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Integrated local energy systems (Energy islands)

RENergetic

Community-empowered Sustainable Multi-Vector Energy Islands

Project Nº 957845

D5.1 – Interim evaluation of actions impact on Pilot site 2: Poznan - Warta Campus

Responsible:	Poznan University of Technology, Górzeński Radosław
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Executive Summary

This document contains a description of the Poznań pilot - the Warta Campus - along with a summary of work done during the first 18 months and plans for further development.

The work done can be split into two main areas of activities. The first concentrated on a preparation of the pilot infrastructure and data to the use within the project. These activities included development of the data acquisition platform to integrate and pre-process data from various sources such as Building Management System (BMS) and the data centre. Preliminary analysis of collected data was already presented. Extension of existing infrastructure by appropriate measurement devices was planned and corresponding purchases initiated. Contacts with potential stakeholders of the energy island were established including collection of feedback through interviews. The second area of activities contained detailed planning of scenarios to be applied within the Poznań pilot. These plans were defined in the form of epics and user stories in a collaboration with WP3. All means to increase the use of renewable energy and energy efficiency are crucial for the Poznań pilot, but the most relevant areas are those related to waste heat re-use and heat management.

The document also contains a comprehensive overview of the pilot infrastructure with development plans relevant for the project so that the reader can understand the context and the whole energy island structure. This information is accompanied by preliminary experiments that can be used as hints for the development and baselines for final evaluation.

As such, this document is a base for the final pilot evaluation document, in which the defined epics will be assessed against project objectives and KPIs. The plans towards this final evaluation include deployment of additional measurement devices, integration of RENergetic platform components such as forecasting models and user interfaces and performing series of simulations and real experiments on the energy island data and infrastructure.

The objective of RENergetic is to demonstrate the viability of so-called “urban energy islands”. Energy islands seek to achieve the highest possible degree of self-sustainability with regards to the supply of its energy demand, be it electricity or heat through local renewable resources. At the same time an urban energy island may offer ancillary services to the public grid surrounding it.

These islands place the consumer at the centre of the energy transition, giving them an active part in energy communities capable of producing their own energy, sharing the surplus with the rest of the public grid and optimizing consumption. RENergetic will demonstrate that Urban Energy Islands increase both the amount of renewables in these areas and the energy efficiency of local energy systems. RENergetic will demonstrate the viability of this energy islands in three site pilots, each of them of a different nature: New Docks, a residential area in Ghent – Belgium, Warta University Campus in Poznan, Poland and San Raffaele Hospital and its investigation and research campus in Segrate-Milan, Italy. The impact of the Urban Energy Islands is assured as technical, socio-economic and legal / regulatory aspects are considered while safeguarding economic viability.

RENergetic will be carried out over the stretch of 42 months involving 14 European partners: Inetum (Spain, France, and Belgium), Clean Energy Innovative Projects and Gent University (Belgium), Poznan University of Technology, Veolia and Poznan Supercomputing and Networking Center (Poland), Ospedale San Raffaele, Comune di Segrate and University of Pavia (Italy), Energy Kompass GMBH (Austria), the University of Mannheim and the University of Passau (Germany), University of Stuttgart (Germany) and Seeburg Castle University (Austria).

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AHU	Air Handling Unit
BMS	Building Management System
CH	Chemistry Building [PUT]
CM	Mechatronics Centre [PUT]
COP	Coefficient of Performance
DC	Data Center
DHO	District Heating Operator
DHS	District Heating System
DHW	Domestic Hot Water
DS4	Dormitory no 4 [PUT]
EPBD	The Energy Performance of Buildings Directive
GH	Gym Hall [PUT]
GSHP	Ground Source Heat Pumps
HDR	Heat Demand Response
HP	Heat Pump
HVAC	Heating, Ventilation and Air Conditioning
ICT	Information and Communication Technologies
LB	Lecture & Library Building [PUT]
nZEB	Nearly Zero Energy Building [EU definition]
PV	Photovoltaics
PUT	Poznan University of Technology
PSNC	Poznan Supercomputing and Networking Center
TABS	Thermally Activated Building System
WA	Architecture Building [PUT]
WP	Wind Power (wind turbines)

I. INTRODUCTION

I.1 Purpose and organization of the document

This document is the first deliverable of Work Package 5 (WP5) and describes the Poznan - Warta Campus Pilot site. The purpose of the document is to present the institutions collaborating within the Pilot, their technical infrastructure and detailed description of the performed and planned actions. These actions refer on one hand to the main epics defined in the project and on the other hand to the pilot-specific work needed to collect required data and enable impact on the pilot. This pilot-specific work includes development and deployment of data acquisition systems as well as experiments performed in the interim period.

The document is structured as follows:

The first chapter introduces the goals of the deliverable and present the scope and relations to other activities of the project. The second chapter contains description of the Poznan - Warta Campus Pilot site 2. It describes the local settings and infrastructure, availability of Renewable Energy Sources (RES) and local stakeholders and roles for all partners involved in pilot site. The third chapter is dedicated to the detailed description of the actions. It includes the list of strategies selected for the site, the main tools to be used in actions and the epics involved. The fourth chapter contains the architecture of the data acquisition systems for PSNC and PUT and describe how the data are stored and imported from databases. In fifth chapter presents the examples of experiments performed with data from PUT and PSNC facilities.

I.2 Scope and audience

Deliverable 5.1 relates to Interim evaluation of actions impact on Pilot site 2: Poznan - Warta Campus. Since this deliverable is the first one released for Work Package 5, three institutions that constitute the Poznan Pilot are introduced within scope of the document. As mentioned before, in organization of deliverable section, the scope includes both the presentation of partners within Pilot, their technical infrastructure and detailed description of the actions. Interim analysis of the data and further actions to be taken were also indicated in the document. In addition, description of the data acquisition system and initial data analysis are presented. The pilot-related experiments are also collected at the end of the document. It is worth noting that due to its unique presence of the data center in proximity to the University campus, in relation to other pilots, Poznań pilot will focus on solutions in the field of waste heat supply and optimization as well as heat demand response. Therefore, significant part of the audience can be referred to these areas of heat reused process. Generally, the audience include partners of the project involved in the design and development of the RENergetic platform and all other readers interested in energy islands and topics such as local waste heat re-use, use of renewable energy and energy management in buildings.

I.3 Relations to other activities

The Poznań Warta campus representing Work Package 5 is one of the three pilots in the RENergetic project. It is worth noting that the pilots in the project are very different from each other, both in terms of infrastructure, the work profile, stakeholders, activities or the main actions and epics carried out within the project. The essential relations between individual pilots focuses particularly on the level of cross functional epics such as interactive platform as well as forecasting. The project's ICT tools for these epics should be applicable and useful to each of these different pilots. There ICT tools are developed under WP3 - ICT for energy island communities with substantial contribution of one of the pilot partners – PSNC. Moreover, the Poznań pilot, like other pilots, puts a lot of effort to the heat optimization. On the other hand, in Warta Campus, scenarios for electric vehicle charging stations are not considered because this infrastructure is not developed yet. In addition, WP2 proposes issues related to social science for energy island communities. For example, interviews with the stakeholder mentioned in point II.1.3 were conducted in cooperation with WP2. Their conclusions are presented in the deliverable WP2. Furthermore, WP7 will use results of WP5 to perform evaluation, derive exploitation plans and maximise potential impact with contribution of Veolia which is an international company with premises across Europe. In addition, WP8 is responsible for replicability within the RENergetic project.

II. PILOT DESCRIPTIONS

Poznan University of Technology (**PUT**) together with Poznan Supercomputing and Networking Centre (**PSNC**) create a strong academic campus and separated district in Poznan city populated by 535 000 citizens, western Poland. Campus is supplied with heat by **Veolia** driven district heating network. Both PUT and PSNC also own properties on Kakolewo airport located 70 km west from Poznan.

II.1 Poznan University of Technology

Poznan University of Technology is one of the largest Polish technical universities. It offers education at 9 faculties, running a total of 31 fields of study. About 16 000 first and second cycle students, doctoral and postgraduate students study here. Over 1 300 academic teachers care about their education. Poznan University of Technology was honoured with the ELSEVIER Research Impact Leaders 2016 award in the Medical Sciences category, awarded by Elsevier to universities whose publications had the greatest impact on the perception of Polish science in the world. The award was granted for research and publications in the field of biomedical engineering. In the international Scimago Institutions Ranking 2018, Poznan University of Technology was ranked 4th among universities in Poland and is ranked 2nd-3rd place among Polish technical universities. In the latest Academic Ranking of World Universities (called the Shanghai Ranking) Poznan University of Technology was classified among the 500 best universities in the world in two disciplines, Computer Science & Engineering and Mechanical Engineering. According to the latest list of Centre for World University Rankings for the years 2019-2020, Poznan University of Technology was ranked 1446 among twenty thousand universities around the world. As a result, the University was among 7.3% of the best universities.

Poznan University of Technology is the leader of the EUNICE project (European University for Customised Education) that aims to bring about a paradigm shift from traditional to customised education through inter-university “blended” mobility. Eunice is the transnational alliance to promote European values and identity and revolutionising the quality and competitiveness of European higher education. It includes partners from all types of higher education institution and cover a broad geographic scope across Europe, are based upon a co-envisioned long-term strategy focused on sustainability, excellence and European values, offer student-centred curricula jointly delivered across inter-university campuses, where diverse student bodies can build their own programmes and experience mobility at all levels of study, adopt a challenge-based approach according to which students, academics and external partners can cooperate in inter-disciplinary teams to tackle the biggest issues facing Europe today.

As a leading Polish technical university PUT has ambitions in creating new solutions in the field of construction, energy saving, renewable energy sources, and the use of waste heat. The campus of the Poznan University of Technology not only serves students to study and scientists to conduct research, it is also a place for testing new technologies. The buildings constructed are an experimental base for new technologies, heat pumps, building automation systems, photovoltaic panels etc.

Figure 1 - PUT Warta campus

II.1.1 Local Settings and Infrastructure

Poznan University of Technology campus is in eastern part of Poznan city close to the historical downtown and is situated on the right bank of the Warta river - hence the origin of the Warta Campus name. Next to PUT campus building, the PSNC office and data centre is located.

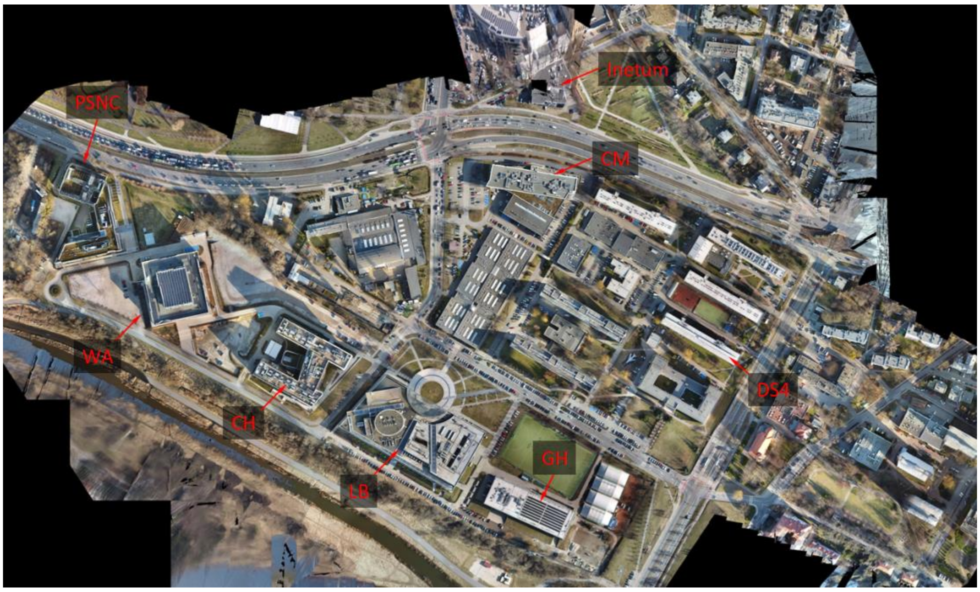


Figure 2 - Ortophotomap of the Warta Campus, with main buildings highlighted

PUT owns 50 properties within the Poznan city, 22 of which are located on the Warta campus. The area of the campus is 22 hectares. Usable area of buildings is 175 000 m². The buildings come from different periods of the 20th century, ranging in campus from old buildings from the 1950s to nZEB buildings from the end of 2020. The satellite Rector office located in Poznan downtown comes from 1904.

There is a widespread between buildings in terms of heat demand for heating.

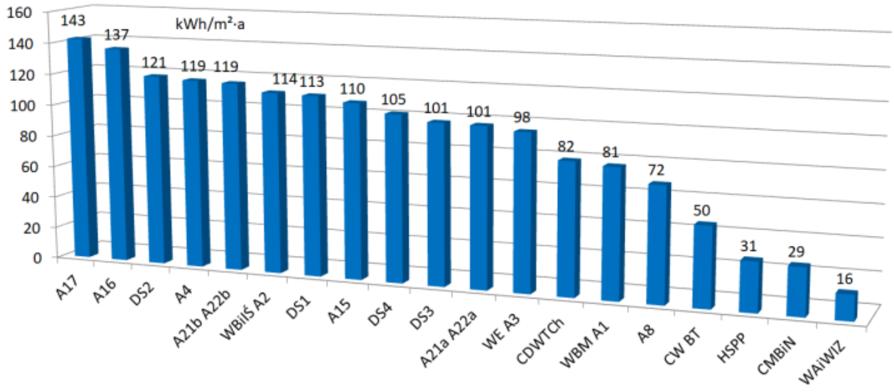


Figure 3 - Heating demand for campus buildings

The buildings of the Poznan University of Technology are powered by the following energy sources:

- district heating network (heating)
- gas fired boilers (heating)
- ground source heat pumps (heating and cooling)
- electrical grid with local PV network (lighting, heating and cooling)

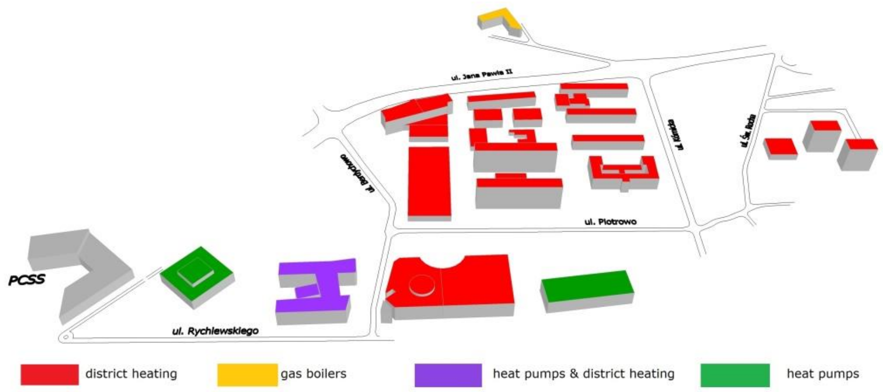


Figure 4 - Warta campus building heat with satellites buildings

Annual energy consumption for space heating and domestic hot water preparation for campus buildings from district heating network (DH) and heat pumps (HP) is shown below.

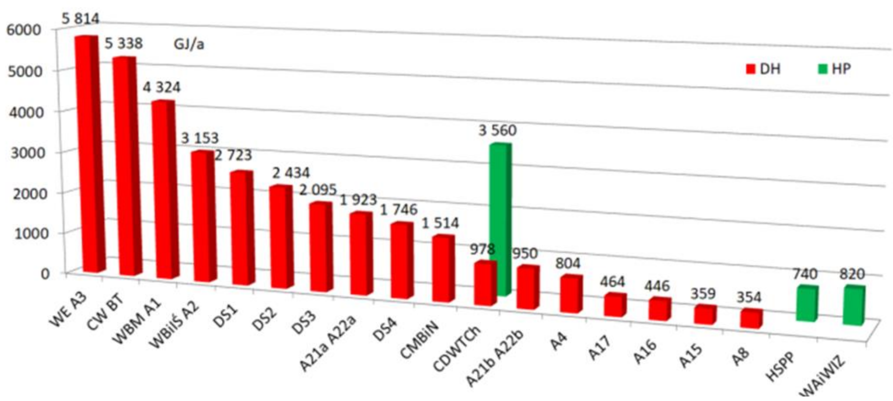


Figure 5 - Annual energy consumption for space heating and domestic hot water preparation for campus buildings from district heating network (DH) and heat pumps (HP).

Total design heat demand for campus is covered by:

- 7.52 MW district heating network (DHS)
- 0.92 MW GSHP

Table 1 - Heating power, consumption and supply temperatures for Campus buildings

Building names		Power		Consumption		Area	Supply temp.
		DHS	HP	DHS	HP		
original	shortcut	kW		GJ/a		m²	°C
DS1	DS1	439.9		2 723		6 673	60
DS2	DS2	307.7		2 434		5 605	55
DS3	DS3	241.9		2 095		5 765	60
DS4	DS4	256.0		1 746		4 630	60
WBM A1	BM	762.6		4 324		14 901	78
WBiIŚ A2	BL	693.2		3 153		7 688	80
WE A3	WE	1 173.2		5 814		16 456	75
A21a A22a	H A21a A22a	403.7		1 923		5 315	
A21b A22b	H A21b A22b	139.2		950		2 226	
A4	A4	142.0		804		1 874	
A8	A8	46.4		354		1 373	
A15	A15	53.6		359		904	
A16	A16	53.5		446		904	
A17	A17	69.7		464		904	
CW BT	LB	1 027.5		5 338		29 883	90
CMBiN	CM	370.9		1 514		14 270	60
CDWTCh	CH	500.0	358.0	978	3 560	15 300	60
HSPP	GH		294.0		740	6 700	45
WAiWIZ	WA		267.5		820	14 449	32
North		**6 681.0**	**919.5**	**35 418**	**5 120**	**155 820**	
DS5	DS5	341.2		3 019		7 348	54
DS6	DS6	349.2		2 381		7 348	54
Sto A20	KA	148.7		956		1 796	80
South		**839.1**	**0.0**	**6 356**	**0**	**16 492**	
Sum		**7 520.1**	**919.5**	**41 774**	**5 120**	**172 312**	

The average annual consumption of heat is covered in 42 000 GJ/a by district heating substations (23 DHS substations) and 5 100 GJ/a by heat pumps (GSHP).

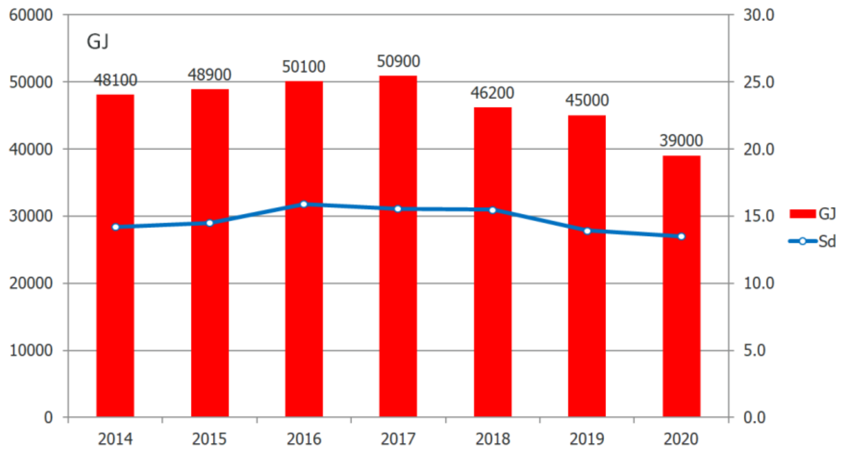


Figure 6 - Campus DHS annual heat consumption 2014-2020.

Campus is equipped with complex HVAC, BMS and RES systems:

- Siemens and Schneider BMS Systems with more than 130 heating and cooling meters and more than 30 000 measuring sensors and actuators integrated in the BMS systems
- Air Handling Units AHU (more than 100 units)
- Chillers and dry coolers (4x 600 kW)
- District Heating System DHS (23 substations, 7.5 MW)
- Ground Source Heat Pumps GSHP (3 buildings, 920 kW heating power, 125 boreholes with single and double vertical U-pipes170-200 m deep)
- PV plants (2 buildings, 350 kWp)

II.1.2 Availability of Renewable Energy Sources

Most campus buildings are supplied from the district heating network DHS with heat produced from burning mainly fossil fuels (coal). Currently primary energy factor for heat from Veolia is 0.90. DHS heat directly from coal has the factor of 0.8-1.3, heat from biogas or biomass 0.15. Electricity from the grid is 3.00, from PV or WP 0.00.

RES possibilities on Campus are limited, though present. At the moment, the following RES sources are used on the campus:

- PV photovoltaics rooftop installation: 150 kWp (GH) + 200 kWp (WA)
- STE solar thermal energy - water solar panels: 100 kWth
- Shallow geothermal energy used in the form of 200m deep vertical boreholes heat exchanger ground source for heat pumps (GSHP), currently heat pump of ~920 kW heating power installed
- 450 kW power heat exchanging water loop connecting CH and WA building for transferring excess heat

The conducted analyzes showed that in the current economic conditions and with the state of technological maturity, there are no plans to use or develop the following RES:

- solar thermal (STE)
- wind turbines (WP)
- outdoor air (as HP heat source)
- surface and underground water (as HP heat source)

The main stakeholders expect an immediate increase in the share of RES in the campus energy balance in terms of:

- photovoltaics at Warta Campus
- photovoltaics at Kakolewo Airfield
- ground source heat pumps

The development of energy transfer between buildings (existing PUT water loop) and waste heat between institutions and institutions (from PSNC data center to PUT heating system and Veolia DHS) is also the subject of ongoing work.

The above-mentioned activities in the scope of expanding the RES infrastructure into Warta Campus and Kakolewo Airfield will be discussed in detail in the infrastructure chapter.

II.1.3 Local Stakeholders and Roles

Users in PUT with a short description:

1) Technical energy manager - people responsible mainly for facility management and energy savings reliability and quality of service.
2) Business manager - people responsible for economic feasibility – Chancellor of PUT. The further development of the campus infrastructure depends on his decisions.
3) Resident - mainly students, residents of student dormitories. They affect the temperature settings in the rooms, window opening and the consumption of domestic hot water.
4) End User (Not Resident) - teachers, students, administration
5) Passers-by - guests visiting the campus (energy island) who are not permanently associated with it.
6) Sustainability Evangelist - person responsible for PR concerning sustainability of the energy island. For this purpose, we want to involve students from the research clubs existing at our university.

Interviews for three groups of stakeholders were conducted as a link to WP2:

- End Users (students) - 2 persons
- Residents (students) - 2 persons
- End Users (teachers) - 3 persons

II.2 Poznań Supercomputing and Networking Centre

Poznan Supercomputing and Networking Centre (PSNC) affiliated to the Institute of Bioorganic Chemistry of the Polish Academy of Sciences is one of the most recognizable and leading information and communication technologies (ICT) research centers in Poland. It offers advanced High-Performance Computing (HPC) and networking infrastructure to science and industry. It operates a date centre and more than dozen of laboratories PSNC has been operating since 1993 and from the very beginning conducts each activity in accordance with a mission: “Integration and development of information infrastructure for science”. With this mission at the core of PSNC, Institute has rich experience in mutli-domain areas inspired by ICT, leading to complete implementations of digital science and industry. The main activities of the PSNC relate to industry 4.0, science, ICT, data protection and cybersecurity, energy efficiency, smart cities and civil society, medicine, health and quality of life, digital art, new media, climate and neutral environment and others. In the RENergetic project the Energy Efficient ICT Department participates, which conduct research in the field of energy efficiency, renewable energy sources and ICT solutions for energetics.

Figure 7 - The main PSNC building

In the RENergetic project PSNC contributes mostly in the WP5 and WP3 tasks. In WP5 - Warta Campus with PUT and Veolia perform simulations of the use of waste heat from the data center in order to increase the environmental issues and autarky of the energy island. PSNC with its high computing capabilities is also responsible for tasks related to prediction, anomaly detection and ICT tools related to WP5.

II.2.1 Local Settings and Infrastructure

Poznan Supercomputing and Networking Centre administrates one of the main national high performance computing centres in Poland. It is worth noting that one of the supercomputers located in the DC, Altair, has been placed on the TOP500 list. This list, created at the largest HPC conferences: ISC (International Supercomputing Conference) in Europe and Supercomputing in the USA, shows the 500 most powerful commercially available computer systems in the world. In addition, Altair is also on the GREEN500 list which shows the 500 most energy efficient HPC systems taking into account electricity consumption.

