atelier
Positive Energy Districts

AmsTErdam BiLbao cItizen drivEn smaRt cities

Deliverable 6.1: PED Execution projects

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[1] PU = Public

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Starting from the knowledge generated in WP3 (with TNO, AMS INST, etc.) and demonstrators in Bilbao and Amsterdam, the following steps are perfomed in each FC with CARTIF:
• Selection of the suitable area to design the PED.
• Identification of technical solutions for each specific local context, together with necessary social actions, potential business and financial schemes to reach positive energy balance in the selected area. Detailed design of the PEDs (co-creation process, technical design and financial plan) will be addressed to deliver an execution project.
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Abbreviations and Acronyms

Acronym	Description
CHP	Combined Heat and Power
CoM	Covenant of Mayors
DoA	Description of Action
DH	District Heating
DHN	District Heating Network
DHW	Domestic Hot Water
EC	European Commission
EE	Energy Efficiency
EPBD	Energy Performance Building Directive
EPC	Energy Performance Certificate
EU	European Union
FW	Fellow
FWC	Fellow City
GDP	Gross Domestic Product
GHG	Greenhouse gas
GIS	Geographic Information Systems
HVAC	Heating, Ventilation and Air Conditioning
ICT	Information and Communication Technologies
KPI	Key Performance Indicator
LH	Lighthouse
LHC	Lighthouse City
NECP	National Energy and Climate Plan
nZEB	Nearly Zero-Energy Building
PED	Positive Energy District
PV	Photovoltaic
REC	Renewable Energy Community
RES	Renewable Energy Sources
SEAP	Sustainable Energy Action Plan
SECAP	Sustainable Energy and Climate Action Plan
SUMP	Sustainable Urban Mobility Plan
SWOT	Strengths, Weaknesses, Opportunities and Threats (analysis)
WP	Work Package

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Executive Summary

The EU ATELIER project aims to contribute to the realization of a climate-neutral society and energy transition by creating and replicating Positive Energy Districts (PEDs) in two Lighthouse Cities and six Fellow Cities. For this purpose, a framework to foster the early replication of ATELIER PED concept in the Fellow Cities and in other areas of the Lighthouse Cities is being created along WP6 activities.

The specific purpose of this deliverable is presenting 6 Positive Energy District designs in the preliminary selected areas in the Fellow Cities (FCs) with the support of the local innovation ecosystem through the establishment of the PED Innovation Ateliers (Task 3.4) for ensuring their feasibility and high impact.

The main conclusions of this deliverable are:

- In most of the fellow cities, government and technology criteria were the most important ones for choosing an area (and thereby giving it priority for PED development); in other cases, these elements were in line with pre-existing plans.
- Every fellow city acknowledges that a Positive Energy District is feasible, and some situations or methods have been shown to work well in each situation. The integration of renewable energy sources, such as solar, wind, and geothermal, for the production of heat and power is the main recommendation. Every city places emphasis on improving building energy efficiency through the use of energy-efficient appliances, lighting, and insulation, as well as lowering the energy demand for water through creative means. Therefore, increasing energy efficiency (EE) and harnessing renewable energy sources (RES) are essential to decarbonizing buildings in Europe. To achieve an economically feasible PED, both EE and RES are required.
- PEDs have the potential to accelerate the attainment of decarbonization objectives, particularly for Mission cities that must attain climate neutrality by 2030.In cities, there is always a problem with RES space availability. The idea of virtual limits may aid in the PED concept's widespread adoption throughout Europe.
- PEDs are somewhat advantageous to Net Zero Energy Buildings (NZEBs) in that they can provide cost-effective energy management as well as balanced energy demand and RES generation, which can reduce congestion management. Co-benefits include decreased energy poverty, increased economic growth, the creation of jobs, better health, a less environmental impact, and climatic resilience.
- PED development necessitates the participation of local stakeholders, political vision, alluring funding sources, and careful evaluation of particular finance and regulatory prerequisites.
- Shortage of funds, a shortage of qualified personnel across the board in the city, supportive laws and regulations, stakeholder involvement, and business models are some of the obstacles to PED implementation. Public funding, grants from the EU, loans, and participation from private investors have all been utilized to support PED initiatives and are the preferred sources of funding for the cities.
- Since the stakeholders are still unfamiliar with the concept, they need capacity building activities (increase awareness) and a mix of financing options (public and private funds) to be involved, invest in it and reduce the risk. Public-private hybrid funds and investment platforms may also be able to assist in PED establishment and risk distribution among stakeholders.

