricity, in order to integrate photovoltaic 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.

Proposed roof photovoltaic systems for SFSB project partner have minimum nominal power of 60-64 kW. This power will be distributed on SFSB building located in Ivan Gundulić Street. This system will be described in this section. Final distribution of power and topology of the photovoltaic systems will be determined in the main electrical engineering project.

Mostly, PV modules will be mounted on the south side of the roof of the object. One section of the PV modules will be added to façade of the building and one section will be on tracker construction in the yard of the building.

Photovoltaic system is planned to be installed on South-oriented roof surfaces on different angles, depending on the roof section. Azimuth of the building is 0° (South is reference). Tilt angle of the roof section on which photovoltaic modules will be installed varies from 14° (roof) to 61° (façade). Conceptual design of the roof PV system proposed nominal output power of photovoltaic array of 60-64 kW while nominal output power of the inverters is approximately 80 kW. Total area of photovoltaic array is 407 m^2. 3D model of the proposed photovoltaic system is given in Figure 6.1.

Figure 6.1 – 3D model of photovoltaic and solar-thermal system on building in I. Gundulić Street

Photovoltaic roof arrays consist of approximately 200-220 photovoltaic modules with nominal power of 300 - 320 W which results in total output power of 60 - 64 kW at the DC side of the system. Façade PV system consists of 20 modules and sun tracking system has about 9 modules.

Proposed photovoltaic modules are monocrystalline silicon modules SUNCECO SEM 300W-HE which technical characteristics are given in Table 6.1.

Table 6.1 – Technical characteristics of photovoltaic modules [SUNCECO SEM 300W-HE]

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	η	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.

Conceptual design of the roof system proposed that photovoltaic array consists of 8 photovoltaic strings connected to 4 equally rated inverters. Each inverter has two photovoltaic strings connected at its inputs. Six photovoltaic strings consist of 22 series-connected photovoltaic modules installed on 4 equal roof surfaces at 14° angle. Last two photovoltaic strings consist of 2 parallel-connected branches of 22 and 23 series-connected photovoltaic modules. During the design of photovoltaic array, technical characteristics of the inverters are taken into account as well as lowest possible probability of shading occurrence during the year. Façade PV system consists of a string with 20 series connected PV modules and inverter 10 kW and PV Sun-Tracking system consists of 9 series connected PV modules and inverter 3 kW.

7. Conclusion

The production of electricity from the planned PV system is expected to cover almost all the electricity needs of the Mechanical Engineering Faculty in Slavonski Brod. Also, in terms of thermal energy consumption, the Faculty of Mechanical Engineering will significantly reduce gas consumption (approximately 25-50% of average gas needs). Asa conclusion, building of the Strojarski fakultet, Ivana Gundulića Street 20a will be closer to near zero energy building.

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