Figure 8 - The HPC cluster in the PSNC’s data centre

The data center itself contains two main HPC clusters: Eagle and Altair accompanied by many other computing, storage and networking systems Currently, the main HPC cluster provides 7.2 Pflops/s of computing power with more than 420 TB of memory. A variety of applications are run on almost 100 000 CPU cores. Supercomputers are cooled using Direct Liquid Cooling (DLC), which allows to take the heat directly from hottest components such as CPU, GPU, memory without using air as a heat transmission medium. In consequence, the liquid used for cooling can have relatively high temperature (even up to 35-45°C), which greatly improves efficiency of the system and make it more useful for heat re-use systems.

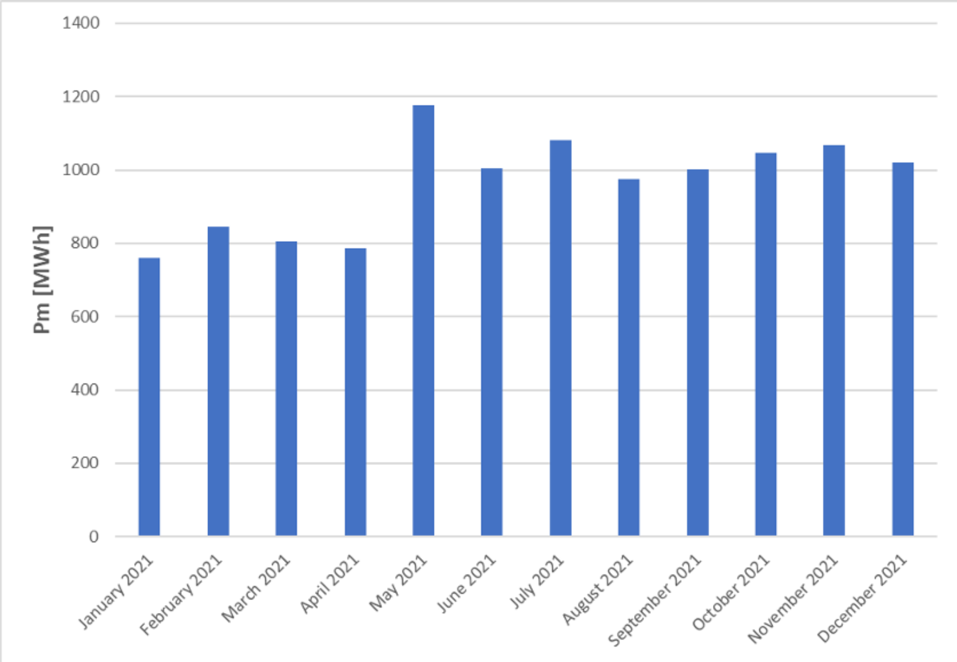


Figure 9 - Annual distribution of monthly medium power consumption

The system power consumption exceeds 1MW as can be seen in Figure 9. However, the delivery of next systems is in progress so it is expected that the power consumption may even double within a year period. Currently, the maximum possible electric power consumption of PSNC is at the level of 2.5 MW. Significant amount of electric energy consumed by a data center is re-used as a waste heat from the supercomputer cooling system. The PSNC office building is not connected to the district heating system (DHS) because of self-sufficiency from a domestic hot water and central heating point of view.

The PSNC main building, where over 400 employees work, is located in the immediate vicinity of the data centre. The building consists of conference rooms, research infrastructure, laboratories and offices.

Resources from the data center are used in the RENergetic for data analysis, simulations, machine learning and prediction tasks.

Both building and data center measurement data are collected in the two Building Management Systems (BMSs).

II.2.2 Availability of Renewable Energy Sources

Poznan Supercomputing and Networking Centre works to increase the share of renewable energy sources (RES). The main driving forces of investments in RES are increase in electric energy prices, increase in electricity consumption because of the development of the data center with new supercomputers and reduction of environmental interference as well.

Since the facility is in the city center the possibility of using renewable energy sources is very limited. There is a 20 kWp photovoltaic (PV) installation on the roof of the building. The rated power of this installation covers small fraction of the average power demand of the facility. Due to these facts, the entire generation is consumed immediately. The PV installation on the roof will be expanded to a power of 50 kWp at the turn of 2022/2023, which will still almost imperceptibly meet the needs of data center.

Figure 10 - The photovoltaic installation on the roof of the PSNC's building

At the same time, a PV installation with a capacity of1 MWp is being designed in Kąkolewo airfield. The start of work is planned at the turn of 2023/2024. However, it is worth noting that the energy supply to the electro energetic grid at the 1 MWp installation site will be very limited due to the lack of an economically viable grid connection point. For this reason, PSNC plans to maximize the energy consumption on-site close to the installation and for the energy demand of offices and data centers working in Poznań, it is planned to build another installation in a different location with higher rated power.

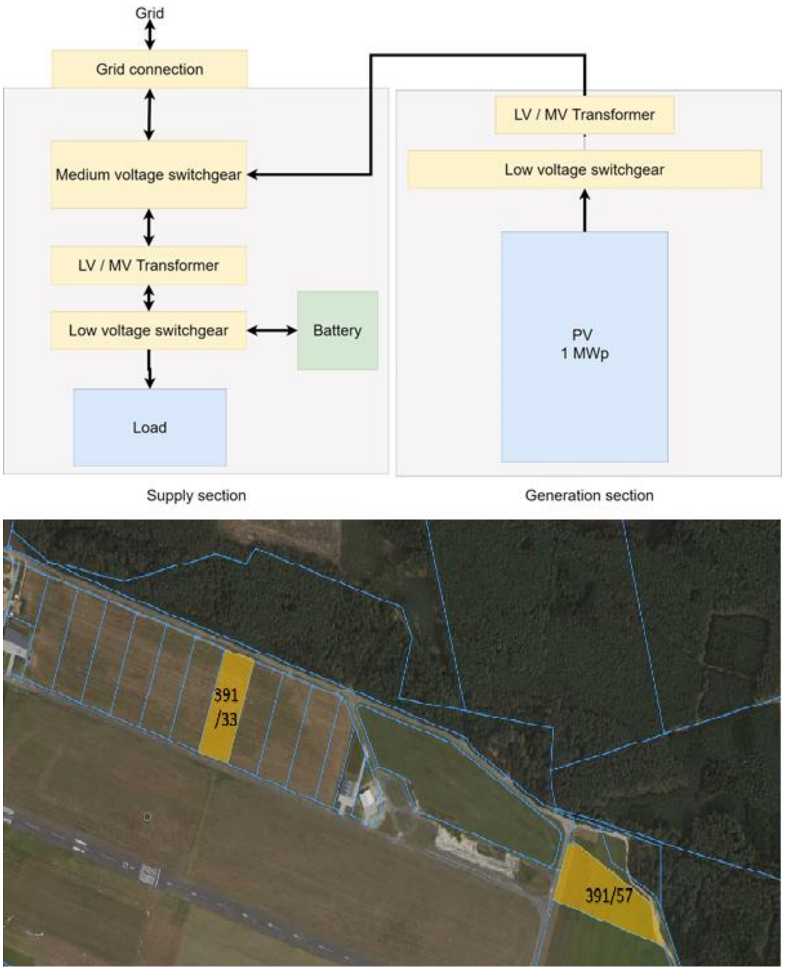


Figure 11 - Planned location of the 1 MWp PV installation in Kąkolewo Airfield

As can be seen in Figure 2 PSNC within two plots of land in Kąkolewo Airfield will locate 1 MWp PV installations (391/57) and on-site energy loads (391/33) with energy storage systems.

In terms of PSNC heat demand, office building is not connected to the district heating system (DHS) because of self-sufficiency from a domestic hot water and central heating point of view from waste heat from the data center. On the other hand, the amount of possible to generate waste heat could largely cover the consumption of the Poznań University of Technology campus with the surplus transferred to Veolia's DHS. Moreover, due to the fact that heat from the data center is treated as a renewable, emission-free source, the DHO is also interested in directly purchasing to DHS (see Section II.3.2 and III.1 for more details). The simulation and modeling of the entire heat reuse process along with the change of its parameters will be carried out within the project in virtual representation as the digital - twin.

II.2.3 Local Stakeholders and Roles

The most important users in PSNC with a short description are listed below:

1) Technical energy manager - responsible for technical infrastructure - its operation, maintenance and security. Technical energy manager is mainly interested in supervising parameters and receiving predictions concerning mainly areas related to the data center. Technical aspects related to ensuring the continuity of work and the security of supercomputer infrastructure have the main influence on decisions. Together with the business energy manager is the most decision-making person with the greatest impact.
2) Business manager - responsible for the business area and investments related to PSNC. Interested in tracking and predicting the impact of specific actions (such as extensions of the infrastructure) on business areas. The business manager has also an interest in using the latest technologies and reducing environmental impact.
3) Staff - mainly consists of researchers, software developers and administrative workers. They have limited impact on energy consumption of the whole infrastructure compared to the data centre. The main energy consumption by staff results from their work, mostly by computers used for work and research, laboratory equipment and HVAC system. Staff often work in an office / home office rotation mode.

II.3 Veolia

In the city of Poznań, the main operating energy company in the field of heat generation and distribution is Veolia Energia Poznań S.A. operating within the Veolia group.

Veolia Energia Poznań S.A. is currently the owner and the operator of the EC II Karolin system source and the owner and the operator of the municipal heating system in Poznań. Veolia holds a license to generate, transmit heat and trade in heat and electricity.

II.3.1 Local Settings and Infrastructure

Characteristics of the heat source

The main source for the municipal heating system in Poznań, supplying heat to facilities in a large part of the city of Poznań and leading beyond its borders towards the areas of Swarzędz, Koziegłowy and Zalasewo, is the EC-II Karolin heat and power plant with the heat capacity available to supply the heating system of 835 MW. The supporting sources are 3 gas-fired boiler houses, acting as peak sources with the total available capacity to supplement the power supply of 23.6 MW.

The Karolin Heat and Power Plant is a combined heat and power plant with three heat units, and the third unit can operate in condensation. The following are the characteristics of the installed units:

District heating unit no. 1 BC 50, equipped with a 102 MW steam boiler fired with coal dust or coal dust with the addition of biomass and a fluidized bed biomass boiler with a thermal capacity of 80 MW, supplied with steam through a common collector, a turbine set consisting of a steam extraction-back pressure turbine with a generator with an installed capacity of 63 MWe.

District heating unit no.2 BC 100 with a steam boiler with a capacity of 314 MW fired with coal dust or coal dust with the addition of biomass, supplying steam to a turbine set with a steam extraction-back pressure turbine and a generator with an installed capacity of 124.95 MWe.

A condensing and heating unit no. 3 type BKC 100 with a steam boiler with a capacity of 314 MW, fired with coal dust or coal dust with the addition of biomass, supplying steam to a turbine set with an extraction-condensing steam turbine and a generator with an installed capacity of 124.95 MWe.

In addition, the following devices for peak operation have been installed in Karolin:

- peak load water boiler, fired with heavy fuel oil, with a thermal power of 150 MWt;
- peak load water boiler, fired with heavy fuel oil, with a thermal power of 120 MWt;
- peak load steam boiler - fired with light fuel oil, with a thermal capacity of 12 MWt.

Maximum power that can be derived from EC Karolin, taking into account the reduction of the degree of combination, with the use of steam supply to the exchanger before the turbine - 495 MW steam boilers + 300 MW water boilers + 40 MW ⟹ 835 MW steam-water exchangers,

The source can produce:

- heating water - up to 130°C,
- process steam 1.0 MPa, 235°C,
- process steam 2.0 MPa, 250°C.

Characteristics of the heat distribution system

The municipal heating system in Poznań consists of water heating networks built in a ring and radial system. The heat for the system is mainly generated in the Karolin CHP Plant. An additional source for the heating system has been ITPOK since 2016, located in the immediate vicinity of EC Karolin.

The networks of the system extend beyond the city limits, supplying heat to recipients from towns located in the north-eastern outskirts of the city - Swarzędz, Koziegłowy and Zalasewo.

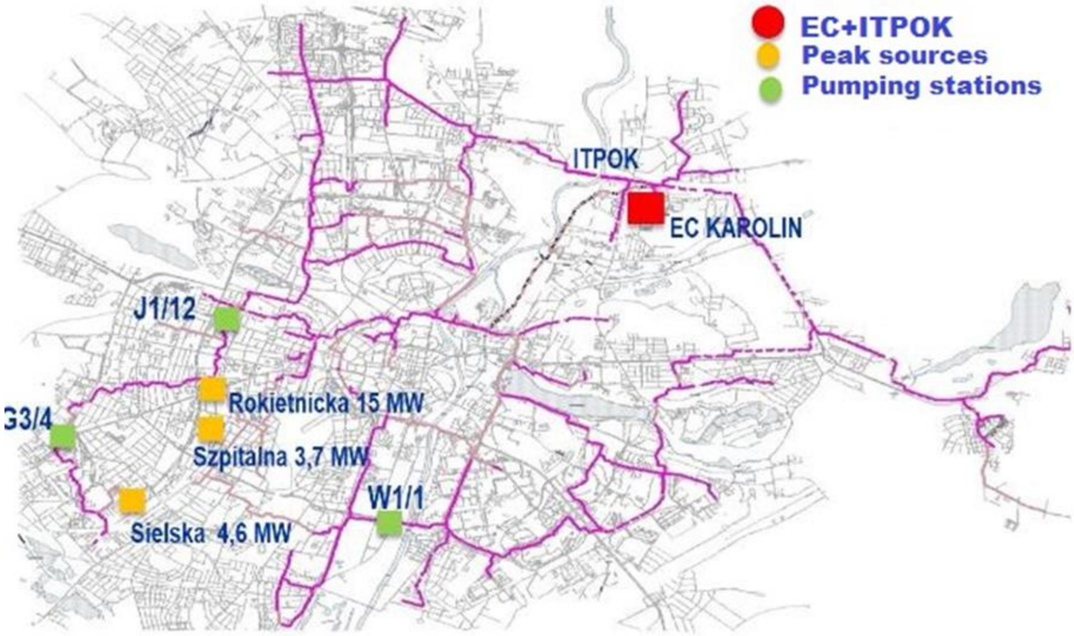


Figure 12 - Veolia's district heating network

The system works for the needs of heating (central heating + ventilation), production of domestic hot water and technology, providing heating water with calculation parameters in the heating season 125°C / 60°C and in the summer season 70°C / 46°C.

The largest group of heat recipients are multi-family housing, whose share in the power ordered from the heating system is 56.4%. The thermal needs of the second group of recipients, i.e., trade and services, currently account for less than 20% of the total power ordered, which in the year amounted to 1 300 MW.

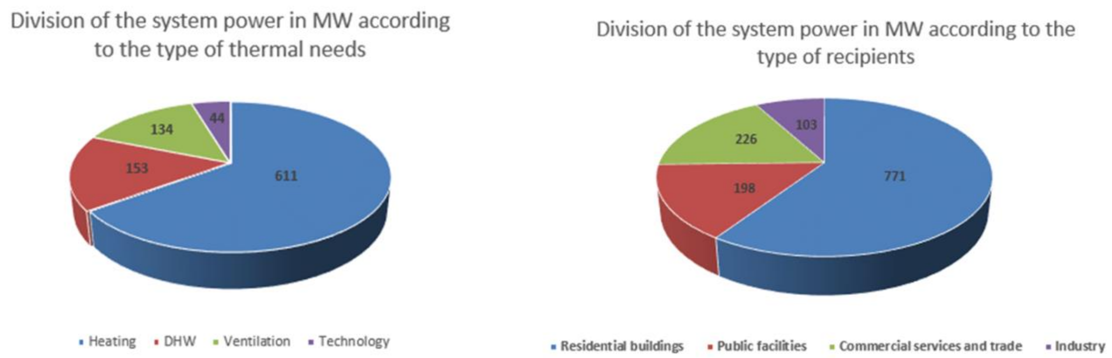


Figure 13 - Division of the system power in MW according to the type of thermal needs and type of recipients

Regardless of the sale of heat via the municipal heating system, Veolia Energia Poznań sells heat generated at EC II Karolin in the form of water vapor through a separate steam network to significant industrial recipients located in the vicinity.

The parameters of the steam are within the limits:

- temperature: 190 ÷ 230°C,

- pressure: 1.0 ÷ 2.1 MPa.

The total ordered capacity ranges from 31.0 - 38.0 MW.

The heat distribution system consists of main networks, distribution, connection and low-parameter networks that are in operation of Veolia Energia Poznań S.A. and powered from system and local sources, it has a total length of approx. 510 km.

District heating system Veolia Energia Poznań S.A. is made of pre-insulated pipelines and traditional duct and overhead pipelines. The share of pre-insulated pipelines for distribution networks, connections, as well as for low-parameter networks and domestic hot water is currently around 50%. On the other hand, on main networks for Dn≥ 300 it is 18.3%.

District heating substations, as elements constituting a connection between the heating network and receiving installations in buildings, are part of the municipal heating system operated by Veolia Energia Poznań S.A. Veolia operates heating substations which supply heat for the needs of central heating and domestic hot water, as well as for technological needs and ventilation.

Only the heating substations with an exchanger installed are built up in the city.

All the district heating substations are equipped with:

- weather automation,
- telemetry for reading measurement systems,
- the ability to control the heating substations from the level of the Energy Management Centre and read its operating parameters - about 3 000 units, excluding heating substations in single-family housing.

Additionally, 3 peak load boiler houses cooperate with the heat network, which are operated at temperatures from -8˚C. In order to regulate the hydraulic situation, the system is equipped with network pumping stations with a total capacity of 4 400 m^3/h.

II.3.2 Availability of Renewable Energy Sources

A new direction of supporting the supply of the heating system network that has appeared recently is the use - purchase of waste heat from external entities. The obtained effect is the improvement of the energy efficiency of the use of primary energy on a global scale.

From 2016, an additional source included in the power supply for Poznań is the Municipal Waste Thermal Conversion Installation located in the immediate vicinity of EC-II Karolin, with an achievable thermal power of 34 MW, owned by the PreZero Company. The energy fed into the grid amounts to approx. 300 thousand GJ per year.

At present, in Poznań, Veolia uses waste heat from compressor cooling systems - from the Volkswagen plant's foundry with a capacity of approximately 1.8 MW and the H. Cegielski - Energocentrum plant with a capacity of 0.05 MW. Energy fed into the grid - from both heat recovery sources, amounts to approx. 15 thousand GJ per year.

The waste heat re-use is a major goal of one of the epics defined by the RENergetic project so more details on this subject can be found in Section III.1.

II.3.3 Local Stakeholders and Roles

The most important users in Veolia Energia Poznań S.A. with a short description are listed below:

1. Technical Energy Manager

   - responsible for managing the municipal heat network and own heat sources in accordance with the applicable programs and work schedules.

   - undertakes activities in cooperation with relevant organisational units, including the Department of Distribution and Services, in the field of managing the power of the municipal heat network as well as sources and installations cooperating with the Poznań heating system.

- conducts ongoing analysis of the operation of the heat network, heat nodes, heat sources and, based on the generated reports in the scope of identified deviations and irregularities, takes action.

- makes decisions to limit the peak heat consumption based on the weather forecast and network parameters.

- manages the heat network through a telemetry system that allows to limit the heat supply, heat supply to the entire system and individual facilities supplied from the municipal heat network.

2. Business manager - people responsible for economic feasibility - Financial Director of Veolia in Poznań. Responsible for the business terms of the DSR service contract and the purchase of waste heat with PUT.
3. Heat consumers - connected to the district heating network. There are about 10 thousand Veolia customers in Poznań with the ordered capacity of approximately 1300 MW.

III. DETAILED DESCRIPTION OF THE ACTIONS

The original plan for the Poznan pilot site, submitted in the proposal, included an investment related to the installation of heat recovery from the cooling installation of the PSNC data center and transferring it to the heating system of the Poznan University of Technology Warta Campus. The plan was to integrate local energy systems to utilize waste heat, transfer heat from one building to another, hence increase the share of RES (up to 1.5MWp in PV and 2MW in GSHP in total) in heat (8MW power DHS) and electricity (1.5 MW power) production and to optimise energy demand with the use of BMS and IoT technology and by involving the end users in RECs. The idea was to build a HP coupled water loop (1 MW power) between PSNC and the CH building. The loop would create the possibility to transfer waste heat from the PSNC to the energy consuming CH building (heating all year round – 5 000 GJ) and to connect PSNC with DHS within campus which would allow to deliver heat for DHW preparation in summer (4 000 GJ), especially high-water demand dormitories, and even to supply heat (10 000 GJ) to Veolia company driven Poznan city DHS.

Originally, it was assumed that the cost of the water loop would be 100% covered by the project as a prototype installation, included in the proposal. After the start of the project, the cost of the water loop was classified as depreciation (several dozen years) and PUT did not have sufficient funds to implement the investment.

As it was a water loop related risk remarked in the proposal (no allocation of funds from local government to build heat pump assisted water loop and remote PV plant in Poznan pilot) proposed risk-mitigation measures have been implemented: analytical and simulation study based on data from PSNC data center and PUT buildings energy demand.

Nevertheless, as the idea of heat recovery from the data center to the campus heating system is the starting point for considerations about a zero-energy campus, therefore a study is being prepared and the resulting materials will be among the result of the project

General methodology for energy island

The first RENergetic objective is to securely maximize the level of energy autarky of a local energy system (energy island) and its share of renewable energy sources at energy consumption, at the same time.

Obtaining an energy-independent island is a long-term process, but possible to implement and requiring at the beginning activities in the field of ordinary modernization of buildings and their technical equipment, by introducing RES and low-temperature heat sources. Below are shown constraints and required action to achieve zero energy island.

Within RENergetic, in order to increase autarky and RES share and to obtain the scalability of the project, the **following methodology will be further developed** outlining the decision, diagnostic and investment path for stakeholders interested in transforming their island to sustainable one. Typical island parameters and constraints:

- an island located close to the city downtown (e.g., university campus, cluster of buildings) - no low emission allowed (gas boilers, CHP, biogas, waste incineration plant)
- existing infrastructure: old (high energy demand) and new buildings
- usually supplied by district heating network, sometimes by gas fired boilers
- no or restricted RS (mainly PV) - limited space for PV plant
- limited possibilities of using wind turbines (downtown vicinity)

Actions:

- for new buildings - construction in the nZEB or ZEB standard (low energy demand, increase of energy self-sufficiency, increasing the use of PV systems, heating and cooling with free cooling option, GSHP heat source, minimizing supply temperature of central heating (<55°C, optimally 30-35°C, e.g. underfloor heating and SGC systems) and cooling systems (15-18°C), mechanical ventilation with heat recovery or with GHE (Ground Heat Exchanger - pipe), minimization of the air flow with VAV regulation, demand control with IR or CO_2 sensors, adequate BMS systems utilization

- for existing buildings - successive thermal retrofitting of buildings (replacement of windows, insulation of walls and roofs), replacement of ventilation systems (mechanical ventilation with heat recovery), heating (surface heating, decreasing the supply temperature below 55°C, adaptation to cooperation with heat pumps) and lighting systems (LED 5 W/m^2) with improved automation (BMS) and replacement of heat sources (GSHP or AWHP)
- without meeting the above conditions, it is not possible to effectively use modern low-temperature heat sources and RES systems (<u>necessary condition!</u>)
- establishing a single electricity connection for an energy island (to improve self-consumption of energy produced locally by PV and WP without necessity to install energy storage accumulators)
- installation of PV and WP systems within the island as much as possible - initially no energy storage required - all energy produced in the island is self-consumed
- when the production of PV and WP begins to exceed the island's energy demand - the need to expand energy storage

Satellite

- local RES production (on energy island) usually insufficient to cover annual heat consumption
- a satellite for energy island with an area that allows the PV plant or other RES (e.g., wind power, biogas plants), with the annual energy production which balances the annual energy consumption of the island
- without a satellite, it might not be possible to achieve the island zero energy goal

Local heat exchange between buildings

- creating a local heat network initially as a heat source for HP located in buildings
    - it makes possible to use low-temperature waste heat and on the other hand
    - it adapts the island to the future use of a single, zero-emission heat source, without the need to modernize heat sources in each building - e.g., the use of hydrogen H2, central fusion power, connection to a zero-emission district heating network

Heat source options

- GSHP with vertical boreholes U-probes ground sources
- HP using water loop with waste heat (e.g., industrial technology, data centres) as a lower heat source

A vision for the future:

- replacement of heat sources for fuel cells and hydrogen engines (generation of heat and electricity) - hydrogen production using PV and electrolysers on island's satellite
- the possibility of using a different, ecological local source of heat and energy of the future, e.g., fusion power
- possibility of connection to a modern, ecological heat network with a zero-emission source in the future

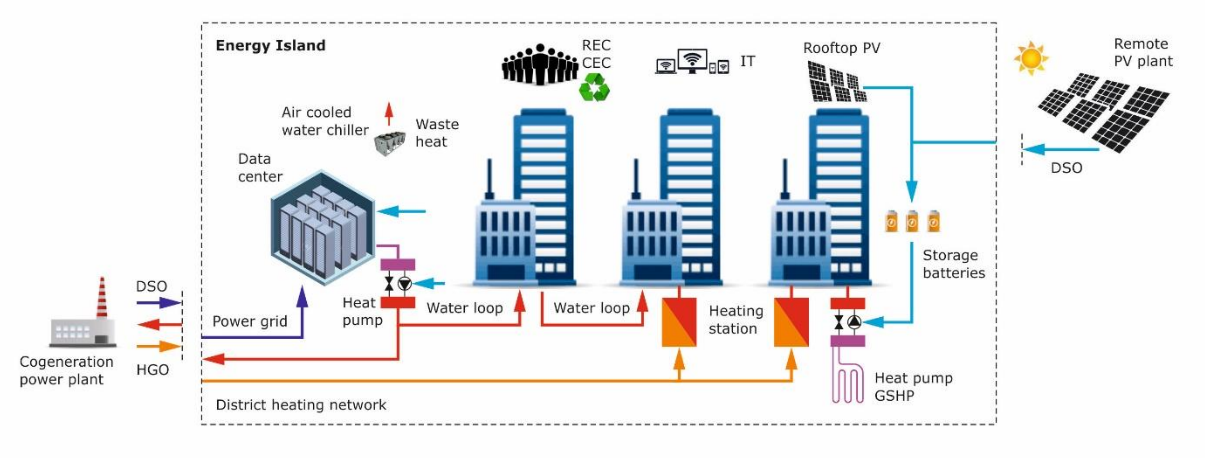


Figure 14 - The idea of the Poznan Warta Campus pilot site

Table 2 - Presents a summary of the most important selected strategies, tools and epics within the Poznań pilot.