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- Although regulatory limitations and restrictions (e.g. at national level: lack of energy communities' transposition, limitations on RES capacity to be installed without permits, etc.; at local level: increase of data platforms, of local ordinances or tax bonifications to support RES and energy communities, etc.) are recognized as possible obstacles, cities are upbeat about impending energy community legislation and other beneficial improvements.

All things considered, the cities understand how critical it is to meet their PED targets through embracing renewable energy, energy efficiency, engaging stakeholders, and getting through regulatory obstacles. Every context has different opportunities and limitations, which affect the strategy and funding sources that are favoured.

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1. Introduction

1.1. Purpose and Target Group

In diverse literature (see section 3.1), Positive energy districts (PEDs) represent a powerful solution towards sustainable urban areas supporting the transition to a climate-neutral society and managing the energy transition. Hence, European countries joined forces to achieve 100 PEDs until 2025 through a comprehensive research and innovation program. The Program on Positive Energy Districts and Neighbourhoods (PED Program) is conducted by JPI Urban Europe in cooperation with the Strategic Energy Technology (SET) Plan Action 3.2 which aims to support the planning, deployment and replication of 100 Positive Energy Districts by 2025 for sustainable urbanization.

The EU ATELIER project aims to contribute to the realization of a climate-neutral society and energy transition by creating and replicating Positive Energy Districts (PEDs) in two Lighthouse Cities and six Fellow Cities. For this purpose, a framework to foster the early replication of ATELIER PED concept in the Fellow Cities and in other areas of the Lighthouse Cities is being created along WP6 activities.

The goal of this deliverable is to report on the process of defining 6 full PED designs in the preliminary selected areas in the FCs. To ensure feasibility and high impact of the PED implementation, a PED Innovation Atelier (Task 3.4) was established in each FC together with the local ecosystem.

This deliverable is structured as follows:

- **Section 1** introduces the purpose of the report, contribution of partners and deviations from the Grant Agreement No 864374.
- **Section 2** summarizes the objectives of the report and expected impact.
- **Section 3** is related to methodological steps defined in D6.2 and applied in T6.1. These steps are applied to each fellow city in section 4.
- **Section 4-9** describes for each fellow city the results for each step.
- **Section 10** discusses a comparison between the cities (although it is not the aim of this deliverable) and extracts some lessons learnt from it
- **Section 11** provides overall conclusions.
- In the **annexes** templates, and detailed results for some cities are included.

1.2. Contributions of Partners

The following table depicts the main contributions from project partners in the development of this deliverable.

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Table 1 Contributions of Partners

Partner short name	Contributions
CARTIF	Deliverable leader. Main contributor
TNO	Local innovation ecosystem engagement supporter (WP3)
Tecnalia, AMS INST.	D6.1 revision
AUAS	
Waag Society	
COB	Sharing examples how their city has selected / designed the PED and lessons learnt (through WP3)
COA	Sharing examples how their city has selected / designed the PED and lessons learnt (through WP3)
MunBud	Leader of the PED execution plan definition of Budapest area
Matosinhos	Leader of the PED execution plan definition of Matosinhos area
Riga EnAg	Leader of the PED execution plan definition of Riga area
COP	Leader of the PED execution plan definition of Copenhagen area
Bratislava city	Leader of the PED execution plan definition of Bratislava area
City of Krakow	Leader of the PED execution plan definition of Krakow area

1.3. Deviations to the Plan

According to the grant agreement, FC together with specific partners (CARTIF) will address the development of a full PED design according to the local conditions following the knowledge generated in WP3 and demonstrations in Bilbao and Amsterdam. The idea was to produce a detailed design of the PEDs (co-creation process, technical design and financial plan will be addressed to deliver an execution project) in FC, that allows them to produce documents to publish a public tender. The information is contained in this deliverable for all cities following a similar approach, except for Copenhagen that has followed a different methodology align with its city priorities. Although this could be considered a deviation, it needs to be seen as a proposal that fits city goals and necessities.

The deliverable was due in October 2022. Deviations in terms of the due date of the deliverable have taken place, due to the slow decision-making process of the municipalities. This has been caused by accumulated delays (COVID-19, data gathering, Cities Mission, etc.) and also due to the involvement of stakeholders in the process (connection with task 3.4 – Innovation ATELIERS).

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2. Objectives and Expected Impact

2.1. Objectives

WP6 aims to create a necessary framework to foster early replication of ATELIER PED concept and solutions across Europe starting with our Fellow Cities (Bratislava, Budapest, Riga, Krakow, Copenhagen and Matosinhos). By means of:

- Establishing standard definition of PED for ATELIER
- Providing guidelines to adapt the validated solutions in the LHs to other scenarios (cultural, social, economic and legal)
- Providing guidelines to replicate PEDs in any context
- Improving our cities knowledge through capacity building activities aiming at understanding the regulatory and financial barriers overcoming.