Strategies selected	Main tools	Epics
Campus heating system (new)	simulations, data acquisition, digital twin	Data Centre (now: Local Waste Heat Optimization), Heat Supply Opt.
Heat loop optimization (existing)	full-scale experiment, data acquisition	Heat Supply Opt., Data Centre (now: Local Waste Heat Optimization)
Heat Demand Response HDR	data acquisition, IT solutions, full-scale experiment	Data Centre (now: Local Waste Heat Optimization), Heat Demand Response
Utilization of RES from PV	data acquisition, machine learning, simulations	Heat Supply Opt., Electricity Supply Opt.
Prediction and anomaly detection	data acquisition, machine learning, simulations	Heat Supply Opt., Data Centre (now: Local Waste Heat Optimization)
Engaging community	IT solutions, data acquisition	Heat Supply Opt., Heat Demand Response

As can be seen in Table 1, the most important epics within the Poznań pilot are:

- local waste heat optimization,
- heat supply optimization,
- demand response for heating domain,

In addition, less effort will be made to electricity supply optimization related to the use of photovoltaic installations. PUT and PSNC consume much more electric energy than their PV installations can potentially generate. Planned remote installations are delayed due to problems with connection and feed-in of energy to the electro energetic medium voltage grid.

These three most important epics are combined in cross functional epics:

- interactive platform,
- forecasting.

Analysis and description of these cross functional epics was presented in D3.1 with PSNC effort and in this deliverable only pilot-specific information and user stories will be presented.

III.1 Epic 1: Local Waste Heat Optimization

III.1.1 Epic description

The heat-related epics are the most important and with highest impact within the Warta Campus pilot. This is mainly due to the fact that a large part of the effort will be spent on simulating the waste heat reuse process from the data center, which is the largest source of renewable heat energy within the pilot as well as within the project. In addition, one of the three partners in the pilot is the district heating operator, Veolia, interested in purchasing this type of renewable heat energy. In addition, the immediate vicinity of the university campus with low-temperature heating networks makes very good conditions for a multi-scenario optimization of usage and parameters of waste heat utilization. Figure 15 shows the heat connections that is currently in operation and planned for simulation within the Warta Campus energy island.

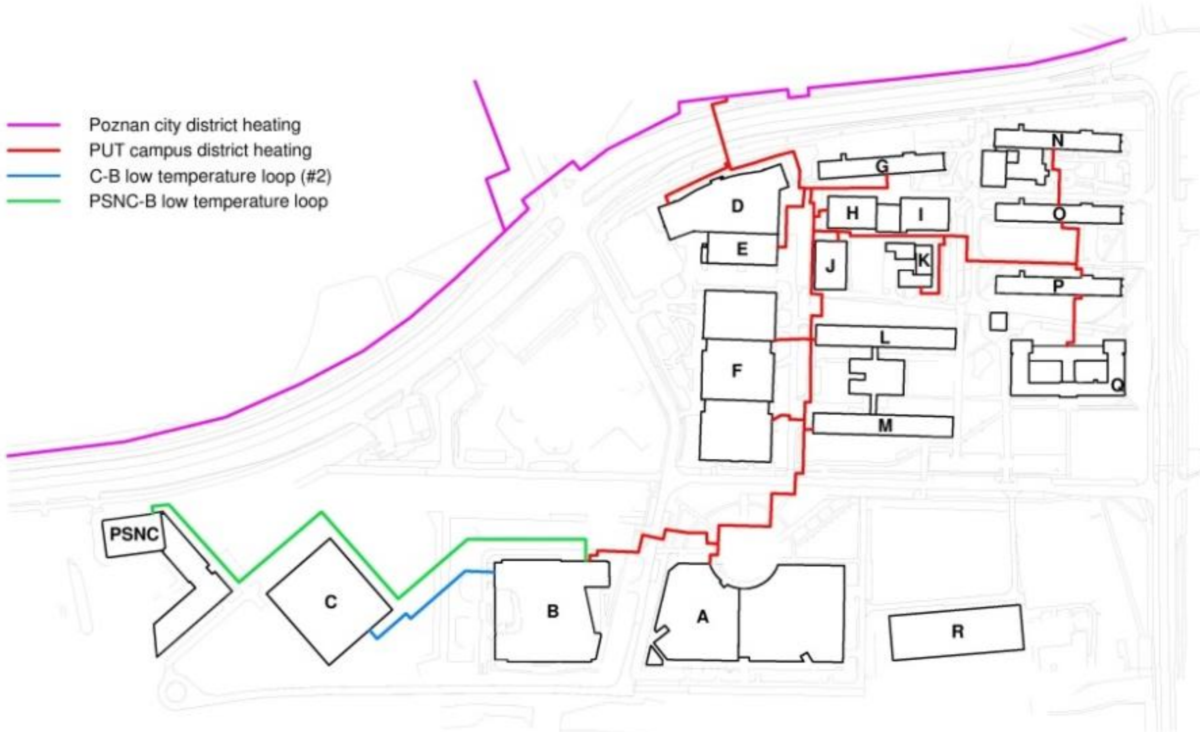


Figure 15 - Heat connections in operation and planned

In the Figure 15 purple line shows the course of the current operating district heating network operated by Veolia. Heating infrastructure on the campus of the Poznań University of Technology is marked in red. In addition, blue line represents the low-temperature infrastructure between the newest functioning buildings. The heating infrastructure marked in green will be simulated and considered in detail in many aspects within the project.

Operation parameters, data centre work profile, technical and economic issues will be taken into account. This simulation of connection will be directly routed from the PSNC data centre, from which waste heat will be reused.

Heat pumps play an important role in the optimization of data center waste heat reuse systems. The value of the heat pump coefficient of performance COP increases with the decrease of the upper heat source supply temperature and with the increase of the lower heat source return temperature. Therefore, the highest COP parameters are achieved by installations using lower heat sources, which are waste from industrial technologies (warm water) or heat of condensation. Therefore, the idea of utilising heat recovery from the PSNC data centre cooling system to support the heating system in the CH building was presented in the proposal.

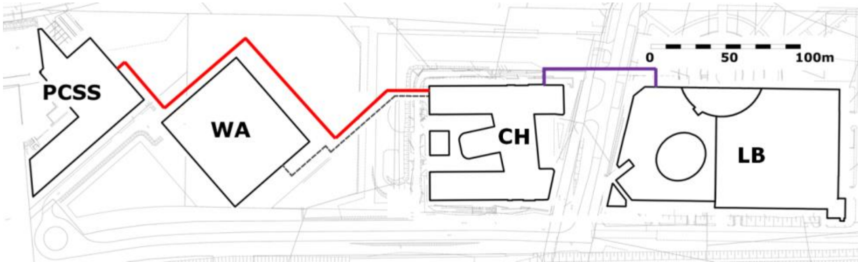


Figure 16 - Waterloop PSNC-CH

The idea was to build a Heat Pumps coupled water loop (1 MW power) between PSNC and the Chemistry Faculty building (CH). The loop will create the possibility to transfer waste heat from the PSNC to the energy consuming CH building (heating all year round – 5 000 GJ) and to connect PSNC with district heating network within campus which allow to deliver heat for domestic hot water preparation in summer (4000 GJ), specially high-water demand dormitories, and even to supply heat (10 000 GJ) to Veolia company driven Poznan city district heating network.

With the ever-increasing demand for electricity for cooling the PSNC facility, the possibility of creating a more developed installation was realized, cooperating not only with the CH building, but with all Campus buildings as part of the water loop constituting the lower heat source for heat. Actually, PSNC constant power is 1 MW, soon it will rise to 2 MW and the facility maximum capacity is 16 MW.

The heating demand for PUT is 7.5 MW at design conditions of -18°C. With COP of 4.0 it gives the required power for lower source of 5.6 MW, still at -18°C.

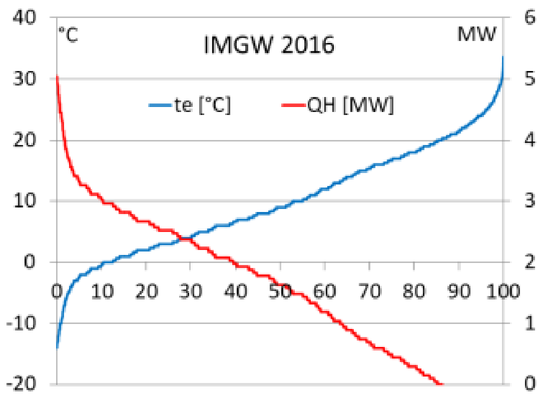


Figure 17 - Outdoor temperature and Campus heat demand in 2016

Average winter temperature is higher than 1°C, which result in half of required power (2.8 MW).

Veolia DHS supply temperature increases with outdoor temperature drop and is far higher than temperature to be obtained with typical heat pump (higher than 80°C with the outdoor temperature lower than 5°C). Nevertheless, summer supply temperature is in the range of 60-70°C and both winter and summer return temperatures are below 50°C. The heat pump can be used to supply the return in wintertime, and also to supply DHS supply.

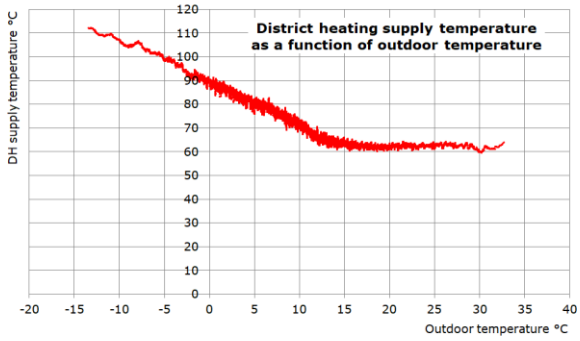


Figure 18 - District heating network DHS supply temperature

The same heat pump can be used to both supply DHN in summertime and campus heating in wintertime with 75°C water. The lower heat source would work 20-30°C, which should provide COP similar to those achieved by GSHP.

Two options are considered:

- direct linkage PSNC to Veolia – first scenario
- linkage from PSNC through PUT to Veolia – second scenario

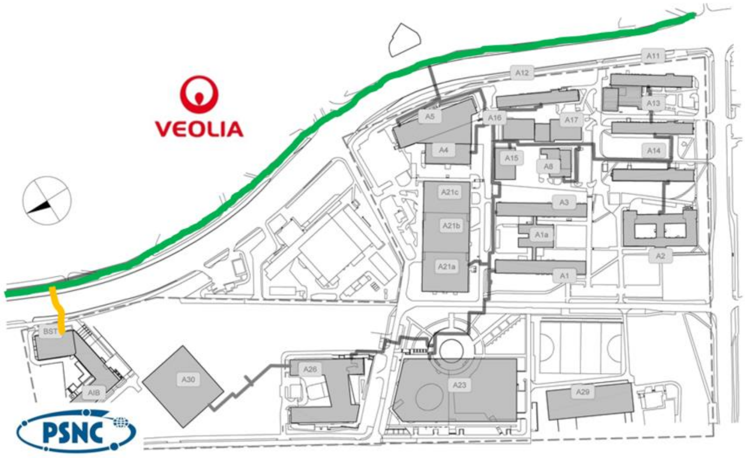


Figure 19 - Direct linkage (yellow) PSNC to Veolia DHS (green)

First variant is the shortest linkage. The upper heat source for heat pump would be high temperature one, which decrease the COP.

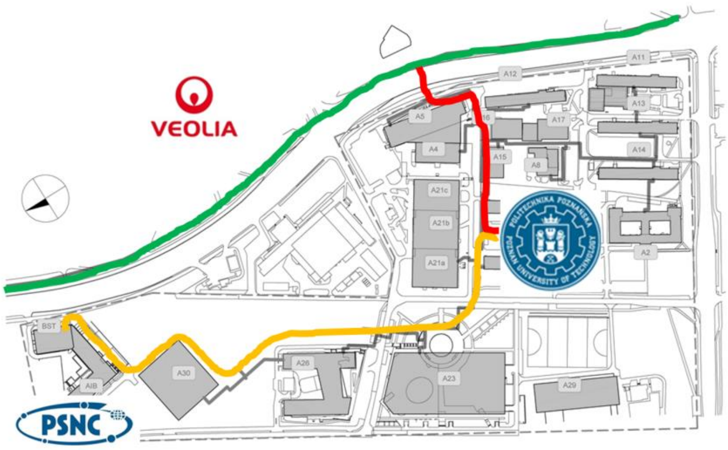


Figure 20 - Linkage from PSNC through PUT to Veolia

Linkage from PSNC through PUT to Veolia offers lower temperature needed in wintertime (55-60°C for most building on campus) which will result in higher COP. Cooling water from PSNC would act as lower heat source for dedicated, large heat pump located in the middle of the campus, next to WE and BM buildings. The buildings on the campus could be supplied directly from the heat pump (+60°C) or from the water loop (20-30°C) acting as lower heat source for individual buildings' heat pumps. In summertime the large heat pump would supply heat directly to DHS supply pipe with temperature of +70°C. As can be seen in the figures, the second scenario assumes the sale of the recovered heat to the PUT heat network and its surplus to the Veolia district heating network. Such solution enables year-round run of heat reuse process.

First scenario assumes the sale of waste heat directly to the Veolia district heating network. Depending on the temperature of the coolant, this process can be seasonal or year-round. In this case, the implementation of this variant is associated with the need to increase the parameters of the supply water with the use of heat pumps (the average parameters of the municipal heat network are about 48°C in the return pipeline, and about 85°C in the supply pipeline during the heating season) and the construction of a connection with a length of about 75 meters to the municipal heat network. As shown in the diagram below.

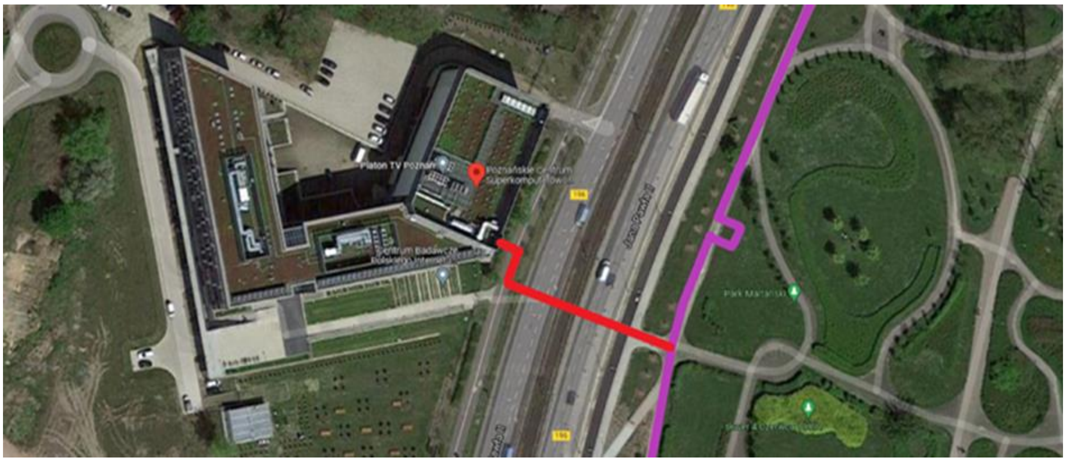


Figure 21 - Short linkage from PSNC to Veolia DHS

Currently, work is underway on the business model of the solution for the variants presented in the table below.

Table 3 - Heat transfer variants

Variant	Power of recovery heat	Volume of recovery heat per year	Electricity	Estimated
-	MW	GJ	MWh	€
1	1,0	29000	2685	700 000
2	1,5	43500	4028	1 000 000
3	2,0	58000	5370	1 300 000
4	2,5	72500	6713	1 600 000
5	3,0	87000	8056	1 900 000

III.1.2 Drivers and Barriers

The main process drivers from the PSNC point of view:

- the possibility of using the heat reuse potential that is very available because supercomputers must be cooled,
- increasing the environmental efficiency of the data center,
- increasing the economic efficiency of data center,
- implementation of interest in environmentally friendly solutions,
- realization of the interest in cooperation within the energy island,

and from PUT point of view:

- reduce primary energy consumption thanks to the use of waste heat,

campus heat supply diversification.

For energy islands, the heat supply is optimized by using continuously recovered heat for the energy island's primary heat demand, while the demand peaks will be replenished from the district heating network. In the case of excess heat, Veolia can accept waste heat and use it to heat other recipients, limiting heat generation from fossil fuels, which will reduce CO2 emissions. From Veolia's point of view, the purchase of waste heat from various sources for the district heating system and the reduction of heat consumption is necessary for at least 4 reasons:

1. Environmental protection as the main priority of Veolia's activities

Veolia Energia Poznań belongs to the Veolia Group and is an active participant in the dynamic changes taking place in the energy and heating sectors, implementing solutions aimed at reducing emissions, developing new ecological technologies as well as reducing energy losses.

The strategy of the Veolia Group in Poland, adopted already in 2009, assumes a gradual abandonment of coal combustion in the heat and electricity production process, until its complete elimination by 2030. In order to implement it, Veolia Energia Poznań is planning further investments in the heat and power plant in Poznań, including construction of a gas-fired unit. Thanks to this investment, we will reduce the emissions of: dust (49%), sulfuric dioxide (76%) and nitrogen oxide (73%).

Over the years of our activity in Greater Poland, we have carried out numerous pro-ecological investments aimed at reducing harmful emissions and improving energy efficiency. Care for the environment is inscribed in the company's DNA, which is why we continue to develop nature-friendly technologies, efficiently use fuel and natural resources. Therefore, among others We have made several investments in installations improving the environmental parameters of production, thanks to which we have been able to significantly reduce dust and CO_2 emissions at EC Karolin.

For many years, Veolia Energia Poznań has also contributed to reducing low emissions in Poznań. It focuses its activities on connecting low-emission buildings to the heating network powered by the CHP Karolin cogeneration source. Connection to the system heat network is a quantitative and qualitative change. Due to the connection of the existing buildings to the heating network in recent years, the local low emission has decreased by 160 thousand tons of CO_2. Our actions in the fight against low emissions are possible, among others thanks to the successful cooperation with the city authorities on programs aimed at eliminating its sources.

2. Legal regulations introduced by the European Union

Due to the conditions related to the structure of the district heating sector and the current state of technical knowledge, meeting the requirements set by the climate and energy policy of the European Union will be a huge challenge. In the context of future challenges for the heating sector, the decisions in the "Fit for 55" legislative package proposed by the European Commission will be of key importance. System heating will be primarily influenced by the legislative proposals in the draft EED27 directive, RED III28 directive and EPBD29 directive.

According to the proposed wording of the draft EED directive, in terms of meeting the criterion of high-efficiency cogeneration, the existing criteria include a new criterion consisting in the introduction of a limit for direct CO_2 emissions (for units using fossil fuels), amounting to less than 270 g CO_2 per 1 kWh of combined heat and power. (Combined heat, electricity and mechanical energy). The direct emissions limit will apply from the entry into force of the recast directive, while its role will be particularly important from 1 January 2026, when the criteria in the definition of an efficient heating and cooling system will refer directly to high-efficiency cogeneration.

These regulations prevent coal-fired cogeneration from maintaining its high-efficiency status and, at the same time, introduce an emission limit for gas-fired units. The entry of the new criterion will mean that coal-fired cogeneration units, which will not be modernised by the end of 2025, will lose the status of high-efficiency cogeneration, which in the vast majority of systems will also translate into the loss of the status of an effective heating and cooling system.

At the same time, the proposed pace of increasing the mandatory share of renewable energy sources means that from 2035 heating systems will not be considered effective on the basis of the share of high-efficiency cogeneration, but only on the basis of the share of renewable energy sources and waste heat. At the same time, some systems may lose this status as early as 2026 due to the failure to meet the emission criteria for high-efficiency cogeneration.

Annex III of the proposed EPBD sets out the requirements for new and renovated zero-emission buildings, which also includes a table of non-renewable primary energy input ratios for zero-emission buildings. In the context of Polish district heating, however, another requirement of Annex III seems to be particularly important, which states that from 2030 new and modernised zero-emission buildings (in the case of public buildings - from 2027) must, as a rule, be supplied only with energy from RES or waste heat.

3. Rising CO_2 prices have a significant impact on business

The dynamics of the CO_2 price determined by the European Union Trading System (EU ETS) increase (around € 90 / tonne) significantly contributes to the increase in heat prices for our customers. In the future, this may result in customers resigning from heat supplies from the district heating network.

4. Limited number of sources of obtaining green and waste heat

In large heating systems, due to the necessity to install very high-power generating units, the transformation of sources towards RES is a significant technical and logistical challenge (i.e., supply of very large amounts of biomass, required water temperature in the network, etc.). Solutions that can be considered in the above-mentioned context are, among others:

- installations for thermal processing of municipal waste (ITPOK) and sewage sludge from sewage treatment plants
- sources powered by alternative fuel RDF (Refuse Derived Fuel) as a way of managing the high-calorific fraction of waste and using it as a fuel
- geothermal energy - in selected locations with appropriate geological conditions
- large-scale solar collectors
- heat pumps which, due to the relatively low installed power, can work as a supplement to another heat source, and the solution increasing the share of RES in the system is electricity from renewable sources dedicated to drive such a pump
- use of renewable gases (green hydrogen, biomethane, biogas).

As of today, Veolia has identified several heat recovery sources with a total capacity of approximately 29 MW as shown in the diagram below. This is not a significant share of renewable energy for a system whose capacity is almost 1 000 MW, therefore Veolia is interested in every possible waste heat and renewable energy to reduce CO_2 emissions.

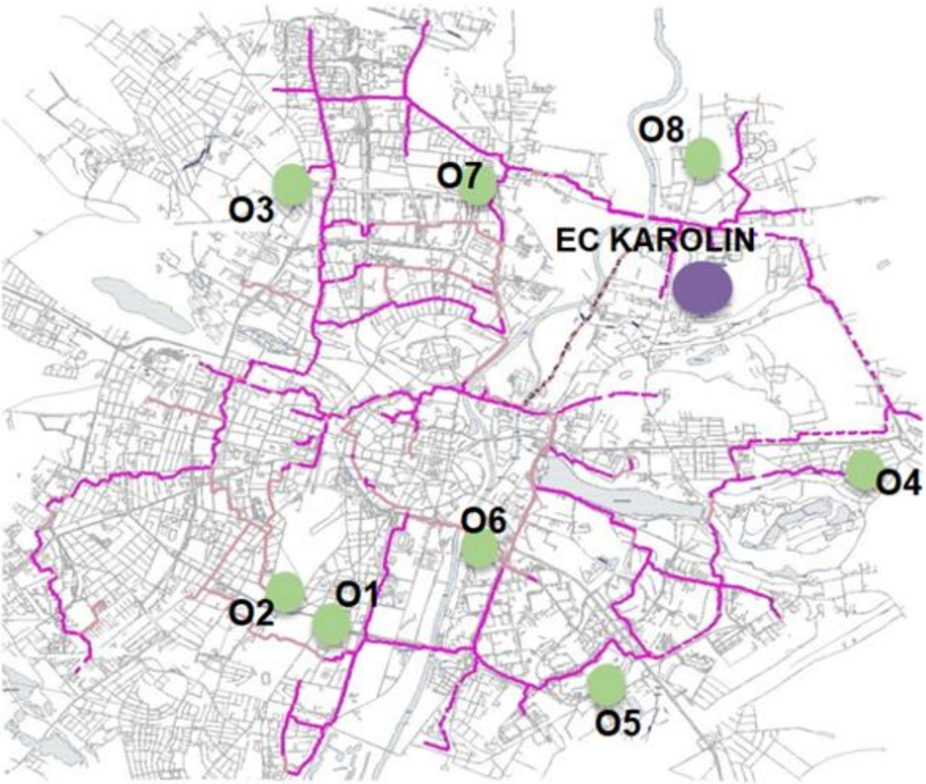


Figure 22 - Veolia heat recovery sources

Table 4 - Veolia heat recovery sources

DESIGNATION	SOURCE	POWER	YEAR
[-]	[-]	[MW]	[-]
O1	Volkswagen	3	2022
O2	Odlewnia BOBREK	1	2023
O3	Lisner	1	2024
O4	Huta Szkła	2	2024
O5	Beyond	2	2024
O6	PCSS	1	2024
O7	LOŚ	4	2028
O8	COŚ	15	2028
	TOTAL	**29**	

The main process barriers from the PSNC point of view:

- no agreement on the purchase price of waste heat for different entities in energy island,
- economic and environmental efficiency of a heat pump depends on the source of electricity and price of electricity as well. High electricity prices from the grid can be a barrier.