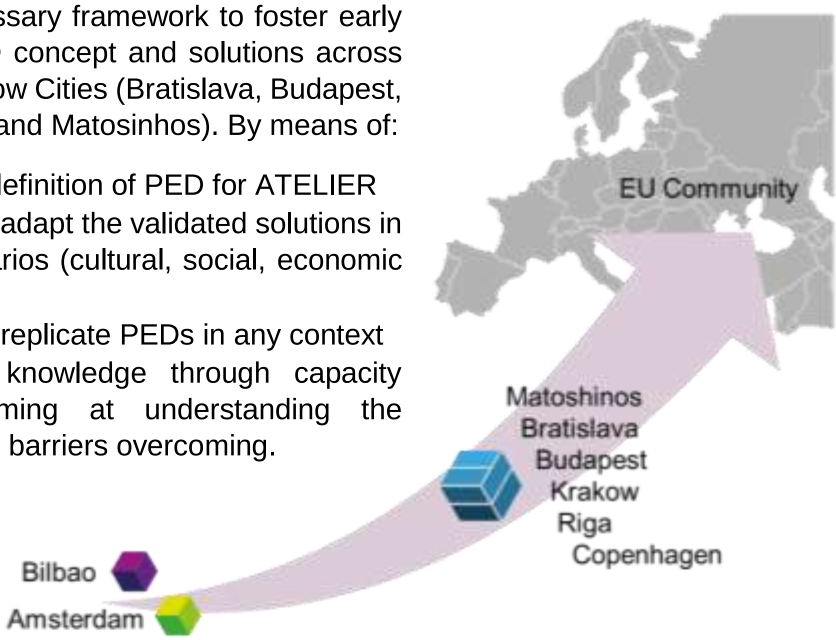

Figure 1 ATELIER's Replication and Upscaling vision

The **Replication and Upscaling strategy** of ATELIER is targeted at implementing solutions from the Lighthouse cities in other districts in the Lighthouse cities, in the Fellow cities and in the metropolitan regions around the Lighthouse and Fellow cities. To foster replicability, task 6.2 developed a replication and upscaling strategy consisting on the establishment of a dialogue among LH and FC to identify commonalities and differences among the urban scenarios as an open discussion among local authority representatives of each city. This is essential as this sharing of experiences and approaches among 8 cities will help in the harmonization of the PED concept, increasing their replication potential. Different supporting tools, methods and guidelines will support this strategy to be applied in the different cities:

a. An easy-to-use tool for PED technologies pre-selection
b. A step-by-step methodology for PED calculation
c. A catalogue of replicable smart urban solutions validated in the Lighthouse cities
d. A set of guidelines for a PED Upscaling and replication strategy definition

The strategy is also supported by the creation of the Innovation Ateliers(WP3) the definition of a new governance model structure (WP2), and the deployment of a continuous capacity building strategy (T6.3). It is worth highlighting that one of the main pillar of this strategy is the establishment of a PED Innovation Atelier to coordinate city council departments, integrate strategies and engage key stakeholders from the PED innovation ecosystem, which also includes citizens (and its engagement). **Innovation Ateliers** materialises an open innovation model, which play an important role in the development, deployment and upscaling of the PED's in cities. Local partners and other relevant stakeholders representing the four quadrants of the local innovation eco-system are invited to participate, or contribute to the process of

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planning, organizing, realizing and/or operating the PED project in the specific urban area. The aim of the PED Innovation Atelier organization is to support the process of realization, by setting up a collaboration for innovation between the various partners and stakeholders, to foster exploring, co-creating new solutions, building up the capacity to learn and to innovate (within the collaboration, but also within each of the participating partner organisations). **The Innovation Atelier aims to develop and review supportive measures, and to remove obstacles becoming apparent from "old structures" that are in competition with the development of an innovative PED (solution).**