III.2 Epic 2: Heat Supply Optimization

Water loop between CH and WA buildings with power of 450 kW already exist. Chemistry Faculty building (CH) due to chemical technology is equipped with extensive ventilation, heating, and cooling systems. In the contrary Architecture Faculty (WA) is newest nZEB building with downsized installations. It is worth noting that the CH building is equipped with a 1.5 MW DHS substation and 380 kW heat pumps, but due to the much lower cost of heat from heat pumps, the use of heat pumps has priority and as much as 80% of heat comes from heat pumps and only 20% from the substation. As a result, the lower heat source for heat pumps is excessively exploited in the winter and should be regenerated in the summer.

Water loop has three modes of operation:

- transfer heating from CH to WA
- transfer cooling from CH to WA
- transfer excess heat from WA to CH and regenerate ground heat source in summer

Table 5 - Waterloop operating modes

<table>
<tr><td colspan="2" rowspan="3">Operating mode</td><td colspan="4">WA Architecture Faculty</td></tr>
<tr><td>Heating</td><td>Cooling</td><td colspan="2">Heat drop</td></tr>
<tr><td>C</td><td colspan="2">A</td><td>B</td></tr>
<tr><td rowspan="3">CH
Chemistry
Faculty</td><td>Heating</td><td rowspan="2">1</td><td></td><td></td><td></td></tr>
<tr><td>Heating and Cooling</td><td rowspan="2">2</td><td>3</td><td></td></tr>
<tr><td>Cooling</td><td></td><td></td><td>4</td></tr>
</table>

typical

unlikely

impossible

Operating modes are presented in table (A - cooling mode, B - heat drop WA2CH, C – heating mode).

Figure 23 - Water loop Schneider SmartStruxure SCADA

In RENergetic, an analysis of the water loop operating conditions will be carried out in order to minimize the consumption of primary energy for heating and cooling and to optimize the operating conditions of the heat source for heat pumps in the CH building.

III.3 Epic 3: Demand Response for Heating Domain

III.3.1 Epic description

Demand Side Response (DSR) is a service that allows energy consumers to reduce it demands according to requests of energy providers. DSR programmes have been already applied in the electricity domain usually to protect the power grid in pick demand periods. In RENergetic we implement this concept in the heat domain. General RENergetic heat DSR epic is described in D3.1.

In the Poznan pilot, Demand Side Response (DSR) means a temporary reduction in power consumption by heat consumers (in this case PUT) to support the stable operation of the district heating system in order to reduce heat consumption peaks and reduce CO_2. DSR programs allow companies to generate additional revenues that can reduce power consumption in response to the call of the operator of the thermal system. PUT will implement DSR thanks to the use of the building structures (walls and ceilings) thermal storage, TABS (Thermally Activated Building Structures), reduced ventilation and preheating/precooling. The decision to change the settings will be made by the technical energy manager based on information from Veolia and calculation of the DSR effect. The reduction of parameters can be carried out automatically (BMS building automation) or with the help of REC (Renewable Energy Community, i.e., students in dormitories or lecturers in didactic buildings) through a system of incentives and suggestions.

Currently, energy managers miss precise and reliable forecasts of buildings heat demands. For example, they can obtain from BMS the information about campus heating power dependence on outdoor temperature presented in Figure 24. The significant distribution of heat values is due to the fact that heating power is also dependent on solar radiation, internal heat gains, wind speed and, above all, thermal storage. That makes heat demand dependence on temperature fuzzier. With the same outdoor temperature quite different heat demand can be observed. Therefore, the implementation and use of more advanced forecasting models with exogeneous variables is planned.

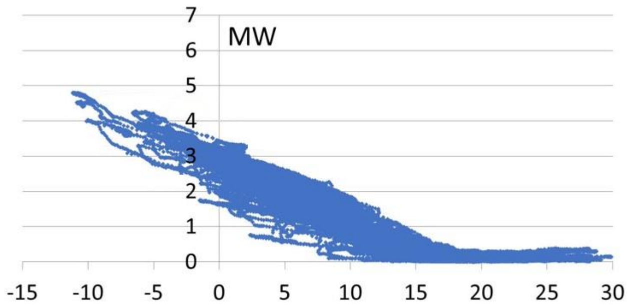


Figure 24 - Dependence of Campus heating demand on outdoor temperature

Due to the use of building structures thermal storage, DSR is analogous to passive cooling, in which, as a result of forecasts, the technical manager may decide to use night-time passive (natural ventilation by windows) or active cooling (increased mechanical ventilation, use of cooling devices) to temper the extreme loads of the next day.

The basic motivation to introduce the Demand Response for Heating service is the following:

1. Environmental aspects as the main priority of Veolia's activities
2. Legal regulations introduced by the European Union
3. Rising CO_2 prices have a significant impact on business
4. Limited number of sources of obtaining green and waste heat

In addition, the weather profile in the city of Poznań and the solar operation in the period of low external temperatures make it possible to use the heat accumulated in buildings and the heat of sunlight for the implementation of the DSR service.

When outside temperatures are low, Poznań has anticyclones, so it is sunny. It can be seen on the presented data from 25.02. at a very high temperature amplitude between day and night.

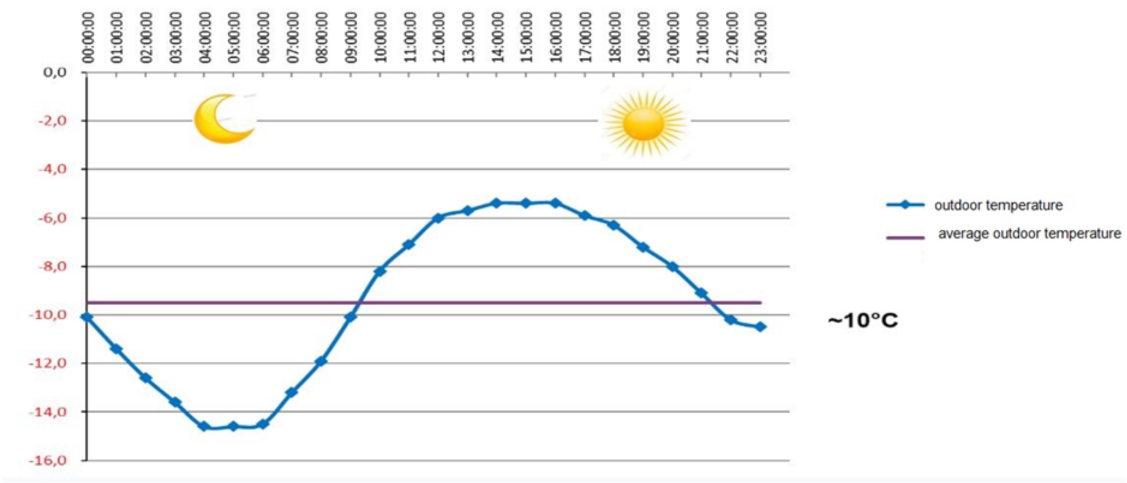


Figure 25 -

By applying the experience gained with the use of DSR to night cooling, it is possible to obtain the effect of reducing primary energy consumption by using the forces of nature and shifting the operation of cooling and ventilation devices to the night period with a reduced environmental cost.

III.3.2 Method of implementing DSR

Veolia, on the basis of weather forecasts, determines each day N-1 the heat demand of the system for the next day N. Anticipating that the peak of heat demand will occur, the Veolia energy management manager sends a signal to the energy management manager in PUT, who initially, according to his knowledge and experience, switches the controllers heating nodes to lower the temperature in PUT rooms on day N. On day N, the heating of PUT facilities is limited and thus the heat consumption is reduced. Such action in the case of Veolia will reduce fuel oil combustion from peak boilers and will generate an average CO_2 savings of 1 650 t CO_2 / year.

To achieve the required heat demand reduction during N Day the thermal storage of the building, reduced ventilation and preheating will be used (mostly during a night before N day). After the buildings PUT reach the set internal temperature and use the heat accumulated in the building, the energy management manager in PUT will again override the heat node controllers to obtain higher internal temperatures and notify Veolia.

Of course, the scale of savings will depend on the duration of the restriction and the temperature of the external factors.

Detailed data should be obtained after carrying out the experiment.

III.3.3 Drivers and Barriers

The following drivers and barriers relate to the heat demand response.

The main drivers:

- very high increase in the price of CO2 per ton (motivation for the district heating operator),
- willingness to increase energy autarky of entities by ability to adapt to energy supply constraints,
- Reduction of peaks in system demand for thermal power
- Fulfillment of the RENERGETIC project with the goals pursued by Veolia
- Possibility of using waste heat by Veolia and reducing the carbon footprint
- implementation of interest in environmentally friendly solutions,
- potential financial income to DSR participant (increasing economic viability of the energy island).

The main barriers:

- The risk of low and unreliable manual heat reduction by individual users (such as residents)
- Typical scheme of Veolia's DSR assumes direct heat power changes on district heating nodes without prior information to the consumer (approach with a notification one day in advance to be tested in the pilot)
- Relatively low financial benefits for DSR program participant (PUT)
- The need for a new organization of work at PUT for effective energy management and implementation of the DSR agreement
- Lack of legal solutions in the case of DSR for heat

III.4 Epic 4: Electricity optimization

III.4.1 Epic description

Project partners such as PSNC and PUT are very interested in developing the use of renewable electricity for their facilities. As mentioned in the previous paragraphs, PSNC and to smaller extent also PUT consume much more electricity than their local photovoltaic sources can potentially generate. Due to the location in the city center, it is not easy to install larger sources of renewable energy locally. Therefore, electricity optimization is justified in view of future simulations. Notable area of development will be the coupling of heat and electricity vectors in a situation where there will be excess generation from renewable electric energy sources. Therefore, Poznan University of Technology and PSNC are implementing project of large photovoltaic installation near the Kąkolewo airfield, several dozen kilometers away from the loads in Poznań. The commissioning of these installations is planned at the turn of the year 2023/2024. However, many legal issues were encountered in the design process.

An example of the preliminary analysis and simulations is presented below. The aim of this actions was to present the variability of the use of photovoltaics depending on the power connection, battery capacity and power load. Using the average insolation data for the 52° N latitude and 16° E longitude, the annual energy yield from 1 MW of the photovoltaic farm was calculated with an hourly step. The algorithm works in such a way that the generated energy supplies the load first, then recharges the battery, and finally it is put into the grid up to value of the grid connection. If the generation is too low to meet the needs of the load, the energy stored in the batteries is used first, and then the energy is drawn from the power grid. This logic allows the maximization of the use of the energy produced by the PV with a limited size of the connection and the battery capacity.

Then calculations were made for 1 MWp photovoltaic power plant and different values of:

- the power grid connection
- battery capacity
- power consumption (load).

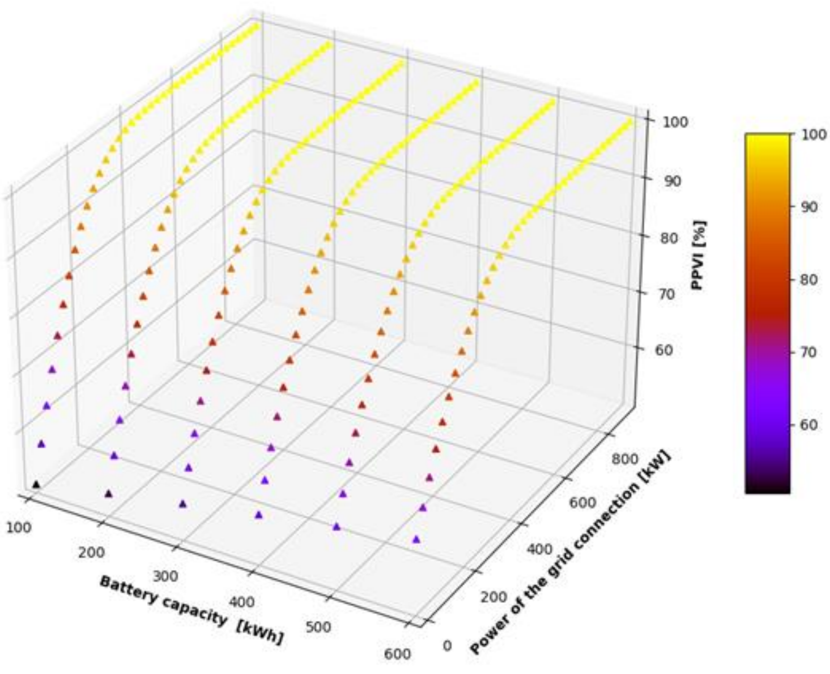


Figure 26 - Exemplary graph showing the relationship between selected parameters for planned PV installation

The graph shows the PPVI (production of PV index) value depending on the variable values of the battery capacity and the grid connection. PPVI is calculated as the ratio of the sum of the photovoltaic energy consumed by the load directly, accumulated by the batteries and that put into the grid, to the sum of energy that the same farm could produce without any feed-in restrictions.

The value of the PPVI coefficient increases rapidly with the increase of the connection to grid value, however, the change of the battery capacity does not have a big impact on it.

As PUT is going to launch the procedure of increasing the power of current Campus 350 kWp roof PV plant up to 1700 kWp, which is close below the contracted energy demand, the optimization in the field of grid connection topology and potential use of energy storage is going to be performed. The current state in this regard is presented in the infrastructure section.

In the first phase of the project the Electricity optimisation epic was treated with lower priority than for instance heat related epics or cross-domain epics such as forecasting and interactive platform. From the Poznan pilot perspective, it was due to (1) significantly lower current PV energy generation compared to the energy consumption of the campus and (2) PV investments that will be realised during the second phase of RENergetic. In the next steps we plan to analyse in detail the integration of PV plants (both local and located remotely) with the energy island and to apply PV data to the development of the RENergetic platform, including KPI calculations and forecasting tools.

III.4.2 Drivers and Barriers

The following drivers and barriers relate to the construction of remote PV installation in Kąkolewo.

The main drivers:

- very high increase in the price of electricity from the distribution grid,
- willingness to increase environmental efficiency of entities,
- willingness to increase energy autarky of entities,
- implementation of interest in environmentally friendly solutions,
- realization of the interest in cooperation within the energy island.

The main barriers:

- the legal issues detailed in D7.1,
- consent of the distribution grid operator to connect the PV sources at an economically unjustified grid point.

III.5 Epic 5: Forecasting

III.5.1 Epic description

The epic of forecasting is crucial for the Poznań pilot and other pilots within the RENergetic project as well. In the Poznan pilot the main stakeholder of forecasting tools is the technical manager interested in observing key parameters, comparing them with historical data and receiving all necessary alerts and notifications. This is important because the forecasting of energy values will lead to taking specific actions enabling the reactions of the demand and supply sides. As part of the actions taken by the Poznań pilot, these predictions will concern especially heat domain, particularly related to waste heat from the data center. Another important issue is anomaly detection, leading to continuous and safe operation within the energy island.

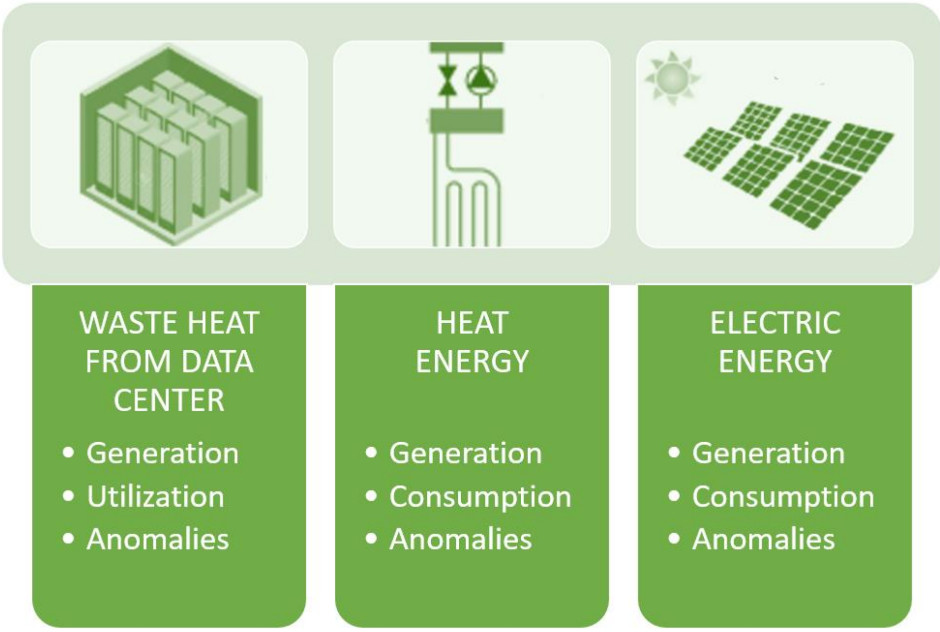


Figure 27 - Summary of forecasting areas in the Poznań pilot

Forecasting epic along with potential prediction methods are described in deliverable D3.1. In this section, we summarize functionalities especially relevant for the Poznan pilot. Basically, epic forecasting can be divided according to the following list within Warta Campus pilot with chosen, important user stories:

- Heat re-used from data center generation and utilization
  - I, as the technical energy manager, want to forecast heat flux to PSNC-DC water loop generation (short term) to perform further analytics and comparisons with historical data. The goal of this analysis is to come up with a strategy to supply as much waste heat as possible in order to avoid having extra heat dissipation cost / maximize profits / perform heat demand response.
  - I, as the technical energy manager/ business manager want to forecast heat flux to PSNC-DC water loop generation (long term) to perform simulations (from the data center (source) and campus (consumer) perspective) in order to evaluate how changes on the input features (e.g., energy consumption, load in data center) would impact the predicted heat flux to PSNC-DC. Another purpose of simulation is to plan development of data center and new investments.
  - I, as the technical energy manager, want to perform "What-if" analyses of various future scenarios in order to be able to check how the change of input features (e.g., Data center load) would impact the predicted heat flux so as to optimize infrastructure.
  - I, as the technical energy manager / business manager, want to perform "What-if" analyses of various future scenarios in order to be able to check how the change of input features (e.g., Data center load) would impact the predicted heat flux and cost, so as to take good investment decisions.
  - I, as the energy manager, want to observe forecasts of the energy island's waste heat supply in order to react in advance to the supply variability.

- Heat energy generation and consumption
  - I, as the technical energy manager, want to observe forecasts of chosen building heat demand, in order to spot undesirable trends in expected heating demand.
  - I, as the technical energy manager, want to observe historic values of building heat demand, in order retrieve information about heating demand in the past.
  - I, as the technical energy manager, want to be able to observe notification, if forecasted heat demand reaches unacceptable heat consumption level set by me, in order to know in advance about unusual trends in heat demand.
  - I, as the technical energy manager, want to choose a building for which I want to observe parameters, such as historic and forecasted heat demand, in order to see a dashboard for only one building.
  - I, as the technical energy manager, want to see statistics about previously detected anomalies by the system, in order to have an overview of the Energy Island performance over some period.
  - I, as the technical energy manager, want to observe forecasts of the energy island's renewable heat energy generation.
- Electricity energy consumption
  - I, as the technical energy manager, want to observe forecasts of chosen building electricity demand, in order to spot undesirable trends in expected electricity demand.
  - I, as the technical energy manager, want to observe historic values of building electricity demand, in order retrieve information about electricity demand in the past.
  - I, as the technical energy manager, want to be able to observe notification, if forecasted electricity demand reaches unacceptable heat consumption level set by me, in order to know in advance about unusual trends in electricity demand.
  - I, as the technical energy manager, want to choose building for which I want to observe parameters, like historic and forecasted electricity demand, in order to see dashboard for only one building,
  - I, as the technical energy manager, want to see statistics about previously detected anomalies by the system, in order to have an overview of Energy Island performance over some period.
  - I, as the technical energy manager, want to observe forecasts of the energy island's renewable electricity energy generation.

A platform for collection of data from PSNC facilities and preliminary data analysis are presented in Section IV. The platform that enables online data acquisition from the Building Management System (BMS) and statistical analysis of data are good input to further development of prediction tools. In fact, some prediction methods have been already successfully developed and tested as highlighted in Section IV.2. Further work, synchronized with WP3, will include development of more advanced forecasting methods, implementation of corresponding dashboards, and application to specific epics and user stories.

III.5.2 Drivers and Barriers

The main drivers:

- great demand for this type of forecasting tools (with potential applications in different scenarios and for other data sets),
- possibility of increasing environmental and economic efficiency thanks to proactive energy management based on forecasts,
- possibility to response to stochastic generation from renewable energy sources,
- maximizing the use of energy island sources, autarky increase,
- optimal use of waste heat from the data center.

The main barriers:

- unavailability of measurement data,
- insufficient historical data,
- pandemic times data disruptions especially in academic areas,
- additional effort required to apply forecasting models to other data and problems (not out-of-the-box solution, assistance of data scientist needed)
- inaccuracy of measuring systems.

III.6 Epic 6: Interactive Platform

III.6.1 Epic description

Epic interactive platform same as forecasting is cross functional. This epic provides the tools to display data, predictions or notifications as well. So interactive platform is linked to all the above epics. The detail and amount of data depends on the user's permissions. Most of the data on this subject is presented in D3.1, while two basic functionalities for Poznan pilot are mentioned here.

One of the pilot specific goals is user interface that can be displayed on the screens in the corridors of the energy island buildings. It will show the status of generation and energy consumption, autarky and renewables status. An example of a mockup of this type of interaction is presented in the figure below. It is worth noting that it will be adapted to a replicable solution for all pilots.

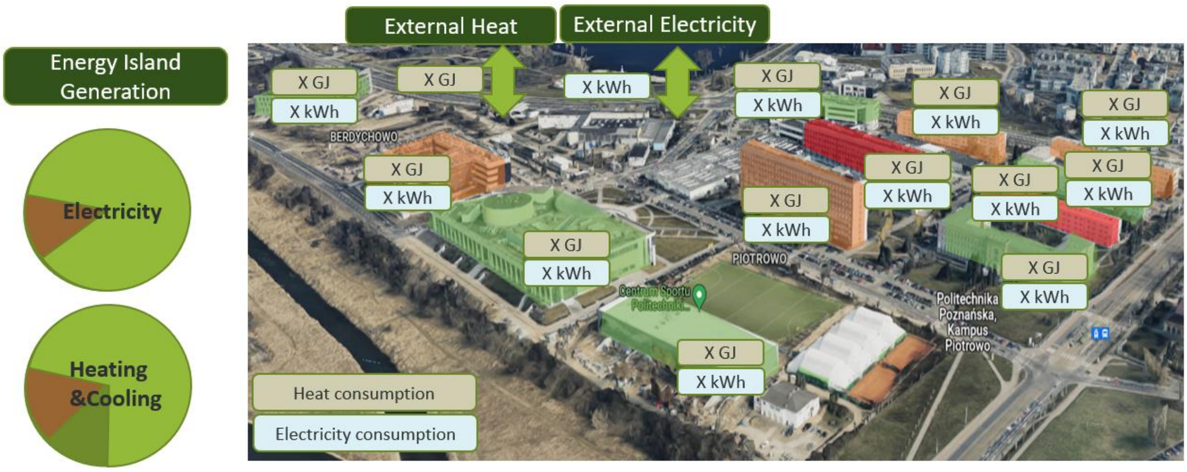


Figure 28 - Exemplary mock-up visualizing Poznań Warta Campus

The second goal is related to the activities of the technical manager. This stakeholder plays fundamental role for all entities within Poznań energy island. The most detailed platform should be provided for him/her and allow a detailed view of all data, alerts, reports, predictions and anomalies.

III.6.2 Drivers and Barriers

The main drivers:

- great demand for this type of tools in the energy island,
- improving energy and environmental awareness within the energy island,
- developing a platform for a technical manager that will improve and facilitate his work and decision-making process

The main barriers:

- unavailability of measurement data,
- inaccuracy of measuring systems,
- overwhelming amounts of data to be followed and analyzed by a technical manager
- illegibility for an energy island with a large number of different loads and sources of energy

III.7 Social Engagement

As part of the involvement of the local community, we want to raise awareness of the energy consumption of buildings. By increasing the automation of the HVAC installation, we squeeze the most out of it. The newer the building, the higher its energy efficiency. As a result, users play an increasingly important role in the building's energy consumption. Therefore, the next step in looking for energy savings is educating users - changing their habits.

III.7.1 Planned activity 1 - Experiment of student responsiveness

Joining the group of DS4 residents on Facebook and informing them about planned energy savings. It will be, for example, asking to close the window. Then, when collecting data from the BMS, we will check how many people living in the building have complied with our guidelines. This test will allow you to check the responsiveness and commitment of residents to energy issues.

Drivers and Barriers

- Problem z komunikacą
- Opóźnienie

III.7.2 Planned activity 2 - Physical installment

As part of one of the activities, we plan to create a place where every passer-by will be able to learn about the energetic aspects of our island. Physical installment is being developed with the WP2 team. A place was initially selected for it in the hall of the technical library. It is a place where a lot of people stay during the day.

Figure 29 - The interior of the Technical Library building [PUT]

The concept created by Kensia Klinger & Hanna Dertinger is to create a place where you can sit down for a while. It may also have a table that will allow you to learn in this place, but it will also be a place to rest. All around (on the vertical walls) there will be information about our project.

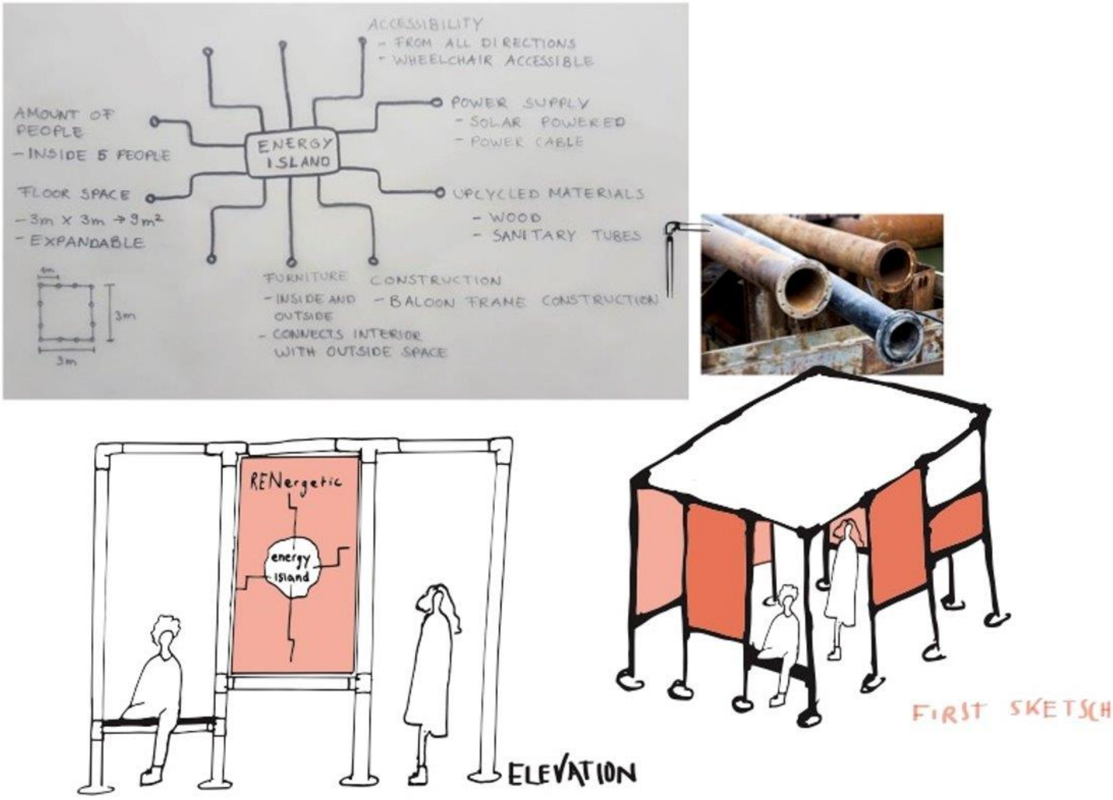


Figure 30 - Concept by Kensia Klinger & Hanna Dertinger form WP2

Drivers and Barriers

- No consent from the university authorities for the assembly,
- Indoor installation, so it makes no sense to mount PV panels on the roof Physical Instlation.

III.8 Infrastructure

Actions taken, the current status and planned activities as well as optimization issues in relation to PV installations, GSHP and renewable waste heat are presented in the chapter.

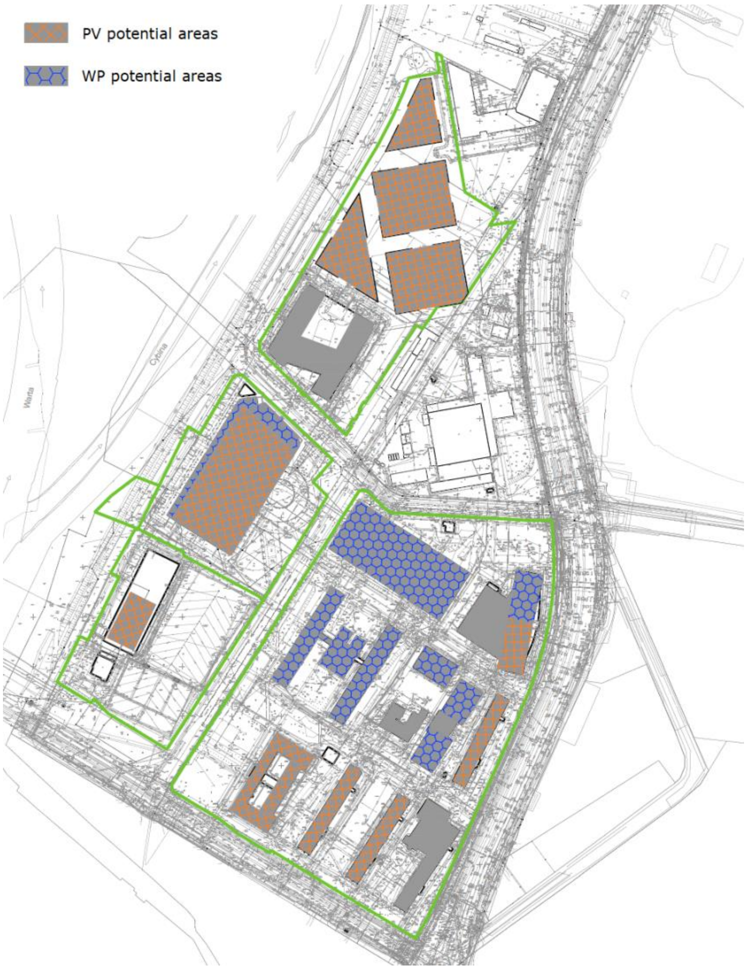


Figure 31 - Campus area with PV and WP potential

Photovoltaics (PV) Warta Campus

Two PV roof plants exist on the campus.

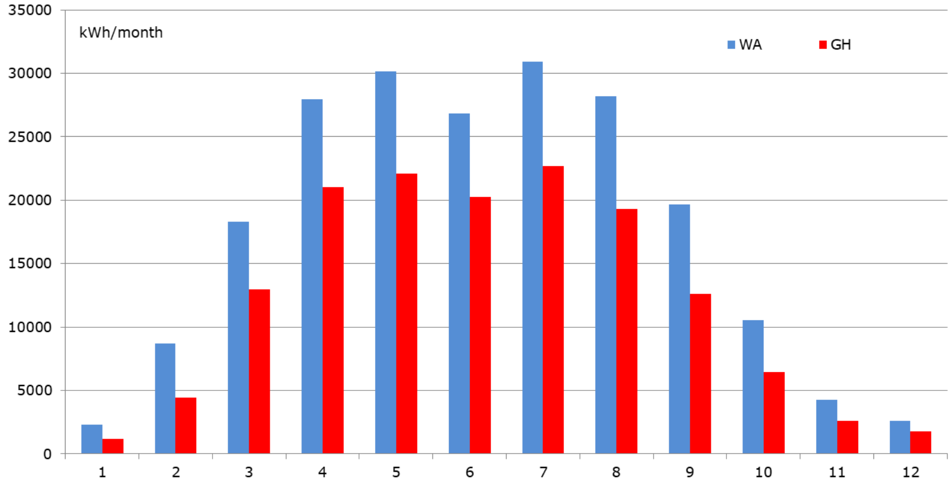


Figure 32 - Campus PV plant (WA & GH buildings) monthly energy production (2020/2021)

Gym Hall building (GH) installation consist of 464 panels, 330 Wp each, east-west (E-W) oriented, which result in power of 153.1 kWp and annual production of 147 304 kWh/a with specific value of 962 kWh/kWp. Plant is connected to K-76 transformer station. The avoided CO_2 emission coefficient in Poland is 0.724 kg CO_2/kWh which stands for 106.6 tons of avoided CO_2 annually thanks to plant operation.

Figure 33 - Gym Hall (GH) PV roof power plant

Architecture Faculty building (WA) installation consist of 666 panels, 300 Wp each, south (S) oriented, which result in power of 199.8 kWp and annual production of 210 320 kWh/a with specific value of 1 053 kWh/kWp. Plant is connected to K-839 transformer station. The avoided CO_2 emission coefficient in Poland is 0.724 kg CO_2/kWh which stands for 152.3 tons of avoided CO_2 annually thanks to plant operation.

Figure 34 - Architecture Faculty (WA) PV roof power plant

The most important, from the point of view of an independent energy island, is the fact that almost the entire campus of the Poznan University of Technology is connected to the DSO through one connection point - the K-76 transformer station. The situation would be completely different if each of the campus buildings had an individual connection to a DSO. Currently, only the dormitories and CH & WA buildings (K-839) are individually connected to the DSO, and all other facilities on the Warta campus are connected directly to the K-76 transformer station. As a result, buildings can be equipped with large RES sources, like wind turbines or photovoltaics plant, while maintaining self-consumption, without the risk of exporting electricity to the grid.

General electricity power supply comes from DSO (ENEA Operator) to the Warta campus from two directions:

- GPZ Bema (K-76 station)
- GPZ Rataje (K-839 station)

Rooftops, selected façades and parking lots were selected as having potential for PV panels installation, as the height of the buildings and its density reduce the solar radiation on the ground. Only accessible, unreinforced roof areas were taken into account in the analysis. That is why, i.e., CH building roof was excluded from the list.

Figure 35 - Example of Warta campus buildings roofs suitable (left, BL building) and non-suitable (right, CH building) for PV plant installation

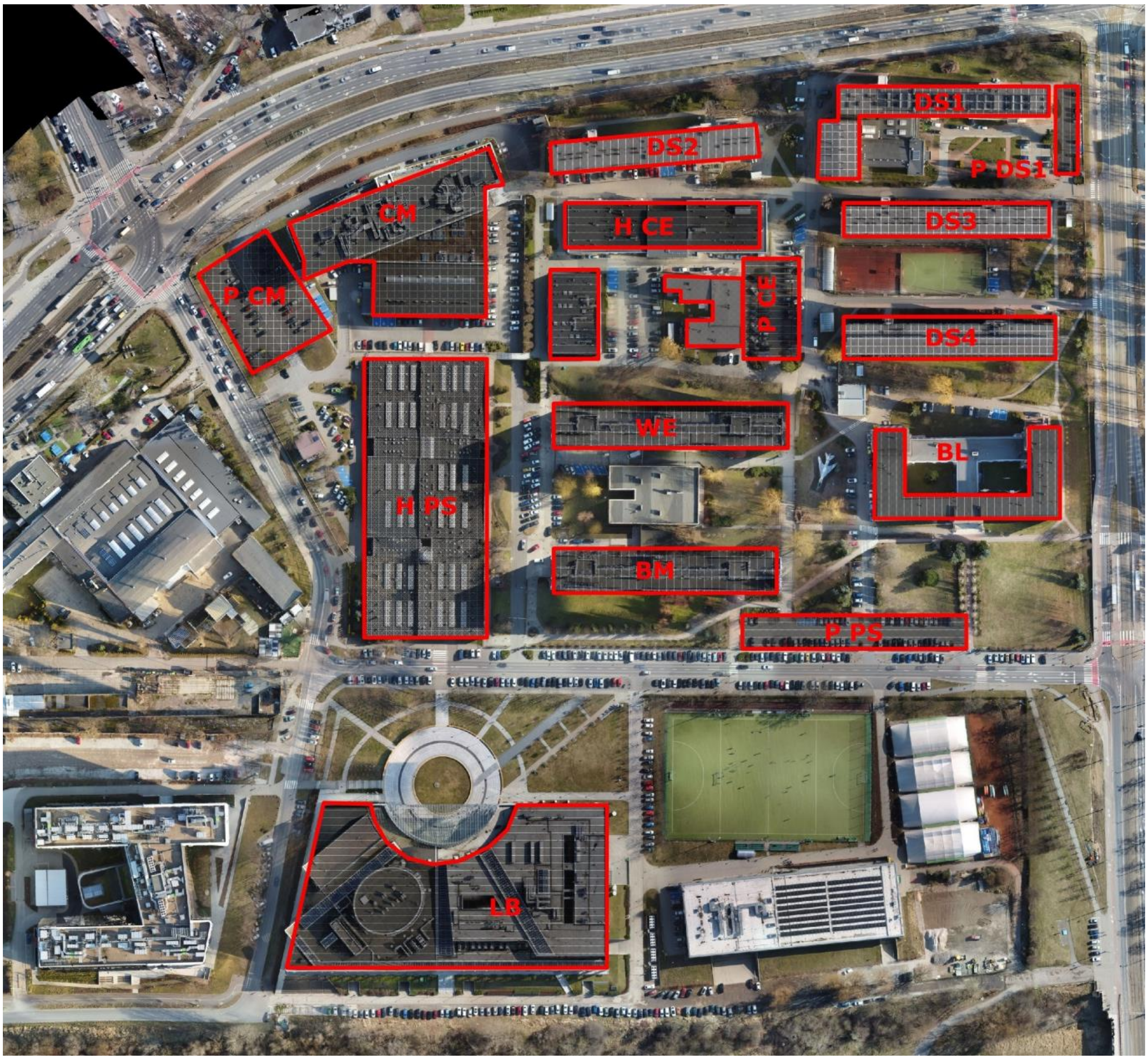


Figure 36 - PV plant possible locations on Campus map

The calculations and constructions and panel configuration optimization were performed in PVSol Premium software. Real 15-minutes period long data of electricity demand for each building comes from Siemens Sentron Power Manager.

Table 6 - PV configuration for the whole campus

Parameter	Unit	DS1-DS6	Campus excl. DS1-DS6	Total
PV plant power	kW	275.4	1 056.3	1 331.7
Specific PV production	kWh/kWp	989.0	1 009.0	1 005.0
PV production	kWh/a	272 239.0	1 065 485.0	1 337 724.0
Self-consumption	kNA/h/a	163 499.0	846 762.0	1 010 261.0
PV export to the grid	kWh/a	108 740.0	218 723.0	327 463.0
Share of PV in self-consumption	%	60.1	79.5	75.5
Object consumption	kWh/a	530 010.0	7 287 569.0	7 817 579.0
Inverter consumption	kWh/a	132.0	467.0	599.0
Total object consumption	kWh/a	530 142.0	7 288 036.0	7 818 178.0
Covered by PV	kWh/a	163 499.0	846 762.0	1 010 261.0
Covered by DSO	kWh/a	366 643.0	6 441 274.0	6 807 917.0
Self-sufficiency	%	30.8	11.6	12.9
CO_2 emission avoided	kg/a	197 019.0	771 091.0	968 111.0

Currently 350 kWp are installed on the campus. The proposal is to install 1 332 kWp on the rest of the campus buildings roof, façades and carports on parking lots. It would result in annual production of 1 337 724 kWh/a. The avoided CO_2 emission coefficient in Poland is 0.724 kg CO_2/kWh which stands for 968.1 tons of avoided CO_2 annually thanks to proposed plant operation. More than 75% share of PV in self-consumption is expected.

The installation cost is assumed to be 1 200-1 500 €/kWp. In case of façade systems or PV integrated blinds it could rise up to 2 000-3 000 €/kWp. The total price of the system is assumed to be 1 135 000 €, specific is 853 €/kWh (quite low price due to large volume on investment). Due to increase of energy price during last quarter of 2020 to 250 €/MWh it could result in 334 500 €/annual savings and the return-of-investment period of less than 3.5 years.

Table 7 - Campus peak, night and contracted power (DSO)

object \ kW	peak	night	order
DS1-DS6	368	102	506
Campus excluded DS1-DS6	1 995	745	2 550
total	2 363	847	3 056

Considering the entire installation (existing 350 kWp and 1332 kWp the one to be installed) the annual PV production would be 1695 MWh and compared to total consumption of the campus ~11 000 MWh/a it would rise the RES share from current 3.25% up to 15.41% resulting in 1 226 tons of avoided CO_2 emission.

Energy storage

Currently, only 350 kWp of solar panels are installed on the campus. The campus peak power is 2.4 MW, and the idle (minimum standby) power demand is 0.85 MW. This is the power demand at night, with no PV production parallelly. During the day, with solar radiation raising the PV production power will rise above 0.85 MW, but parallelly the power demand of campus also increases. As a result, 100% of the energy generated in the photovoltaic power plant is used for self-consumption and this will continue until the PV installation power more than 1 MWp. As they continue to grow, energy storage systems must be installed to store energy. In the case of a campus, an energy storage with capacity for only one day is needed due to high campus energy demand, even at night, and the limited power of the PV plant, lower than peak power demand of the campus.

Photovoltaics (PV) Kakolewo Airfield

Within a dense urban area at least equalization of annual solar production and electricity consumption is technically not feasible. Electricity storage can improve the efficiency of electricity auto consumption, but it is still economically not viable.

Figure 37 - Cochin Airport (left https://cial.aero) and Neuhardenberg Airfield, Brandenburgia, 147 MWp (right) http://www.airportpark-berlin-neuhardenberg.de)

As an RENergetic idea the concept of satellite PV power plant was introduced, a Kakolewo Airfield as a satellite for Warta Campus. It was concluded, that for such dense urban area as Warta Campus we can assume that the satellite and the campus form an independent energy island. Kakolewo airfield potential will be described in the chapter. PUT and PSNC both have the investment areas at the airport in Kąkolewo.

Currently 350 kWp are installed on the campus and it generates 357 627 kWh annually. With additional 1 332 kWp PV plant campus production can be 1 337 724 kWh/a. In total campus PV production may estimate 1 695 351 kWh/a.

Remote production of electricity in a PV power plant, from economic point of view, must take into account the DSO transmission fee as well as the fact of the different prices of energy exported and imported from the power grid. In the case of prosumers, this difference is 20% or 30% depending on the size of the installation. Due to the lack of a sufficient number of pumped-storage power plants, the power grid cannot be treated as an unlimited energy storage each time, and as the number of photovoltaic installations increases, the problem of overproduction and energy storage in periods of high solar radiation will increase.

Nevertheless, from the environmental point of view to reset carbon footprint, it is correct, in the case of zero-energy objective, to achieve the same level of annual production as consumption.

Campus energy consumption is approximately 11 000 000 kWh/a. In the case of postulated change of Campus heat sources to GSHP an additional 3 000 000 kWh/a must be taken into account. With average 1 000 kWh/kWp coefficient 14 MWp PV plant for Campus purposes is needed, 1.5 MWp on-site and 13.5 MWp on Kakolewo Airfield.

Figure 38 - Kakolewo Airfield with Poznan University of Technology construction site

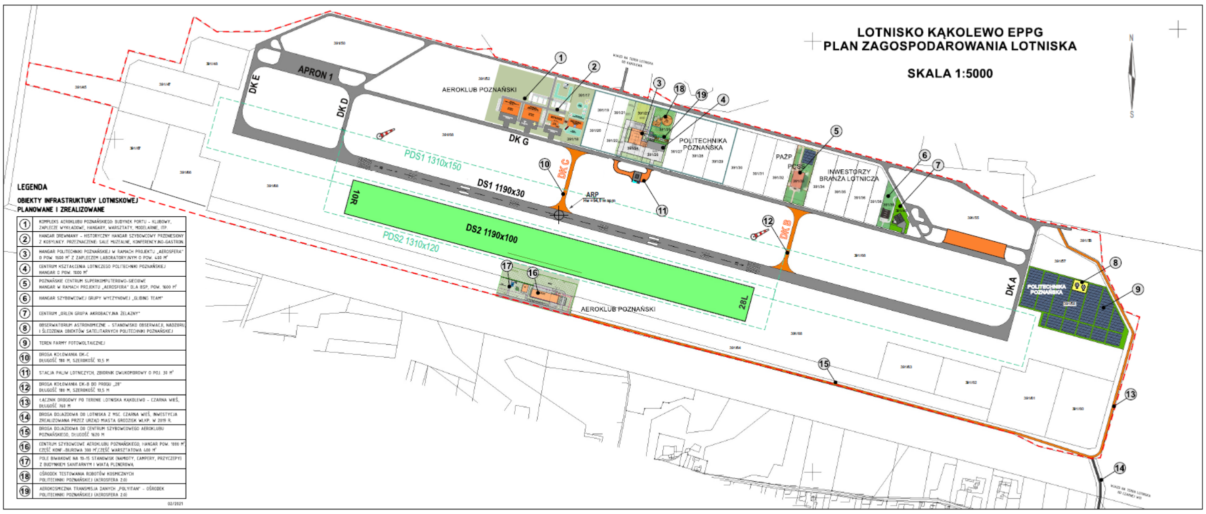


Figure 39 - Kakolewo Airfield land development plan

The Local Development Plan (MPZP) provides 33 hectares for the photovoltaic plant on Kąkolewo Airfield. The average terrain demand for the ground-based installation is 1.4÷1.7 ha/MWp with 900÷980 MWh/MWp. 22 MWp fulfills with excess 13.5 MWp PUT need. With average price of 647 €/kWp it would result with 8 092 100 € for PUT 13.5 MWp plant. Additionally, the cost of locating the Main Power Collection Station should be anticipated.

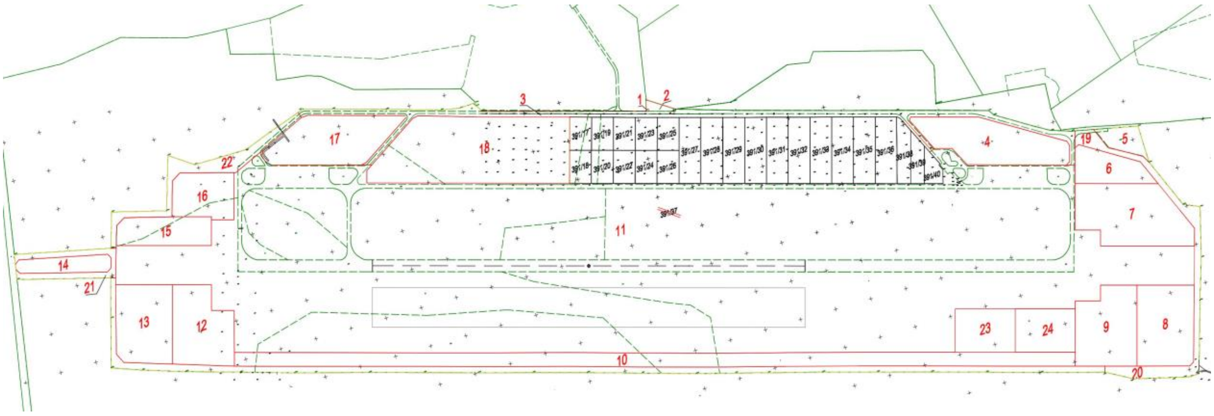


Figure 40 - Kakolewo Airfield PV dedicated 33 ha fields (red colour)

PUT and PCSS have been promised subsidy money and applied to the distribution network operator (DSO Enea Operator) for Connection Conditions (WP) for 2x1 MWp plant each. PUT also applied for Connection Condition for 2x 8 MWp plant. Connection Conditions for 2x 1 MWp plants were issued. Civil aviation administration and environmental approvals were granted, and the tender design is under development.