Presenting a systematic approach to steer a city through the stages of a PED (Positive Energy District) project design, the methodology presented in D6.2 and summarized in Figure 3 offers a comprehensive roadmap spanning multiple steps. Commencing with STEP 1, which entails a holistic understanding of the city's context, involving an in-depth survey, meticulous analysis of plans (WP2), and city context questionnaires. These initial efforts converge into a SWOT analysis, providing a strategic foundation. Progressing to STEP 2, the focus shifts towards identifying a suitable area for PED implementation. This involves a precise prioritization of impacts, further characterization of preselected zones from the proposal phase, and a thorough assessment of these zones based on the prioritized impacts. The outcome is a composite indicator, facilitating the selection of the most fitting area for PED integration within the city. Upon selecting the area, STEP 3 is enacted. This phase encompasses baseline establishment through modelling, exploration and selection of potential technical solutions, leading to tangible outcomes. These findings are then presented to stakeholders, fostering discussions to evaluate challenges, strengths, and the formulation of a financial model. Throughout this entire process, capacity building initiatives from WP3 and WP6 play a pivotal role. These initiatives stem from T6.3, outlined in D6.3, and activities documented in D3.8 (T3.4). The process is further enriched by workshops within WP6, including the City Energy Analyst workshop held within 2023 year with fellow cities. Additionally, robust stakeholder engagement forms a cornerstone. Notable gatherings took place in Bratislava (March 2023, Budapest (November 2022), and Riga (June 2023). These meetings showcased preliminary PED results and facilitated discussions on implementation. While bolstering this task, these activities also contribute to the establishment of the Innovation ATELIERs (T3.4).

2.2. Expected Impact

WP6 activities will effectively support the replication and upscaling of the smart urban solutions. Within this deliverable and as a result of Task 6.1 each Fellow City delivers a PED execution plan demonstrating the replication potential of ATELIER PED concept, delivering the necessary specification documents to publish a public tender and launch a public procurement procedure.

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3. Overall Approach

The replication and upscaling approach within ATELIER project is understood as the strategy to ensure ATELIER PED concept growing path by adding value to Bilbao and Amsterdam PEDs ensuring their upscaling in extending the initial district by adding new buildings and projects, or replication in other cities (or districts in same city). **Replication** refers to implementing a proven PED concept (including technologies, business models and governance) in the city or in another city without a direct connection to the initial PED. To start with the replication, the PED concept is reviewed with fellow cities (see section 3.1), followed by presenting the method for PED design (see section 3.2). These steps are applied to each fellow city in section 4. Section 5 discusses a comparison between the cities (although it is not the aim of this deliverable) and extracts some lessons learnt from it. Section 6 provides overall conclusions and further work to be performed.

3.1. PED concept

One of the initial capacity building activities with the fellow cities was organised around the concept of Positive Energy Districts (PEDs). The concept of PEDs initially emerged from the EU Horizon 2020 Smart Cities and Communities project calls and from the Strategic Energy Technology Plan, of which an action is dedicated to realising 100 PEDs throughout the EU by 2025.

The European Commission defines PEDs as: *"Positive energy districts consist of **several buildings** (new, retro-fitted or a combination of both) that actively manage their energy consumption and the energy flow between them and the wider energy system, have an **annual positive energy balance**, make optimal use of elements such as advanced materials, local RES, local storage, smart energy grids, demand-response, cutting edge energy management (electricity, heating and cooling), user interaction/involvement and ICT. They are designed to be integral part of the district/city energy system and have a positive impact on it. Their design is intrinsically scalable and they are well embedded in the spatial, economic, technical, environmental and social context of the project site. Assessing Positive Energy Blocks/Districts: as Primary Energy Factors used for energy balance calculations differ substantially depending on the framework, we evaluate energy need, RES produced locally and energy flows through test site boundaries"*[2]

Whilst **SET Plan**[3] defined PEDs as: *"Positive Energy Districts (PED) are energy efficient districts that have net zero carbon dioxide (CO2) emissions and work towards an annual local surplus production of renewable energy (RES)",* introduced back in 2018.

Regarding the already funded projects (since SET Plan was launched), each one has taken their own definition, which can be summarized in the following table:

[2]https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/lc-sc3-scc-1-2018-2019-2020

[3]https://jpi-urbaneurope.eu/wp-content/uploads/2021/10/setplan_smartcities_implementationplan-2.pdf

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Table 2 PED concept overview

SCC1 call	Project	PED concept definition
2018	MAKING CITY	"a district with annual net zero energy import and net zero carbon emissions, working towards an annual local surplus production of renewable energy" (MAKING-CITY project, 2023)
	+CityxChange	+CityxChange H2020 project defines a positive energy district in a similar way as the SET-Plan Implementation Working Group 3.2 on Smart Cities and Communities (IWG 3.2) emphasizing energy retrofitting, RES on-site, active management, mobility, social aspects, and flexibility, among others (Vandevyvere, Ahlers, & Wyckmans, 2022).
2019	ATELIER	ATELIER project defines a PED in a similar way as the SET-Plan: "Positive Energy Districts (PED) are energy efficient districts that have net zero carbon dioxide (CO2) emissions and work towards an annual local surplus production of renewable energy (RES)."
	POCITYF	POCITYF combines Positive Energy Blocks (PEB) with grid flexibility, e-mobility, innovative ICT technologies and citizen engagement strategies, while respecting the urban cultural heritage (POCITYF, 2023).
	SPARCS	SPARCS project defines a PED with virtual boundaries, where the energy management, storage, e-mobility, RES production, NZEBs and retrofitted buildings concepts are integrated (among other characteristics) (Ntafalias, y otros, 2020).
2020	RESPONSE	RESPONSE aims to reach high energy efficiency, good indoor climate and energy positivity through new built and deep renovation activities containing increased local RES (renewable energy source) generation on the building level "Positive Energy Building Systems", which is the first technical step to reach Positive Energy districts (PED) (Shemeikka, et al., 2021).

The PED concept has been also discussed by other new formed initiatives and organisations like the Smart Cities Marketplace and the European COST Action on PEDs. At global level, the International Energy Agency, which has started a new annex to work on PED definition and development: IEA Annex 83 Positive Energy Districts.

JPI Urban Europe defined PEDs and Neighbourhoods *"are an integral part of comprehensive approaches towards sustainable urbanisation including technology, spatial, regulatory, financial, legal, social and economic perspectives. They require interaction and integration between buildings, the users and the regional energy, mobility and ICT system. In this sense, a Positive Energy District is seen as an urban neighbourhood with annual net zero energy import and net zero* CO_2 *emissions working towards a surplus production of renewable energy, integrated in an urban and regional energy system. Active management will allow for balancing and optimisation, peak shaving, load shifting, demand response and reduced curtailment of RES, and district-level self-consumption of electricity and thermal energy. A Positive Energy District couples-built environment, sustainable production and consumption, and mobility to reduce energy use and greenhouse gas emissions and to create added value and incentives*

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for the consumer. Furthermore, implementation has to come with a high and affordable standard of living for its inhabitants" (JPI Urban Europe., 2020).

The Implementation Working Group (IWG) on positive energy districts and neighbourhoods for sustainable urban development (PED) or **IWG 3.2** defined PEDs as *"Urban neighbourhood with annual net zero energy import and net zero CO2 emissions working towards a surplus production of renewable energy, integrated in an urban and regional energy system"* (European Commission, 2014).

PED typologies:

Four typologies of PEDs can be distinguished dependending ong the way energy balance is achieved (JPI Urban Europe., 2020):

- **Auto-PED (PEDautonomous):** 'plus-autarkic', net positive yearly energy balance within the geographical boundaries of the PED and internal energy balance at any moment in time (no imports from the hinterland) or even helping to balance the wider grid hinterland outside
- **Dynamic-PED (PEDdynamic)):** net positive yearly energy balance within the geographical boundaries of the PED but dynamic exchanges with the hinterland to compensate for momentary surpluses and shortages
- **Virtual-PED (PEDvirtual):** net positive yearly energy balance within the virtual boundaries of the PED but dynamic exchanges with the hinterland to compensate for momentary surpluses and shortages
- **Candidate-PED (pre-PED):** no net positive yearly energy balance within the geographical boundaries of the PED but energy difference acquired on the market by importing certified green energy (i.e. realizing a zero-carbon district)

In this deliverable both, virtual and dynamic PED are considered as options to design the PED. The other options are open as well, but not prioritized by the cities.

Types of district boundaries:

From a technical point of view a PED is characterized by achieving a positive energy balance within a given boundary. Such boundary can be divided in the following three types (JPI Urban Europe., 2020):

- **Geographical boundary:** Spatial-physical limits of the PED in terms of delineated buildings, sites and infrastructures –these may be contiguous or in a configuration of detached patches
- **Functional boundary:** Limits of the PED in terms of energy grids, e.g. the electricity grid behind a substation that can be considered as an independent functional entity serving the PED; a district heating system that can be considered as a functional part of the PED even if the former's service area is substantially larger than the heating sector of the PED in question; or a gas network in the same sense
- **Virtual boundary:** Limits of the PED in terms of contractual boundaries, e.g. including an energy production infrastructure owned by the PED occupants but situated outside the normal geographical PED boundaries (for example an offshore wind turbine owned through shares by the PED occupant community)