The problem for the large PV plant in Kąkolewo is the small connection capacity within the existing power grid. Therefore, larger PV plants will require a separate power cable from the remote Main Power Supply Station (GPZ) in Grodzisk Wlkp.

PV connection to the grid study has been performed. Five 3x YHAKXS 1x500/50 mm² 15 kV power cable possible ways were designed. Each 8 MW power should use separate cable.

Table 8 - Five power cable possible ways from GPZ to Kakolewo

	total	developed	undeveloped	forest	private
[-]	[m]	[m]	[m]	[m]	[m]
I	**8350**	830	6120	1400	0
II	**6560**	830	3620	2110	0
III	**7410**	830	2210	3635	735
IV	**6930**	830	1150	3625	1325
V	**7240**	1500	5610	130	0

Variant II, the shortest way and out of private terrains was selected.

The cost of the power cable is estimated as:

- 1x 8MW - 1.53 mln €
- 2x 8MW - 2.78 mln €

PV business model study has been also performed. Three legal options for use Kąkolewo PV plant were proposed:

- RES auction participation,
- energy sale through PPA (Power Purchase Agreement)
- energy sale through a commercial company or other entity to PUT/PSNC

RES auction participation gives 15-year contract guarantee and is the safest form of earning income. The daily-hourly profile of the PV plant has no influence on the contract, important is only the volume of annually PV plant production. Income is about half the cost of the electricity from the grid. The initial price is indexed according to inflation rate.

Sale energy through PPA (Power Purchase Agreement) is indexed to the current market price or may be - unlikely - also fixed price. Although there are contracts guaranteed for 25 years in the world, in Poland one can count on a contract of 3-7 years

To sale production to PUT/PSNC a commercial licensed company (licensed to operate energy transfer) should be established. Generally, it is profitable with PV plant larger than 10MWp or if production is sale to larger number of entities.

As the installed capacity in unstable RES sources increases, there will be more and more volatility on the SPOT market. In order to take advantage of the volatility of energy prices, it may be advisable to build an energy storage that will allow energy to be stored and returned to the grid during the period of the highest prices. Magazines are irrelevant for RES auction participation, where important is only the volume of annually PV plant production.

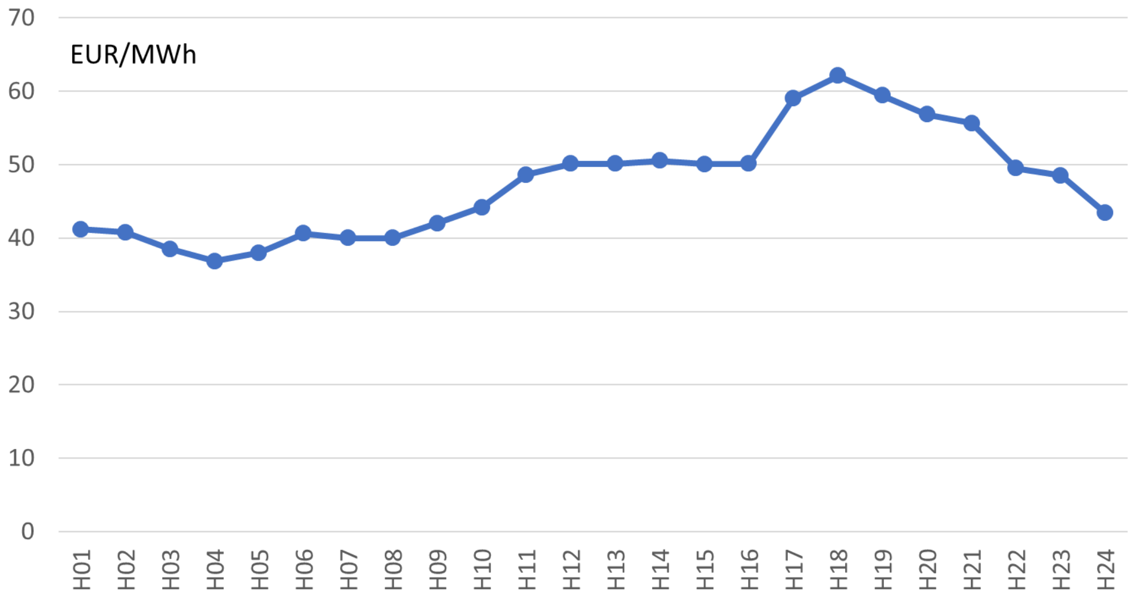


Figure 41 - Hourly prices [€/MWh] for an exemplary day in 2020

Ground source heat pumps (GSHP)

Shallow geothermal energy is used on the Campus in the form of 125 vertical boreholes heat exchanger ground source for heat pumps (GSHP), 170-200 m deep each, in total 22 km length and power of 920 kW.

Three buildings are equipped with heat pumps installed:

- CH - Chemistry Faculty building
- GH - Gym Hall
- WA - Architecture Faculty building

Two reversible brine-water compressor-type heat pumps are installed in the CH building. The ground source consists of 51 vertical borehole heat exchangers with a depth of 170 m each. The heating power of the pumps is 358 kW, the cooling power is 300 kW. The pumps are also used for passive cooling. The annual production of heat is 4 680 GJ.

CH building is supplied from two heat sources: DHS and GSHP. 1 500 kW DHS substation and 358 kW GSHP were designed and built in. Due to the difference in heat cost (8 €/GJ from GSHP and 16 €/GJ from DHS) heating system works with GSHP priority which results in share of heat production: 80% from GSHP and 20% from DHS.

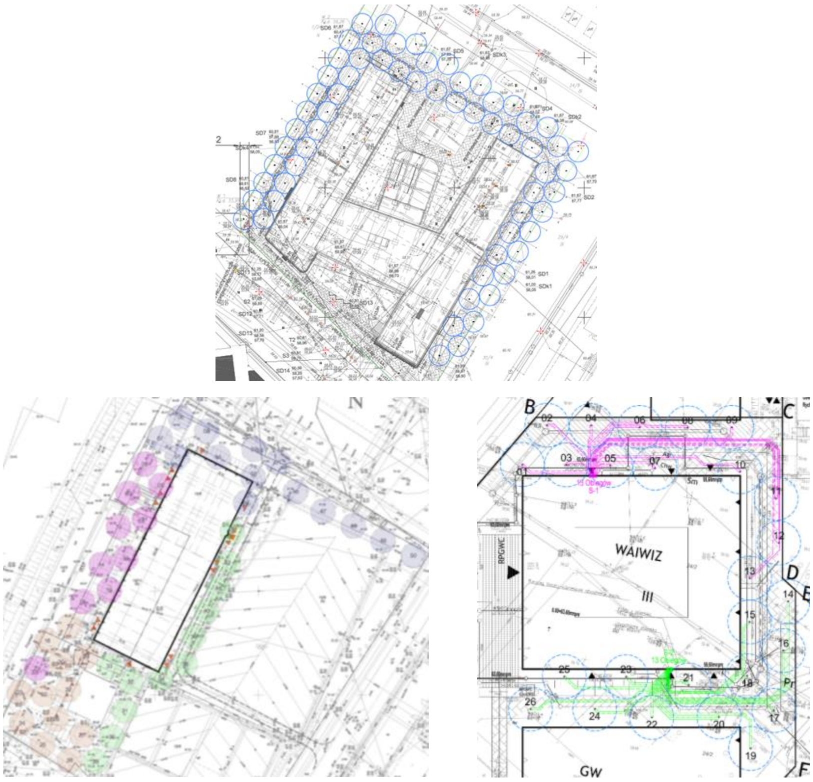


Figure 42 - CH/GH/WA building ground source for HP with (51/48/26) borehole heat exchangers 170-200 m deep plan

In the Gym Hall (GH) building three brine-water compressor-type heat pumps are installed, two reversible ones with a capacity of 120 kW each and one working only for heating with a capacity of 54 kW. Additionally, it is possible to use those heat pumps for passive cooling. Reversible heat pumps have an output for DHW preparation. The ground source for heat pumps consists of 48 borehole heat exchangers with a depth of 170 m. The total heating power of the installed heat pumps is 294 kW, the cooling power is 260 kW. The annual production is 744 GJ for heating and 858 GJ for cooling.

Architecture Faculty building (WA) is equipped with three brine-water compressor-type heat pumps for space heating and cooling, power of 72 kW for heating and 64 kW for cooling each, in total 216 kW heating and 192 kW cooling. The ground source for HP is 26 double-U vertical borehole heat exchangers with a depth of 200 m each.

For DHW preparation 5 small water-water 10 kW heating power heat pumps are installed. The lower source of heat is heating circuit with supply/return temperatures of 25/20°C supplied from main GSHP. COP is 4.95.

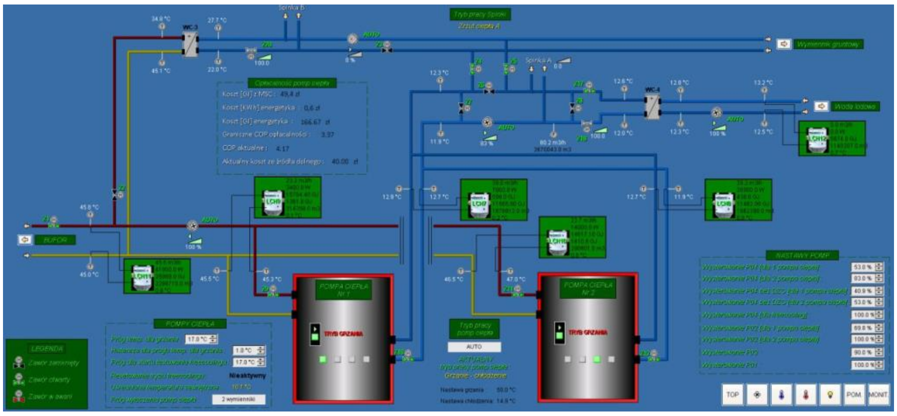


Figure 43 - Heat pumps in WA building in Siemens Desigo BMS SCADA

Further investments in vertical borehole heat exchangers ground source were performed. The following technical solutions are provided, analogous to those currently used, in line with the methodology of vertical drilling generally accepted in the world:

- closed-loop vertical borehole in series
- plastic pipe PE-Xa DN40 (100 years lifetime guarantee)
- conduction coefficient of the borehole filling material higher than 2 W/(mK)
- borehole technology according to German VDI 4640
- supply temperature higher than 0°C
- temperature difference of 3-4K for heat pump
- no visible reduction in the efficiency of the source over a period of 20 years (regeneration in summer by extraction of heat from cooling systems in buildings) confirmed by Earth Energy Designer (EED) software calculations

Based on previous Thermal Response Test (TRT) conducted on Campus specific power of 40 W/m was assumed. Two variants of surface distances between boreholes (10 and 15 meters) and two variants of boreholes deep (150 and 200 meters) were analysed.

Table 9 -Ground source borehole heat exchangers potential analysis for Warta campus

Separation [m]	10		15	
Deep [m]	150	200	150	200
Number [pcs]	1 066		566	
Length [m]	159 900	213 200	84 900	113 200
Power [kW]	**6 396**	**8 528**	**3 396**	**4 528**

Figure 44 - Campus plan with 10/15m separated borehole's locations (1 066/566 boreholes)

COP was measured average 4.3 for CH (supply/temperature heating system 60/45°C, intensive exploitation of the ground heat source) while 5.3 for WA (supply/temperature heating system 32/27°C). Assuming the total heating power of the Warta Campus buildings at the level of 7.5 MW and the average COP of heat pumps at the level of 4.0, the required power of the ground heat source should be:

- approx. 5.6 MW with 100% demand coverage by heat pumps
- approx. 3.4 MW with 60% demand coverage by heat pumps

Low air temperatures, for which the heat demand exceeds 60%, occur relatively rarely, which makes it reasonable to undersize the heat pump and the ground source, which allows to reduce investment costs. An air heat pump, an electric boiler, a heat substation or a gas boiler can be used as the peak heat source, operating for a very short time during the year.

In analysis 7 variants has been taken into account based on % of heat demand covered by DHS and GSHP:

1. 100% by existing DHS substation (basic variant – current state)
2. 100% of the demand covered by brine-water GSHP
3. 100% of the demand covered by air-to-water AWHP
4. 60% of the demand covered by brine-water GSHP, 40% by the electric boiler (EB)
5. 60% of the demand covered by air-to-water HP, 40% by the electric boiler
6. 60% of the demand covered by brine-water GSHP, 40% by existing DHS substation
7. 60% of the demand covered by air-to-water HP, 40% by existing DHS substation

The following COP assumptions has been concluded:

- brine-water GSHP COP=4.5 for heating and COP=4.0 for DHW
- air-water AWHP COP=3.5 for heating and COP=3.0 for DHW

Table 10 - Operation cost for different HP variants, €/annually

Building	1	2	3	4	5	6	7
DS1	40 822	20 517	29 267	32 019	37 212	23 969	29 162
DS2	30 947	15 785	21 571	24 465	28 539	18 362	22 436
DS3	24 351	12 382	17 073	19 219	22 402	14 417	17 600
DS4	25 903	13 200	18 086	20 468	23 871	15 360	18 763
BL	38 776	18 704	29 890	29 763	34 231	22 116	26 584
BM	47 120	22 944	35 748	36 347	41 904	27 054	32 612
WE	66 689	32 281	51 105	51 281	59 033	38 130	45 882
CM	20 222	9 808	15 446	15 566	17 928	11 578	13 940
LB	58 132	27 903	45 177	44 506	51 123	33 042	39 659
CH	45 408	21 881	35 062	34 835	40 054	25 881	31 100
Total	398 371	195 405	298 425	308 468	356 296	229 909	277 737

When calculating the costs of the GSHP, the cost of the ground heat source and the heat pump itself should be taken into account. Vertical borehole with U-pipe cost is estimated as 26 €/m. In addition to vertical probes, the cost of run-up sections, which may constitute 10-20% of the length of the probes, should also be taken into account. It should also be remembered that in the case of investments in an already developed area, a significant cost component may be the cost of land reconstruction (lawns, roads, paving stones) and it could reach 21 €/m². The average terrain requirements for 100 vertical boreholes with 10 m separation is 1 hectare (10 000 m²).

Table 11 - Investment cost for different HP variants, € (GS - ground source, HP - heat pumps)

Variant	60%	40%	HP	GS	Total
1	DHS		0	0	0
2	GSHP		3 599 109	5 632 753	9 231 862
3	AWHP		5 530 339	0	5 530 339
4	GSHP	EB	2 159 466	3 379 652	5 539 117
5	AWH	EB	3 318 203	0	3 318 203
6	GSHP	DHS	2 159 466	3 379 652	5 539 117
7	AWH	DHS	3 318 203	0	3 318 203

Taking into account market prices, the payback time for the investment is several dozen years and there is no economic justification for such an action. However, in the case of public institutions, one can count on co-financing under programs related to reducing carbon dioxide emissions. In the case of co-financing at the level of approx. 80%, the return-on-investment time is reduced to less than 10 years, which is an economically justified solution in the case of large systems.

As described before, the campus heating power within DHS substations is 7.5 MW and the annual heat consumption is 42 182 GJ. With COP at the level of 4.0 the ground source heat exchanger should be 5.6 MWh and the compressor power (electricity) 1.13 MWe. The annual electricity consumption to drive the HP would be 2 930 MWh and to equalize production and consumption annually 3 MWp PV plant would be required.

Data centre excess heat (PSNC)

Originally CH-WA water loop was planned to be built within RENergetic framework. As the cost of the water loop was classified as long depreciation a decision was made to give up the investment. In place of it the analytical and simulation study based on data from PSNC data center and PUT buildings energy demand is to be made. The measurement of the PSNC data center and PUT heating power work parameters were conducted. The heat meters have been identified that should be replaced or built in the facilities. Accurate measurements and simulations are planned for the next stages of the project.

III.9 Timeline

All the following dates and the feasibility of the tasks depend on the approval of changes in RENergetic budget.

Table 12 - List of planned tasks

Activities	Date
Finalizing data aquisition from DC (including IT monitoring systems)	End of 2022
PSNC 50kWp PV on the roof	End of 2022
Experiment with DSR triggerd by Veolia	Winter 2022
Experiment with students in dormitory	Until the end of Q1 2023
Data from PUT Siemens Desigo and Schneider	2022/2023
New supercomputers delivery	2022/2023
Prediction models of DC	In 2023
PSNC Kąkolewo 1MWp PV	2023/2024
Replacement of heat meters for better resolution	2022/2023

IV. DATA

IV.1 Data acquisition systems

Access to detailed and up to date data is essential to enable proper management of the energy island and to develop useful platform which is the goal of WP3. On the other hand, various BMS and other energy-related systems may have different ways of accessing data, data formats and semantics, and security constraints. Hence, to enable integration of the pilot specific systems with RENergetic platform the work on data collection and preprocessing was performed within the Poznan pilot.

IV.1.1 Data acquisition at PSNC

The architecture of our data acquisition system is shown in the diagram below.

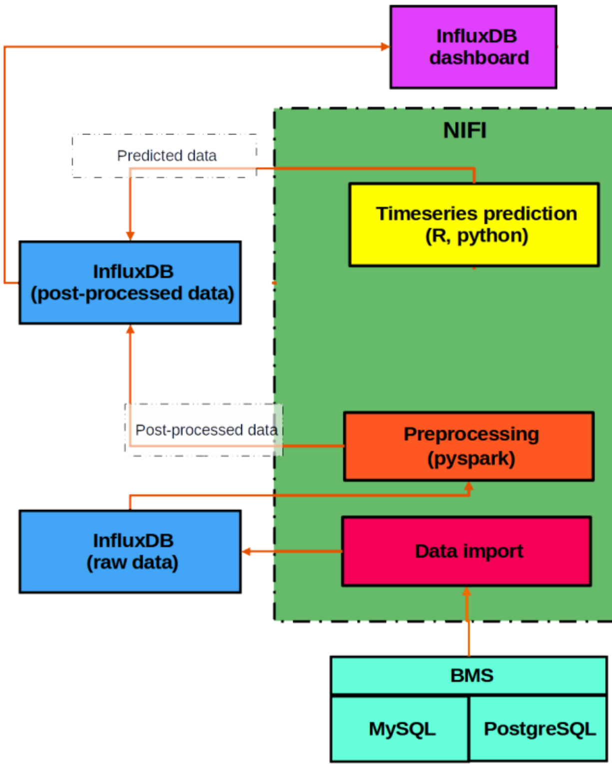


Figure 45 - Architecture of our data acquisition system

Data from PSNC BMS is stored in 2 databases: PostgreSQL (measurements from rooms) and MySQL (supercomputers data). We needed to get access to BMS server and download this data to our virtual machine. There we created a data lake, where we keep a copy of BMS data. For this purpose, we used Influx DB, which is a database, designed for effective storing and querying time series data.

To import data to our data lake, we used Apache NiFi, which is a tool for management of automated data flow from one system to another and which can also be used to schedule processes. We created a flow, which queries BMS databases, transforms data to required format and writes it to Influx DB. This process is scheduled to run once per hour. In first version, both BMS databases were queried directly from Apache Nifi, but it resulted in high BMS server load. Now, this data is first aggregated into one table in another MySQL database on BMS server and from there is imported by Apache Nifi.

After getting access to raw data, we needed to determine its meaning and a way of calculating useful information from it. Based on this knowledge, we created pre-processing script, which transforms raw data into data used for further analysis. For this purpose, we used Apache Spark – framework for large-scale data processing. This script is scheduled using Apache NiFi to run once per hour. To process data from one hour, it is enough to launch Spark on only one machine, but it can also be used in a cluster in case of the future need for processing larger amounts of data.

Pre-processing consists of the following steps:

- reading data from InfluxDB
- aggregation of several time series into one in order to get energy consumption values and other useful information
- calculation of power consumption based on the difference between subsequent energy meters values
- filtering incorrect values out
- interpolation of missing data in order to keep values equally spaced in time
- writing data to destination database

To fill in the missing power consumption data, various interpolation methods were tested. At the beginning, linear interpolation was used, but it resulted in inaccurate values in larger data gaps. In the current system version, smaller gaps are filled with spline interpolation and longer gaps are filled using values from before given period (week or day) with noise added to them. More details on this process are given in Section IV.2.

Pre-processed data is stored in another Influx DB database. At the moment, it keeps time series mainly related to energy and power consumption in PSNC. This data is used to generate predictions of future values, which are also saved to this database. It is done using R scripts. Influx DB also enables creation of dashboards, which visualize predicted and actual time series.

Data other than time series is stored in PostgreSQL database. It includes user data, metadata and some statistics.

The future plans for system development are related to:

- integration with machine learning platform to generate predictions using AI models
- implementation of anomaly detection
- integration with other visualization tools
- creating API for accessing data from databases
- loading data from other sources into data lake
- further pre-processing of raw data

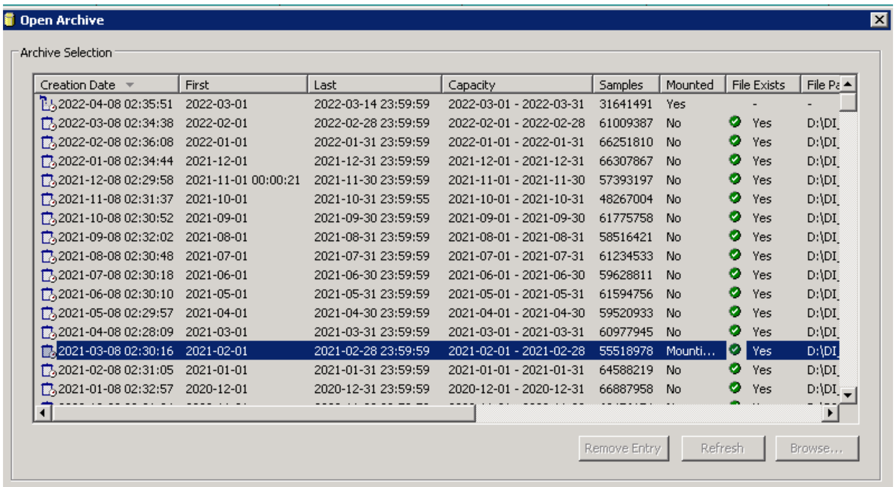
The development of the data acquisition platform and tools is synchronized with WP3 development, which includes a design of common data model and interfaces for communication between pilot systems and RENergetic components.

IV.1.2 Data acquisition at PUT

Two Building Management Systems (BMS - Desigo by Siemens and EcoStruxure Building Operation by Schneider) are implemented at PUT. These systems are mainly used to maintain the proper operation of buildings' systems. However, because they operate on the campus, they are equipped with much larger number of sensors and heat meters than is standard.

Currently, the process of downloading data from the BMS is manual and takes a lot of time. Due to safety reasons creating scripts and software to automatically download the data is not allowed.

Figure 46 - Floor plan SCADA in Desigo Insight



Creation Date	First	Last	Capacity	Samples	Mounted	File Exists	File Pa
2022-04-08 02:35:51	2022-03-01	2022-03-14 23:59:59	2022-03-01 - 2022-03-31	31641491	Yes	-	-
2022-03-08 02:34:38	2022-02-01	2022-02-28 23:59:59	2022-02-01 - 2022-02-28	61009387	No	Yes	D:\DI_
2022-02-08 02:36:08	2022-01-01	2022-01-31 23:59:59	2022-01-01 - 2022-01-31	66251810	No	Yes	D:\DI_
2022-01-08 02:34:44	2021-12-01	2021-12-31 23:59:59	2021-12-01 - 2021-12-31	66307867	No	Yes	D:\DI_
2021-12-08 02:29:58	2021-11-01 00:00:21	2021-11-30 23:59:59	2021-11-01 - 2021-11-30	57393197	No	Yes	D:\DI_
2021-11-08 02:31:37	2021-10-01	2021-10-31 23:59:55	2021-10-01 - 2021-10-31	48267004	No	Yes	D:\DI_
2021-10-08 02:30:52	2021-09-01	2021-09-30 23:59:59	2021-09-01 - 2021-09-30	61775758	No	Yes	D:\DI_
2021-09-08 02:32:02	2021-08-01	2021-08-31 23:59:59	2021-08-01 - 2021-08-31	58516421	No	Yes	D:\DI_
2021-08-08 02:30:48	2021-07-01	2021-07-31 23:59:59	2021-07-01 - 2021-07-31	61234533	No	Yes	D:\DI_
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2021-02-08 02:31:05	2021-01-01	2021-01-31 23:59:59	2021-01-01 - 2021-01-31	64588219	No	Yes	D:\DI_
2021-01-08 02:32:57	2020-12-01	2020-12-31 23:59:59	2020-12-01 - 2020-12-31	66887958	No	Yes	D:\DI_

Figure 47 - Data archive view in Desigo Insight

Typical benchmarking BMS analysis is based on monthly or annual data, where resolution of heat meters reading does not play a significant role. As a result of requirement of using hourly data it was concluded that resolution of the heat power and consumption measurements should be increased. 78 heat meters are used for the analysis in a basic way. It is problem with data resolution from heat meters on PUT. Most of the heat meters have the resolution of 1GJ or 0.1GJ, what can be still considered sufficient with the old buildings, which consume more heat and low-resolution meters are not a problem. New buildings with better heat insulation and HVAC systems use less heat and resolution becomes a problem, especially with hourly analysis. A thorough inventory of all heat meters at PUT with manufacturer has been performed. It turned out that most of the older models are to be replaced, while those installed in new buildings are fit enough to be reprogrammed. A public tender is required to select a contractor for the work.