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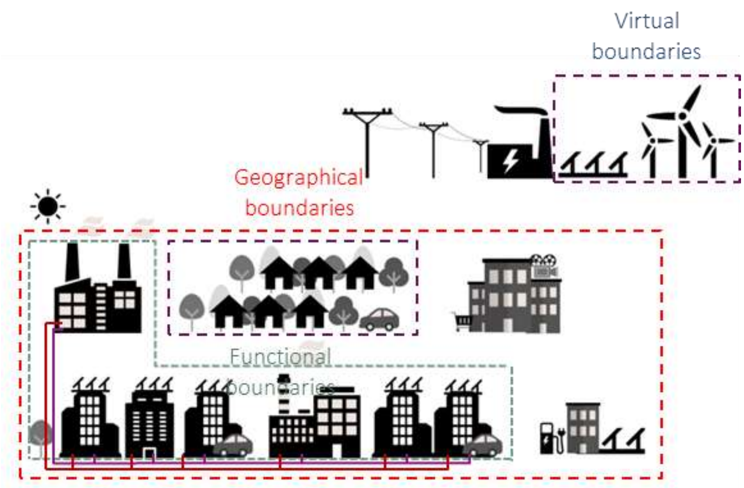

Figure 2 Type of PED boundaries

All actors operating within these boundaries need to come together to define the PED and consider the previous characteristics and boundaries. The method described hereafter, takes into account these features and factors affecting the PED design in cities.

3.2. Method for PED design in FC for early implementation

In order to address the development of a full PED design in the six Fellows cities, the following steps have been implemented:

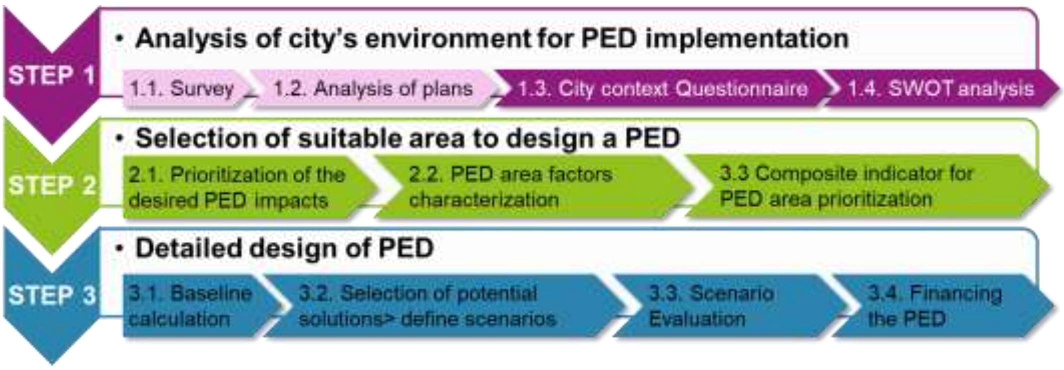

Figure 3 Method for PED design in FC for early implementation

Commencing with STEP 1, which entails a holistic understanding of the city's context, followed by STEP 2, the focus shifts towards identifying a suitable area for PED implementation. And finalising upon selecting the area, STEP 3 is enacted. Throughout this entire process, capacity building initiatives (from other tasks of ATELIER project) play a pivotal role as said before. Hereafter, each step is described in detail.

STEP 1: City's environment analysis for PED implementation

Aim: This stage aims at identifying the starting point of the city in relation to replicating ATELIER PED concept, in terms of cities' planning framework, since an integrated approach with respect to energy and spatial planning is of utmost necessity to ensure PED concept replication. An analysis of the City Plans in execution have to be performed to identify gaps of integration or barriers that may avoid PED concept replication. As a result, a SWOT analysis

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is performed for each city, identifying the strengths, weaknesses, opportunities and threats to the PED implementation.

Way of working: ATELIER partners decided to work together on the understanding of ATELIER cities' context, since the knowledge gathered would be useful for many ATELIER activities. The activities (survey, analysis of plans, questionnaires, Kahoot and validation of the Kahoot) and the aim of each activity is summarized in the following figure:

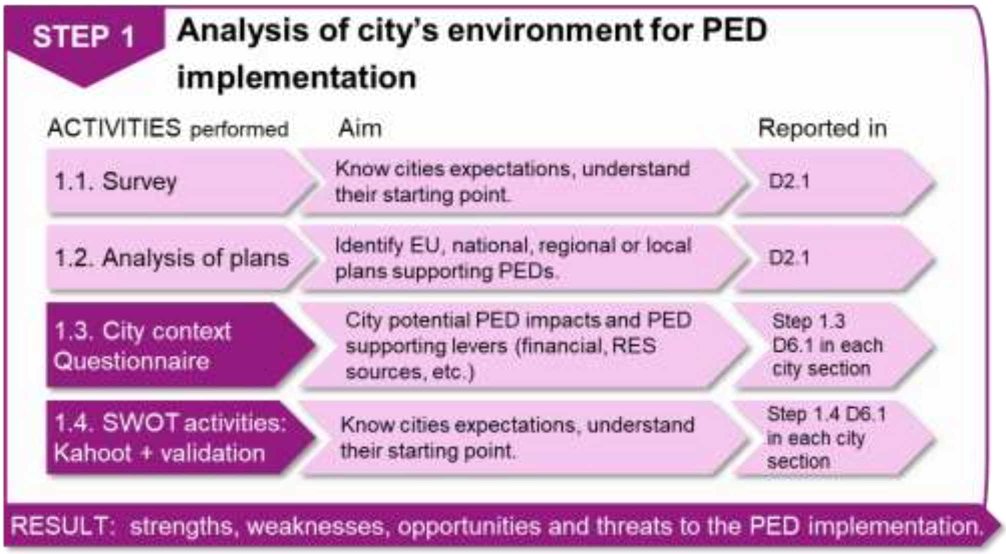

Figure 4 STEP 1 summary

Therefore, an **Initial Survey** (step 1.1) was developed and launched in collaboration with partners from the other WPs in which all ATELIER cities are involved (WP2, WP3, WP6 and WP8). As it was already reported in *D2.1. Planning framework: report on each city's context,* the survey aimed to identify cities expectations and establish baseline in relation to the issues that ATELIER project faces: Local innovation ecosystem and City priorities identification, and analysis of city experiences on managing smart city urban strategies or ways of collaboration with other cities or experts due to their involvement on international cooperation networks. The survey results and main conclusions were included in *D2.1.* (step 1.2).

The **analysis of ATELIER City plans in execution** was also performed in the context of WP2 activities (Task 2.1), but of utmost priority for PED concept replication, since it provides the framework through the European, national, regional and local level policies for setting priorities, goals and milestones in the integrated planning process, that is taking place for City Vision 2050 definition, in which the basis for PED concept replication should be stablished.

Specifically for WP6 and aiming at understanding the City Context for PED concept replication a **Questionnaire** (step 1.3 - see In summary, cities do believe the PED concept is valuable for expediting their climate neutrality ambitions, but they struggle to engage stakeholders and secure the funds necessary to invest in such massive installations. To support these kinds of methods across Europe, more policy incentives at the local, national and European levels are required (see section 10 for more recommendations).

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ANNEX 1- CITY CONTEXT TEMPLATE) is performed, in which information on: city potential PED impacts that the city wants to achieve by PED implementation are collected and basic information in relation to general expectations or plans for PED concept replication, such as potential investment, expected time to return that investment, or the expected time for PED implementation, are gathered. In addition, information to evaluate the potential energy sources available in the city (e.g. solar, geothermal, wind, etc.).

Finally, based on the multisource data collection and the analysis performed in previous steps, a **SWOT analysis** (step 1.4) is performed. The goal was to organise all the information and identify the strengths, weaknesses, opportunities and threats to replicate the PED concept in the Fellow cities. The process consisted of two-steps: 1) a Kahoot questionnaire (questions depicted in Table 3, 2) validation process. The Kahoot was answered by the cities during a WP6 meeting to set some basis and ideas. The validation process consisted in checking the information obtained from the Kahoot with fellow cities to dive in the main aspects to be considered to develop a PED in the cities (see Table 4).

Table 3. SWOT aspects asked for to the cities during WP6 meeting (through Kahoot tool)

Kahoot Questions related to PED implementation
To what extent are citizen communities for power or heat generation possible in your city?
Does the Building Stock have a big influence in the decarbonisation of your city's energy system?

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Is there any legal burden on the installation of some specific energy technology?
Regarding the electricity regulation in your country/city… Is it possible to export energy to the power grid?
Regarding the electricity regulation in your country/city… Is it possible the peer-to-peer exchange?
Regarding the electricity regulation... Is there any limit on the capacity to be installed (e.g. self-consumption regulation)?
Regarding other regulation... Is it possible to inject hydrogen in the gas grid?