IV.2 Preliminary data analysis

The primary goal of the data analysis was to characterise the available data in the context of forecasting. This includes determining features such as variability, seasonality and predictability. In addition, potential imperfections in the data were investigated, including outliers and missing values. This was mainly so as to design the pre-processing procedure that unifies the data while preserving its properties. Afterwards, the available time series were passed through a basic forecasting procedure to identify the best candidate for the development of forecasting tools.

Raw energetic data of interest consists of energy readings from multiple meters across PSNC. These can be aggregated into three general measurements – representing energy consumption of the offices, HVAC systems, and the data centre. Ideally, the measurements are made of accumulated energy values, which are taken every 5 minutes. Realistically, however, many entries are omitted, so the actual interval between them usually oscillates between 10 and 15 minutes. Furthermore, the whole system can occasionally be taken offline for prolonged periods of time that can reach up to several days. As a result, pre-processing is needed to make up for the erroneous data by interpolation and conversion into a more transparent form.

Interpolation can be done in two ways:

- Spline interpolation – small gaps can be inferred by simple polynomial extensions
- Value repetition – larger gaps are filled with existing past values to preserve seasonality

The above methods are executed on the data to ascertain that all values are present. This facilitates converting energy to average power – the difference between consecutive data points constitutes the total energy consumed over 5 minutes (in kJ), and the average power in kW can be simply computed by dividing over that time interval. As a result, a time series of power figures is acquired, which is more interpretable than raw energies, and thus, better fit for forecasting. In addition, the granularity of the data can be easily decreased with windowed functions. E.g., for the purpose of forecasting it is most convenient to use hourly figures, since they work well with seasonal models. Finally, there may still be outliers in the transformed data, so it is essential to identify them – mainly power entries below zero or above the attainable energy supply. These are rare and can be erased and replaced with interpolated values.

After pre-processing, the analysis focuses on the three aggregated time series – average power consumption of the data centre, HVAC systems and the offices. Each of these has different characteristics, and therefore, requires a distinct forecasting strategy. An example plot of power consumption values in July 2021 is presented below.

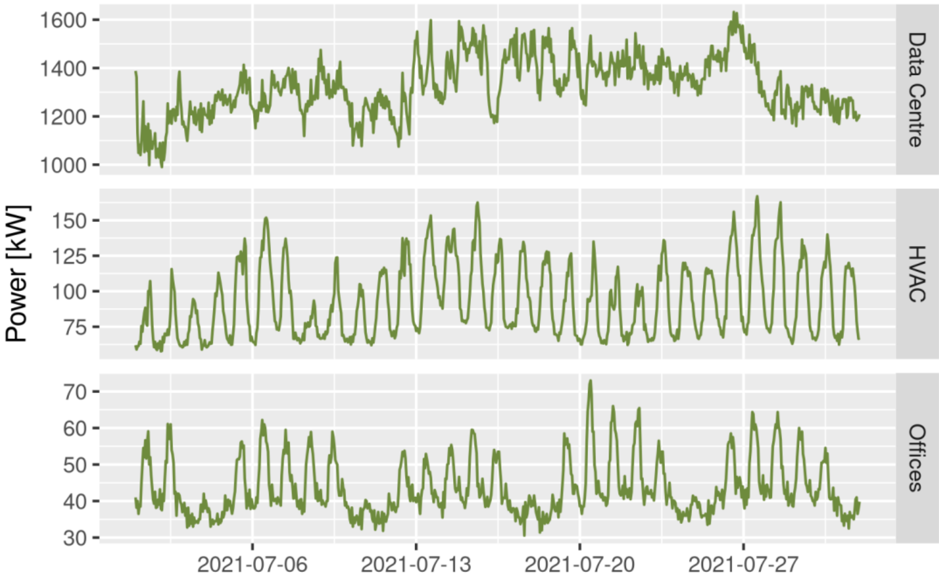

Figure 48 -

A few basic properties can immediately be deduced – the data centre has the highest overall consumption with large variations, while the offices consume the least, with smaller variability. The summary statistics of the whole dataset look as follows:

Table 13 -

Source	Mean	St. Dev.	Min	Max
Data Centre	884.0 kW	236.0 kW	438.0 kW	1 670 kW
HVAC	90.7 kW	23.5 kW	37.0 kW	255 kW
Offices	47.1 kW	15.6 kW	22.7 kW	330 kW

Lastly, it is important to notice how the seasonality differs in each of the time series. The data centre is very irregular, without any discernible patterns. In principle, this restricts the forecasting models that could fit the data well to the most basic approaches, such as mean value repetition. On the other hand, the HVAC time series has clear regular daily seasonality, with only the variations changing from day to day. Meanwhile, power consumption of the offices lies somewhere in between – it does have a noticeable seasonality, but it is more complex, featuring both daily and weekly patterns. As a result, more elaborate models are required to fit it accurately, but such models should be realisable.

When constructing a forecasting framework, it is a good practice to focus on one set of data only, for the sake of repeatability and comparability. The chosen dataset ought to be the most representative of other data, so that it is straightforward to ultimately extend the designed methodology. Hence, the time series of average hourly power consumption in the offices was deemed most suitable – it requires involved methods that can be simplified or modified when forecasting a different set of values. For example, complex seasonality can be initially modelled with a Fourier series (a collection of wave-like patterns). This series is then passed into the forecasting function as an external (exogenous) variable, and the forecasts are made on the deviations from the series (residuals). Here, the exogenous variable was derived directly from the data, due to information contained in the seasonality. However, when dealing with a less regular time series with fewer intrinsic properties, the exogenous series can be obtained from a distinct, but correlated source. In the case of data centre power, external data could come from the scheduler, pointing to how many processes would be active in the near future. Accordingly, an expandable predictive toolkit can be assembled around the basis dataset of office power figures.

Basic introduction to forecasting

After the training set has been agreed upon, various forecasting models can be designed, compared, and evaluated. On the fundamental level, they be classified into two general groups:

- Statistical models – a regressive approach based on computing a small number of coefficients that reflect the time series and can be used to forecast future values given some past values and possibly additional external data.
- Deep learning models – a neural network approach that constructs a large, multi-layer network of neurons, each of which is parametrised based on the training data and used to forecast future values given a vector of past values and external data.

Deep learning models have also been used in the approach. The tried and tested methods are based on recent publications. In the analysis, a prediction was made 24 hours ahead. The input to the model was data from a few weeks ago (the number of weeks was changed) of energy consumption. In addition to current data, ambient temperature data was also used. In addition, information about the day of the week, weekends and the year were artificially created and applied as historical data and as future data to add relevant information to the prediction for a given day. Neuronal models handle different input very well and generalize knowledge well - allowing such a dataset to be applied as input to the model. As it turned out later, the results were very good.

The undoubted advantage of using deep learning is the need to train the model once (although it usually takes a long time) and the ease of modelling complex seasonal dependencies (difficult to extract by classical methods). An additional advantage is the creation of prediction confidence intervals in an easy way - this allows for easy analysis of the confidence of predictions. The main disadvantage of such models is the necessity of using a very large amount of data and tuning hyperparameters.

At this point, the Data Centre data is too complex (resembles noise) and no good results were obtained. However, it is hypothesized that with the addition of additional external data (such as information from the scheduler system), the prediction can be improved.

For Power Office data, deep models performed very well in modelling values on weekends. Neural networks were able to capture both long and short dependencies. However, in some situations these models were not able to predict the current values correctly, and the confidence intervals also did not cover the actual waveforms. Nevertheless, by observing the technical metrics, it was possible to get slightly better results than the classical methods using this approach. However, depending on the use case, and the data available, both approaches can perform very well - the difference on this data was not definitely enough to clearly state which approach is significantly better.

It will be necessary to test deep models on more difficult series, but they have a positive premises. The undoubted advantage is that with their help it is possible to model several outputs in which one depends on the other - the results of the models can affect each other, which is not easy to achieve with classical methods. Also modelling with many inputs of different type can help in more accurate prediction. It seems to be a good idea to further test and compare classical approaches with deep models in the future - both approaches have many advantages and disadvantages.

V. EXPERIMENTS

V.1 Experiment 1 - Heat reuse from a data center within energy island with the district heating system

V.1.1 Context

This experiment is related to epic local waste heat optimization and heat supply optimization within Warta Campus energy island. The specificity of the data center operation allows for heat reuse process throughout the year, both during the day and at night. Therefore, the aim of the experiment is to simulate the amount of waste heat under specific assumptions. Ultimately, the system will be more accurately measured, which allows for more accurate simulations and design.

V.1.2 Objective

The main objective of this experiment is to initially simulate the potential of waste heat generation from data center taking into account the source of renewable heat as well as the PUT campus consumers or the heating network. This is the first milestone for energy and economic further simulations and analyzes within the project.

V.1.3 Implementation/Planning

At the present stage, calculations have been made with certain assumptions and estimations. After the planned purchase of additional heat metering and the development of data center models, the experiment will be further proceeded.

V.1.4 Results (if any so far)

In order to characterize the annual energy profile in 2021, the annual medium power consumption indicator was used according to the equation below:

$$P_a = \frac{1}{T_a}\int_0^{T_a} P_c(t)dt$$

where: P_a – annual medium power consumption, T_a – duration of the measuring period, P_c – power consumption at the t time.

Then, the value of annual medium power consumption of supercomputer was determined:

$$P_a = 0.97MW \approx 1MW$$

In order to determine the heat reuse potential from the data centre, first the electric power of the heat pump (HP) compressor should be determined in accordance to the equation:

$$P_c = \frac{\eta_H P_a}{COP - 1}$$

where: P_c – electric power of the heat pump compressor, η_H – heat reuse efficiency determined on the basis of measurements, COP - coefficient of pperformance of HP, depends on the inlet and outlet temperature of the heat pump.

The following equation was used to determine the heat reuse potential from supercomputers:

$$Q_a = 3.6 T_H P(\eta_H P_a + P_c)$$

where: Q_a – annual heat reuse potential from supercomputers, T_{HP} – annual heat pump operating time.

To determine emission reduction, it can further be assumed that CO_2 eq for district heating system is 74.17 t CO_2eq/GJ. It is worth noting that the final reduction of CO_2eq emissions will be influenced by the heat pump power source and the outlet and inlet temperature of the medium at the heat pump determining heat pump medium power. Due to the increasing price of electricity, the operation of a heat pump is becoming more and more expensive, which means that the process will be profitable only in the case of a large profit from the sale of waste heat or if the pump is powered by own renewable sources.

In further part of the project, it is planned to accurately measure the heat potential with the use of purchased heat meters. The simulation of process parameters and the planned creation of the data center model will allow for a detailed examination of the process in cooperation with the energy island in the further part of the project.

Average 1 MW power form PSNC result in 31 500 GJ/a. The total heat consumption of the Campus is 42 000 GJ, which result in 1.33 MW (upper source). Taking COP of 4.0 into account ($COP=106.67 \cdot \Delta t^{-0.894}$) it turns out that lower heat source of 1.0 MW and compressor of 0.33 MMW is needed. This is only a simplified assumption, but it shows that even just 1 MW of power removed from PSNC is of a similar scale to the PUT demand.

Distribution of heat production and consumption (simplified assumption) shows the possibilities of transferring excess heat to PUT campus and DHS network.

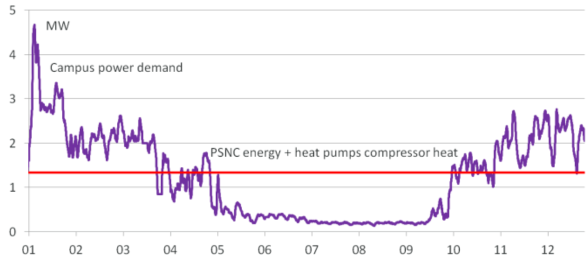

Figure 49 – 42 000 GJ/a Campus annual heat demand (violet colour) and PSNC 1 MW power + compressor

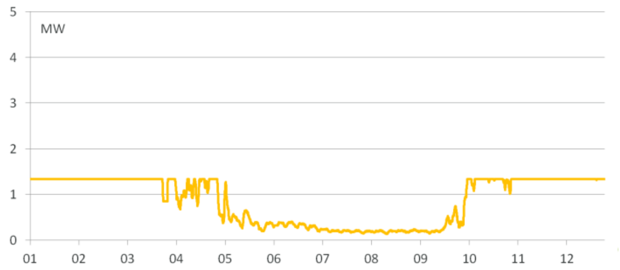

Figure 50 – 27 500 GJ/a (orange colour) to be covered annually by PSNC 1 MW power + compressor

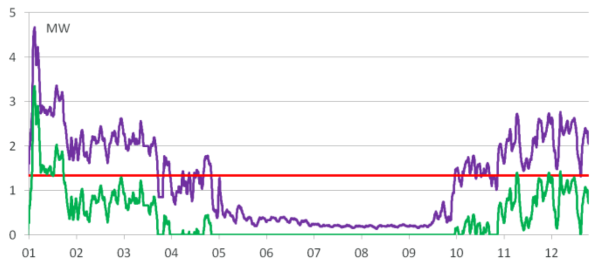

Figure 51 – 12 000 GJ/a (green colour) energy lacks for Campus heating

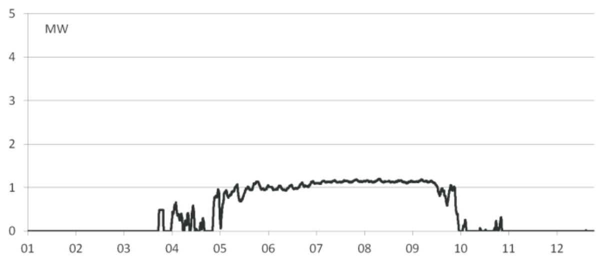

Figure 52 - 14.700 GJ/a (black colour) excess heat to supply to DHS supply

Based on simplified assumptions PSNC constant power can cover the following Campus heat demand and produce excess heat to be supplied to DHS network.

Table 14 - System potential (PSNC - constant heating power, PUT - coverage of demand, Veolia - excess heat transferred)

PSNC	PUT	Veolia
MW	%	GJ/a
1	64	12 600
2	96	38 100
3	99	74 600

As can be seen in the table above, power at the level of 2 MW at PSNC side will allow to almost fulfill PUT heat demand. Its further increase will allow to increase the volume of heat sales to Veolia district heating network.

V.2 Experiment 2 - preliminary assumptions of the heat demand response run with the district heating operator

V.2.1 Context

Demand Side Response (DSR) means a temporary reduction in power consumption by heat consumers (in this case PUT) to support the stable operation of the district heating system in order to reduce heat consumption peaks and reduce CO_2.

V.2.2 Objective

The aim of the experiment will be to check the following elements of the process:

1. Information flow between VEOLIA and PUT
2. Determination of the shortest lead time for increasing heat accumulation by PUT in its facilities
3. Determining the maximum level of heat accumulation in PUT objects and the time of their cooling down to achieve the planned minimum internal temperatures in the objects
4. Determination of the time of their reheating until the set temperature is reached
5. Determining the amount of reduction of the heat consumption peak for PUT and for the heating system
6. Determination by VEOLIA of the amount of fuel oil saved and the amount of CO_2 reduction

V.2.3 Implementation/Planning

In order to conduct the experiment, it is suggested:

1. Establish a working team composed of representatives of PUT and VEOLIA, which will include representatives of the Pilot in the RENERGETIC project and the operational services of PUT and VEOLIA
2. Signing a cooperation agreement in the field of DSR
3. Establishing the technical framework of the experiment

   It is initially proposed that the experiment should be carried out during the next heating season, i.e., 2022/2023, at different temperatures of the outside air. It is proposed, if possible, to conduct the experiment at the following external temperatures: -2^{0}C, -5^{0}C, -8^{0}C, -10^{0}C.

4. Implementation
5. Conclusions and calculations

V.2.4 Results (if any so far)

This experiment is planned to happen in the future.

V.3 Experiment 3 - Manual heat source change

V.3.1 Context

In previous years it was observed that at the end of winter in the CH building, the temperature of the heat source for HP approaches the operating limits. There are two heat sources in the building: heat pumps and municipal heat grid.

V.3.2 Objective

In order to avoid the depletion of the lower heat source for HP supplying the CH building, the heat source has been changed manually.

V.3.3 Implementation/Planning

On 02/10/2021 the following actions were taken:

- The temperature increase in the comfort mode has been removed and the temperature in the precomfort mode has been increased by 2°C
- Set temperatures in technical rooms and communication in accordance with the design (unless there was a lower setting earlier)
- The DHW temperature alarm was set to 70°C and the circulation pump was turned on for continuous operation 24h / 7 days
- Raising the CO heating curve at night by 10°C (according to the old schedule)

Additionally, the Heat Pumps and the Municipal Heat Grid was set up in the following hours:

- 15:00-6:30 manual mode only Heat Grid for 100% valve opening (Heat pumps are turned off)
- 6:30-15:00 HP in auto mode (MSC stays for 100% valve opening)

V.3.4 Results (if any so far)

The aim of the experiment was achieved. However, attention must be paid to the increase in heat consumption during its duration.

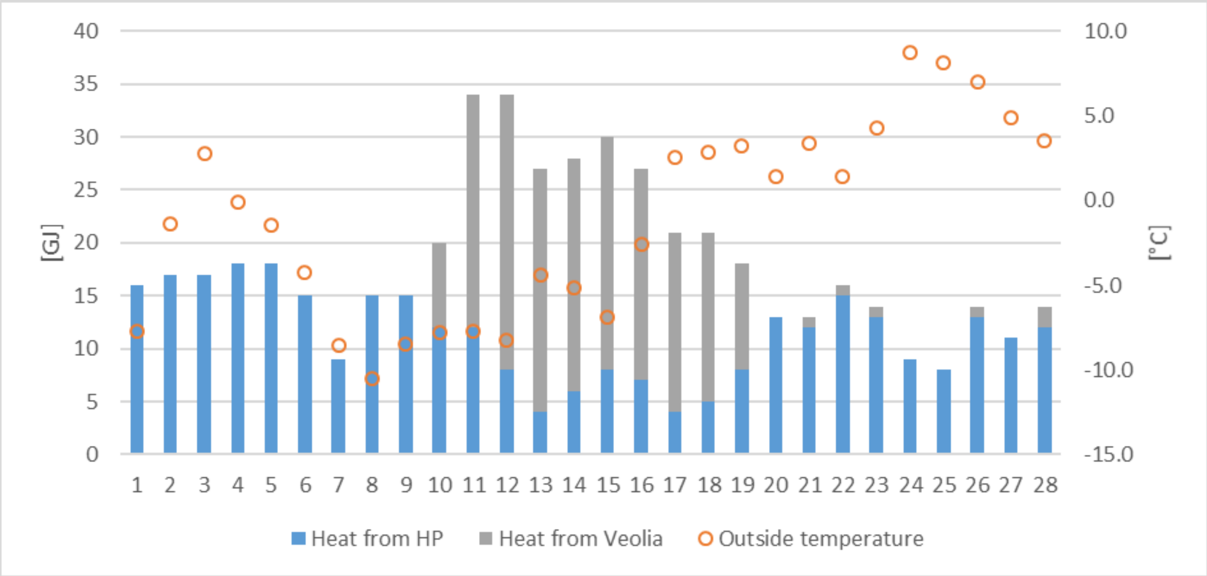

Figure 53 - Heat consumption in February 2021 including outdoor temperatures

The diagram below shows that the temperature of the heat source after February 19 has lower fluctuations and is slightly higher than that before February 10.

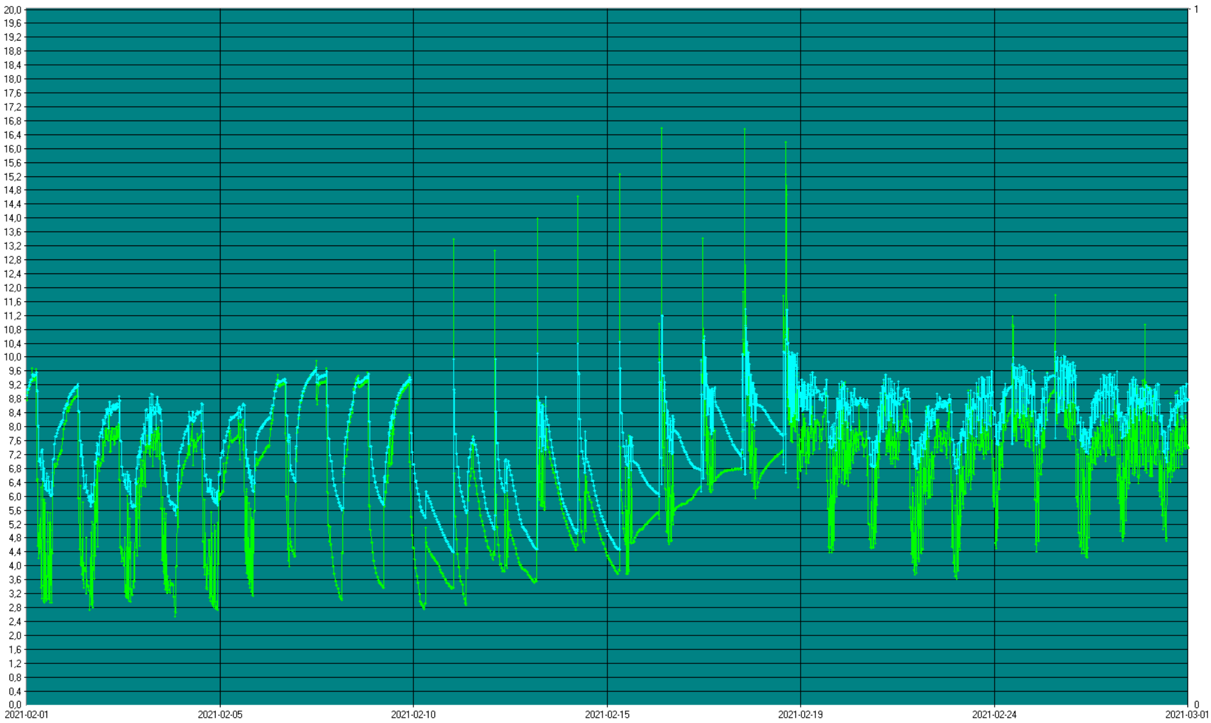

Figure 54 - Supply (blue) and return (green) temperatures for the heat source

The experiment can be repeated over a longer period and additionally collect data on the internal temperature of the building. This will allow in the future to analyse the impact of complete switching to one of the heat sources in CH for a short period of time.

V.4 Experiment 4 – WAWIZ

V.4.1 Context

In the case of the existing several years old buildings and settlements, the goal of achieving annual balance of production and electricity consumption seems to be far from practical, especially in urban centres with limited space for photovoltaics. Nevertheless, such surrounding is a good background for the demonstration of low-energy or even zero-energy solutions.

V.4.2 Objective

Single building, even nearly zero energy, without energy storage or prosumers programs deals with the fact of wasting excess energy from PV production. The aim of the experiment is to analyse and demonstrate the effect of operation of nZEB buildings in comparison to ordinary building and to demonstrate the role of settlements in self-consumption of surplus energy production.

V.4.3 Implementation/Planning

Heat and electricity meters are needed to be properly installed, with detailed resolution, for the analysed building and the rest. Trend or reports are to be precisely configured to allow to evaluate different energy flows in longer periods but also in short terms to estimate the flows in fast changing environment (i.e. solar radiation).

V.4.4 Results (if any so far)

Architecture Faculty (WA) building is in use for two years and it is connected to the DSO transformer station K-839. It is 15138 m² nZEB building with very low energy demand, efficient HVAC systems and the PV plant consisted of 666 panels which result in annual production of 200 MWh/a.

Figure 55 - Architecture Faculty building (W)

Measurement of electricity consumption during 2021 are presented in the table.

Table 15 - Measured energy for WA building

kWh	HVAC +DHW	Lighting	Total consumption	PV Production	Import from DSO	Self consumption	Export to DSO
21/03	11 481	3 745	15 226	16 731	18 366	9 586	7 145
21/04	8 689	3 418	12 107	21 575	13 635	10 343	11 232
21/05	9 174	3 478	12 652	27 201	13 093	11 337	15 864
21/06	9 802	4 368	14 170	31 204	12 635	11 680	19 524
21/07	10 256	4 672	14 928	28 192	12 903	12 757	15 435
21/08	8 745	4 494	13 239	23 104	14 733	9 468	13 636
21/09	6 626	4 831	11 457	19 203	13 302	9 375	9 828
21/10	9 758	7 280	17 038	14 872	20 586	9 336	5 536
21/11	13 528	7 551	21 079	3 840	31 280	3 253	587
21/12	19 679	6 798	26 477	1 850	38 010	1 843	7
22/01	17 738	6 601	24 339	3 670	33 472	3 549	121
22/02	13 189	5 442	18 631	9 135	24 011	6 442	2 693
Total	**138 665**	**62 678**	**201 343**	**200 577**	**246 026**	**98 969**	**101 608**

Table 16 - Energy consumption an CO2 emission for WA building

Parameter		Unit	Required	Tender design	2020	2021
Delivered energy for HVAC+DHW	EKH	kWh/(m²·a)	23.33	14.86	8.90	9.16
Delivered energy for lighting	EKL	kWh/(m²·a)	8.33	11.89	3.70	4.14
PV production	EKPV	kWh/(m²·a)		13.21	13.89	13.25
Delivered energy - total	EK	kWh/(m²·a)	31.67	13.54	-1.29	0.05
Primary energy	EP	kWh/(m²·a)	95.00	40.62	0.00	0.05
CO2 emmission	ECO_2	$kgCO_2/(m^2 \cdot a)$	16.29	9.45	0.00	0.04
Energy cost	K	€/(m²·a)	4.00	1.71	0.00	0.01

Following assumptions were considered:

- primary energy factor for electricity from the grid - 3.00
- CO_2 emission coefficient for electricity from the grid 698 kg CO_2/MWh
- electricity from the grid cost 125 €/MWh
- only heating, ventilation, air conditioning (HVAC), domestic hot water (DHW) and lighting are considered according to EPBD methodology
- no energy used by users (computers, appliances) were taken into account

WA building result has the result of 0.01 €/(m²·a) and it is incomparably less than the campus average of 5.62 €/(m²·a). Use of RES in 2021 was 99.9% as the measured COP for heat pumps were 5.3. Such perfect result was possible only thanks to the energy island which consumes all excess PV production from the WA building. Without energy island and electricity storage excess production would have to be sold to the grid with loss.

V.5 Experiment 5 - Regulation of heating in selected rooms of the building without a BMS system with the use of wireless thermostatic heads

V.5.1 Context

The subject of this experiment is to analyse the operation of wireless radiator thermostatic heads, used in order to achieve savings on energy necessary for heating buildings. The introduction of top-down temperature settings in rooms and the ability to set heating work schedules in individual rooms will allow for a much more efficient control of the central heating system in the buildings tested.

V.5.2 Objective

Reduction of heat consumption in buildings without a full BMS system without large investment costs. Expanding a BMS system is very costly. It requires the distribution of new cables, which is associated with a major renovation.

V.5.3 Implementation/Planning

The buildings of the Faculty of Mechanical Engineering and Management (A1) and the Faculty of Electrical Engineering (A3) were selected for the implementation of this task, because they currently have the highest ordered heat power, which translates into the highest heating costs on the entire Campus of the Poznań University of Technology. In addition, these buildings are identical to each other, which allows for testing only in one of them and the solution verified in this way can be implemented in both facilities.

Figure 56 - Building of the Faculty of Electrical Engineering (A3) on the left and the Faculty of Mechanical Engineering and Management (A1) on the right

In order to verify the correct operation of the set schedules and algorithms controlling the heads, temporary measurement systems were installed in six test rooms, including air temperature sensors and presence sensors. Additionally, in the reference rooms, where the heads were not replaced, external temperature measurement was installed at the eastern and western elevations of the building.

List of measuring equipment (specification of essential parameters):

- 4 x Ahlborn Almemo 2 590 recorder (4 measuring inputs, 0.5MB internal memory),
- 8 x Jumo class 1/3 B PT100 temperature sensor (operating range -70 - 500°C)
- 6 x PIR presence detector by Bosch (12m range)
- 8 x Ahlborn PT100 test plug
- 6 x Ahlborn ± 26V voltage test plug

The measured values in the installed measuring system were:

- indoor air temperature in individual rooms [°C],
- outside air temperature on both sides of the building [°C],
- presence or absence of occupants in the premises [-].

Figure 57 - A box with a data recorder with temperature measurement and a presence sensor

Figure 58 - Room 311 in building A3 (west wing of building)

V.5.4 Results (if any so far)

Calculation of heat loss of test rooms based on heat consumption (heat meters)

In order to determine the power of the entire facility, data was collected from the BMS system for WE and WBMiZ buildings. Due to the fact that the building of the Faculty of Electrical Engineering has a heat meter independent of the ŁPP (additional building) only from the beginning of 2020, it is necessary to compare it with the neighbouring twin building during the works. By analysing the periods in 2018 (February) and 2019 (December) with the lowest outside temperatures in a given year, it was determined that the average heat power related to the calculated outside temperature of -18°C is 656 kW, in accordance with table.

Translating this into the rooms where the measurements took place, the demand is 1.51 kW for rooms 324, 325, 326 and 2.30 kW for rooms 310, 311, 312.

Table 17 - Summary of average power of WE and WBMiZ buildings

Building	Design heat load [kW]		
	2018yr	2019yr	Mean
WE (A3)	795.69	829.36	**812.53**
WBMiZ (A1)	637.61	674.70	**656.15**

Due to the fact that the Heat Node of building A3 is also connected to the ŁPP central heating and the similarity of both analyzed buildings, the heat load for the entire facility was assumed to be 656.15 kW. The conversion into individual rooms, taking into account the total area of the building equal to 14 002.1 m^2, is summarized in the table.

Table 18 - Summary of the heat load for individual analyzed rooms

Rooms	Area [m^2]	Thermal load [kW]
324, 325, 326	37.0	1.73
310, 311, 312	55.4	2.60

Measurements

Measurements that were carried out in selected rooms of the building of the Faculty of Electrical Engineering (A3) took place in the period from May 8 to June 10. At that time, the outside temperature ranged from about + 2°C to + 26°C (temporarily, due to sunlight, there were also higher temperatures). Due to the large amount of sunlight during the day and the lack of cloud cover at night, the temperature amplitude was very high.

The intense insolation from the eastern side meant that during the entire duration of the tests, the temperature in the rooms did not drop below 20°C, which made it impossible to verify the correct operation of the system and to make any analysis for these zones. On the west side, however, despite reaching the set temperature, in the afternoons, when the sun appears on this side of the building, there is a further increase in the internal temperature.

The central heating installation in buildings A1 and A3 is controlled by the BMS Siemens Desigo Insight system. The algorithms implemented in it allow the circulation pump to work only when it is necessary. The building is divided into two main circuits with separate circulation pumps (one on the east side and the other on the west side of the building). The heating period is set until May 31st each year. After this date, despite the lower outside temperatures, the circulation pumps do not start any more. Additionally, when the outside temperature exceeds 16°C, the circulation pumps are also turned off.

In addition to flow restrictions, the algorithm adjusts the supply temperature of the central heating installation to the current outdoor temperature in accordance with the heating curve below.

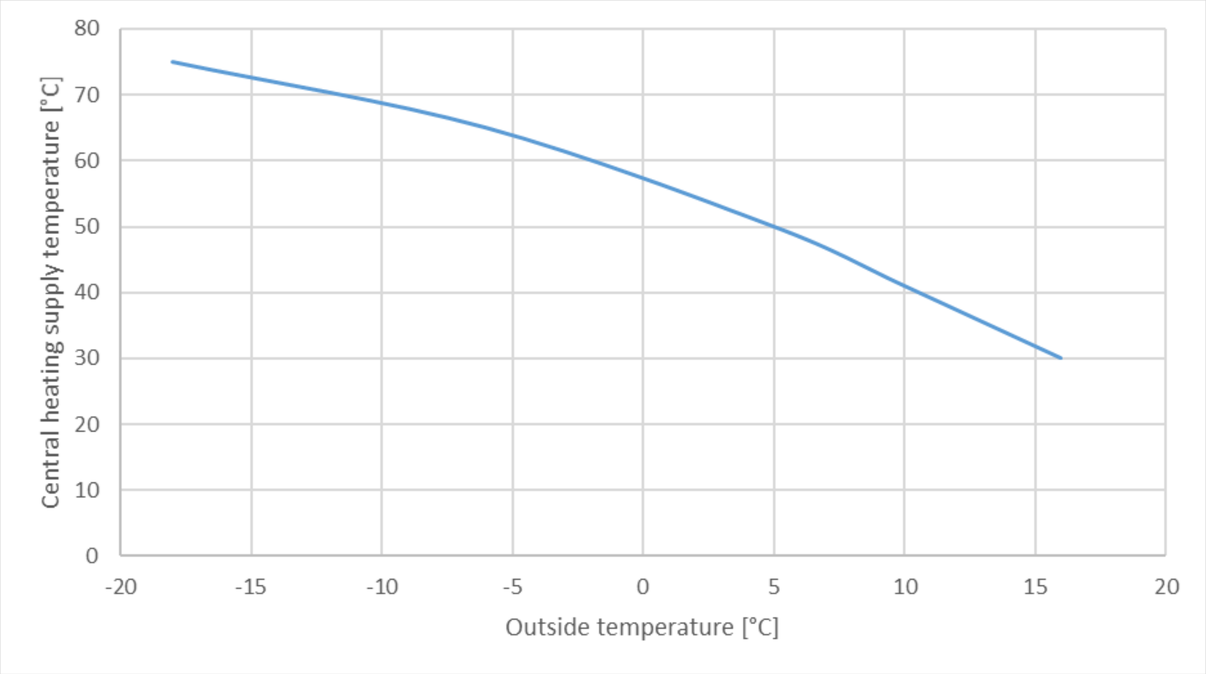

Figure 59 - EC building heating curve (A3)

In the BMS system supporting heat nodes of the Poznań University of Technology, it is also possible to operate the heating system according to time schedules. For the building in question, such a schedule has two setting levels - comfort and pre-comfort. In the first mode, the supply temperature complies with the setting from the heating curve (7:00-15:00 only on working days), while the second mode lowers this temperature by 10°C (15:00-7:00 only on working days and during whole weekend).

In the diagrams below, the lines described as TXXX (where XXX is the number of the room) are the measured air temperatures [°C] in individual rooms. Another parameter presented in the charts is the presence (or lack thereof) of users in the room. If the curve reaches zero, it means that there is no person in the room, while if the value is different from zero, there are people in the room. In addition, the graph also shows the outdoor temperature (Te [°C]) and the grey line shows the set temperature [°C] in rooms according to previously established schedules.

Symbols placed on the graphs (Figure 60, Figure 61):

T310, T311, T312, T324, T325, T326 - internal temperatures in test rooms [°C],

Te - outside air temperature [°C],

TH - set room temperature according to the established schedule [°C],

310, 311, 312, 324, 325, 326 - presence (or lack thereof) of users in the premises [-].

In the second graph (Figure 61), the timeline has been shortened to highlight the period when indoor heating was needed, and solar gains were not too high.

Analysing the first graph (Figure 60) and considering the above, it is clearly visible that the rooms on the eastern side of the building, despite the lower outside temperatures than internal temperatures, did not cool below the set comfort temperature (20°C). This state does not allow to determine whether the algorithms controlling the tested warheads are working properly.

On the other hand, in Figure 61, we can observe that Danfoss Eco performed the best among the working heads. They did not lead to overheating of the room, and the failure to maintain the temperature in the morning hours of May 31 was due to the subsequent activation of the circulation pump, caused by appropriate algorithms of the BMS system.

An important conclusion from the charts below is the need to repeat the tests and analysis in the period of lower outside temperatures and with less sunlight. It seems that the period between December and February will be the best period for such research.

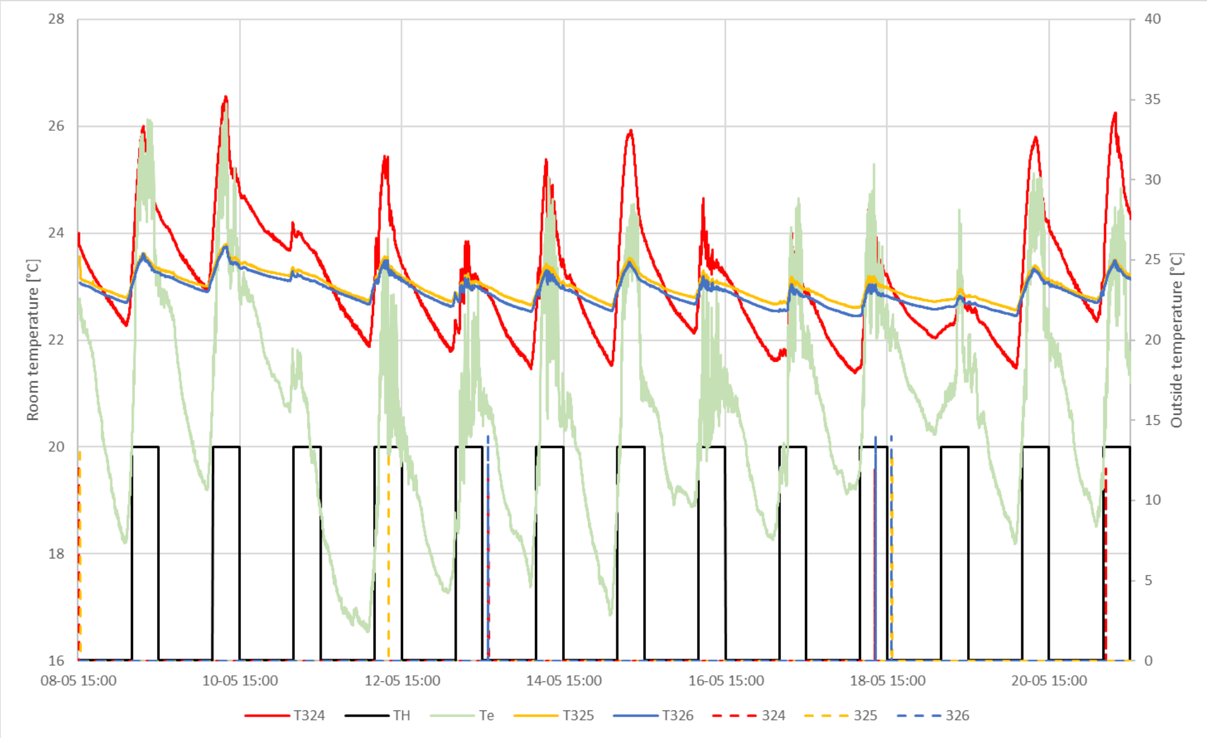

Figure 60 - Measurement data of rooms on the eastern side of the building

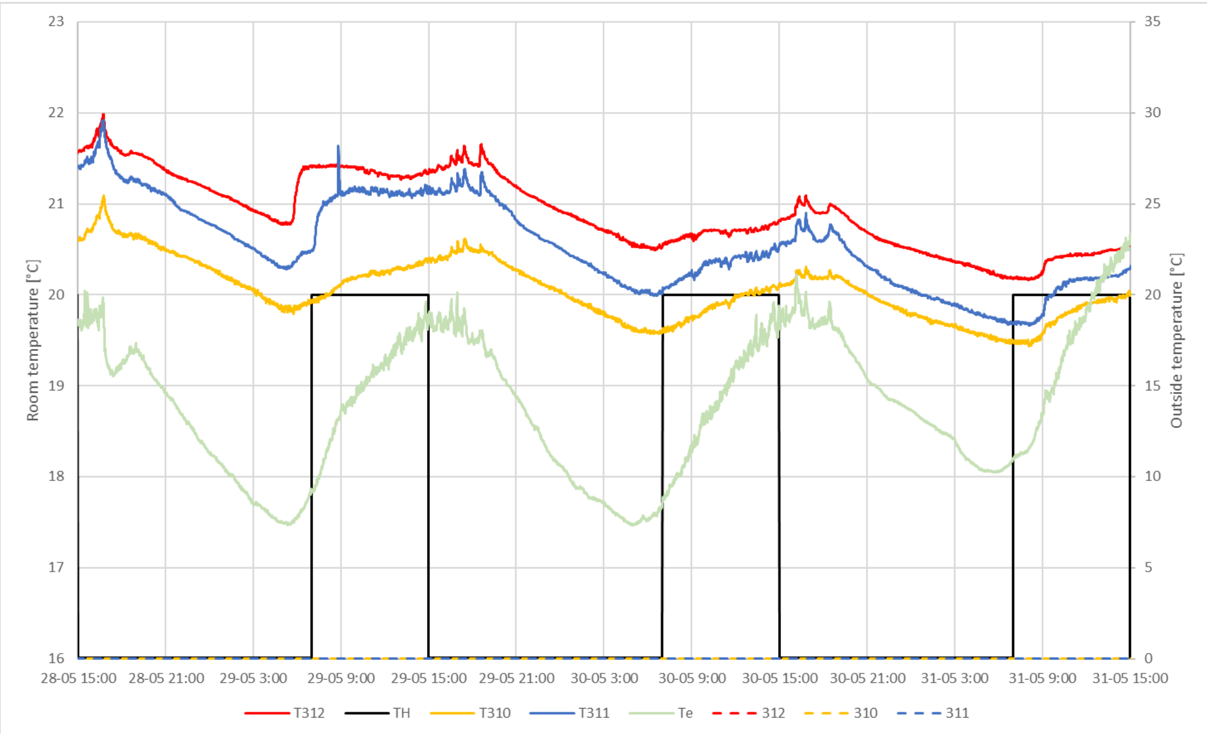

Figure 61 - Measurement data of rooms on the western side of the building

Calculations and analysis

When calculating the savings caused by the installation of the new system, the average outdoor temperatures in 2001-2010 were first downloaded from the Central Statistical Office

[5] (they are closer to the outdoor temperatures currently occurring in the world than ministerial data). Then, the degree of heating conditions appropriate for each of the months were determined in two variants:

- constant set temperature (20°C),

- variable set temperature (8h comfort / 16h precomfort).

Later, the comparison of both variants was made, and after summing up and multiplying by the heat loss coefficients for the tested rooms determined in the previous section of this study, the annual savings in heat demand were determined.

The calculations were made using the following formulas:

$$Q_H = \frac{\Sigma HD \cdot (Ti - Te) \cdot \tau}{1000} [kWh]$$

where:

ΣH - Sum of heat loss coefficients for the entire building [W/K]

Ti - Room temperature [°C]

Te - Outdoor temperature [°C]

τ - number of hours of a given mode in a month (comfort / pre-comfort) [h]

Table 19 - Compilation of energy calculations without time schedules for room temperature settings

Month	Mode	Outside temp. [°C]	Indoor temp. [°C]	ΣH [W/K]	τ [h]	Q_H [kWh]
September	Comfort	14.3	20	19711.3	720	80 895
	Precomfort					
October	Comfort	8.8			744	164 250
	Precomfort					
November	Comfort	4.6			720	218 559
	Precomfort					
December	Comfort	0.0			744	293 304
	Precomfort					
January	Comfort	-1.2			744	310 902
	Precomfort					
February	Comfort	0.3			672	260 946
	Precomfort					
March	Comfort	3.5			744	241 976
	Precomfort					
April	Comfort	9.3			720	151 856
	Precomfort					
May	Comfort	14.3			744	83 592
	Precomfort					
					ΣQ_H	**1 806 280**

Table 20 - Compilation of energy calculations with time schedules for room temperature settings

Month	Mode	Outside temp. [°C]	Indoor temp. [°C]	ΣH [W/K]	τ [h]	Q_H [kWh]
September	Comfort	14.3	20.0	19711,3	240	26 965
	Precomfort		17.5		480	30 277
October	Comfort	8.8	20.0		248	54 750
	Precomfort		17.5		496	85 058
November	Comfort	4.6	20.0		240	72 853
	Precomfort		17.5		480	122 052
December	Comfort	0.0	20.0		248	97 768
	Precomfort		17.5		496	171 094
January	Comfort	-1.2	20.0		248	103 634
	Precomfort		17.5		496	182 826
February	Comfort	0.3	20.0		224	86 982
	Precomfort		17.5		448	151 887
March	Comfort	3.5	20.0		248	80 659
	Precomfort		17.5		496	136 875
April	Comfort	9.3	20.0		240	50 619
	Precomfort		17.5		480	77 584
May	Comfort	14.3	20.0		248	27 864
	Precomfort		17.5		496	31 286
					ΣQ_H	**1 591 033**

The difference between the total QH values is the expected heat savings. It amounts to 215 247 kWh (774.27 GJ) for the entire building. Then, in order to determine the financial savings, the price of one GJ of heat was set. When analysing the last invoices issued by Veolia to the Poznań University of Technology, the cost was assumed to be 42 PLN/GJ. When introducing the new tested solution, savings can only be made on energy consumption, therefore only variable costs have been considered.

By multiplying the energy savings and its unit price, the annual savings of approximately 32 500 PLN were determined.

It should be remembered that the above results are indicative because they do not take the heat gains and heat capacity of the building, and in this type of analysis it was not possible to consider periodical drops in the supply temperature of the central heating installation.

In the entire A3 facility (building of the Faculty of Electrical Engineering) there are approx. 800 heaters, which are located on 8 floors. The building is 110 m long, which translates into the need to install probably 3 control computers or ZigBee gates (depending on the system) on each floor. Based on the manufacturer's data on the range of connection between the system components and the above data, the costs of introducing this type of solution for the entire building were determined.

Table 21 - Summary of material costs related to the installation of the analysed system in the entire building A3

Manufacturer	*Komponent*	*Price*	*Quantity*	*Worth*
Danfoss	Head	189.00 PLN	800	151 200.00 PLN
	Adapter	14.00 PLN	800	11 200.00 PLN
	Control Panel	880.00 PLN	24	21 120.00 PLN
	The cost of assembly with programming	135.00 PLN	824	111 240.00 PLN
	Suma			**294 760.00 PLN**
Honeywell	Head	199.00 PLN	800	159 200.00 PLN
	Adapter	14.00 PLN	800	11 200.00 PLN
	Control Panel	890.00 PLN	24	21 360.00 PLN
	The cost of assembly with programming	135.00 PLN	824	111 240.00 PLN
	Suma			**303 000.00 PLN**

Additionally, after introducing the analysed solution, operating costs in the form of replacement of batteries in the heads should be taken into account. Assuming the cost of a pair of AA batteries at PLN 10:

- PLN 7 - two AA batteries,

- PLN 3 - the average cost of a person replacing one head,

and the fact that replacements should be made every 2 years, the average annual cost is PLN 4 000.

By dividing the costs of introducing a new solution (PLN 303 000) by savings (PLN 32 500 / year) fewer operating costs (PLN 2 000 / year), we get a simple payback time - the entire investment should pay off after approx. 10-11 years.

Of course, the above calculations very strongly depend on the correct operation of the installation and the building, which have a significant impact on the achievable savings in heat consumption, and thus also directly in operating costs.

V.5.5 Conclusions

Due to relatively high temperatures outside and the lack of users in the facility (due to the announced state of the Covid-19 epidemic), it is recommended to re-test in the next academic year during the heating season. Selecting the measurement period for the fully developed heating season will allow to increase the temperature difference between the room and the outside of the building, which will contribute to greater cooling of the room during the night hours and will give more accurate results. The main difficulty during the measurements was high sun exposure, which translated into high heat gains in the room and despite the outside air temperatures below 10°C, the rooms during the day needed very little energy from the central heating system to heat them.

VI. SUMMARY AND CONCLUSION

This document introduced the planned and ongoing realisation of the energy island in the Warta Campus pilot in Poznan. The prepared infrastructure, software tools and data, described in this document will be applied to integrate the RENergetic platform solutions and demonstrate impact of project results.

To drive the development process, epics with user stories that will be evaluated in the pilot were defined. These user stories along with cross-domain epics including forecasting and interactive tools are being designed in detail as collaborative work with WP3.

One of the main pilot's objectives is to optimise the heat management within the campus including the use of local waste heat. As the water loop connection between data centre and University cannot be constructed by the project, the focus will be put on detailed virtual models and simulations of this process to analyse various what-if scenarios, which might help to both find optimal configuration of this process and convince decision makers to start an investment in the local waste heat re-use installation.

The next steps will include completing the infrastructure extensions, deployment of RENergetic tools, and performing experiments that aims at evaluation of impact on the energy island according to the project objectives and KPIs.

VII. REFERENCES AND INTERNET LINKS

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