Table 4. SWOT aspects investigated by CARTIF for the first approach

CHARACTERISTICS OF THE PED	WHAT TO LOOK FOR
Positive Energy Balance	Regulation on energy certificates (transposition of the EPBD)
	Electricity regulation (*Is it possible to export energy? At what price?*)
	Electricity regulation (*Is the peer-to-peer exchange possible?*)
	Electricity regulation (*Does an energy community need too much paperwork to be created?)*
	Gas regulation (*Is it possible to export H_2?*)
	District Heating regulation (*Is it necessary to connect? Is it possible to be a prosumer?*)
Renewable Energy Production	Electricity regulation (*Is there any limit on the capacity to be installed?*)
	Is there any legal burden on the installation of some specific energy technology?
	Does the city have experience in similar projects (nZEBs, Low DHN, VPP, living labs, etc.)?
Efficient buildings / Building stock demand	Existing building stock status
	Regulation on energy certificates (EPBD)/ nZEBs
	Social housing requirements (also related with affordable)
	Funds to energy saving renovations
Affordability	People density
	Gross Domestic Product (GDP)
	Cost of Energy (GRID + DHN, gas, etc.)
Liveability	Green areas available (*Is there any regulation on minimum areas, or something?*)
	Holistic approach (*Does the city build in a holistic way, mixed-used districts?*)
	Public transport and sustainable mobility status
	Average time that people spent to get to work
	Number of supermarkets per km^2
	Unemployment rate
PED implementation	National plans
	Local plans
	SEAP/SECAPs
	Incentives to district projects
Context	Experiences
	Mobility
	Other

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STEP 2: Selection of suitable area to design a PED

Aim: Cities preselected in the proposal phase of the ATELIER project several areas in their cities. The aim in STEP 2 is to select one of them to conduct detailed studies in it.

Ways of working: The selection of suitable areas to design a PED within Task 6.1 has been focused in areas previously identified and selected by the Fellows cities. The selection in proposal stage was based on previous existing plans, preferences or interests. Despite it would have make sense to perform a city-wide analysis to obtain areas in the city suitable to become a PED, since the city energy characterization in Fellows cities were still under definition in WP2, T6.1 did not perform this city analysis (the city PED analysis will be performed in T6.4). Instead, the prioritization consisted in 1) know which PED impacts city prioritizes, 2) Assess how PED impacts affect overall city goals and, therefore, give weights to each characteristic an area can have to obtain a PED, 3) obtain the data of each area and, as a result of the weights and assessment of each characteristic, a PED composite indicator is obtained for each area. The best score of the composite indicator is chosen to select the area.

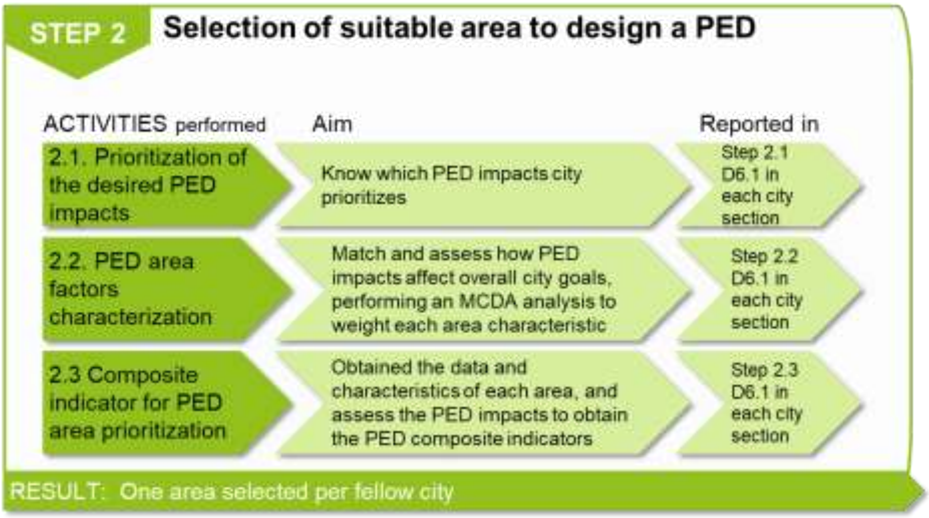

Figure 5 Selection of suitable area to design a PED summary

As said before, a Prioritization method was defined to support cities in the selection of the most suitable area among the different options. The prioritization was based on the following three aspects[4] highly needed to ensure the future PED concept replication:

- **Spatial and energy planning integrated approach:** Supporting the city challenges and objectives on climate protection and the energy transition by means of spatial planning. PEDs provide an opportunity for starting and supporting a highly efficient and sustainable route to progress beyond the current urban planning dynamics.
  - City challenges and goals are stated to prioritize the area that has the greatest potential contributing to city goals.
- **PED implementation impacts:** PEDs are intended to be one of the many actions that a city can do towards meeting its long-term strategies (Bold City Vision 2050). Therefore:
  - Expected PED implementation impacts are stated to prioritize the area that has the greatest potential contributing to city goals.

[4] Positive Energy Districts Solution booklet. *EU Smart Cities Information System,* 2020.

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- **PED concept integrated approach:** PEDs require an integrated approach including technology, spatial, regulatory, financial, legal, social and economic perspectives. In this way, the preselected areas are evaluated, compared and prioritized by analysing these factors in order to select the area that encourages an integrated approach.

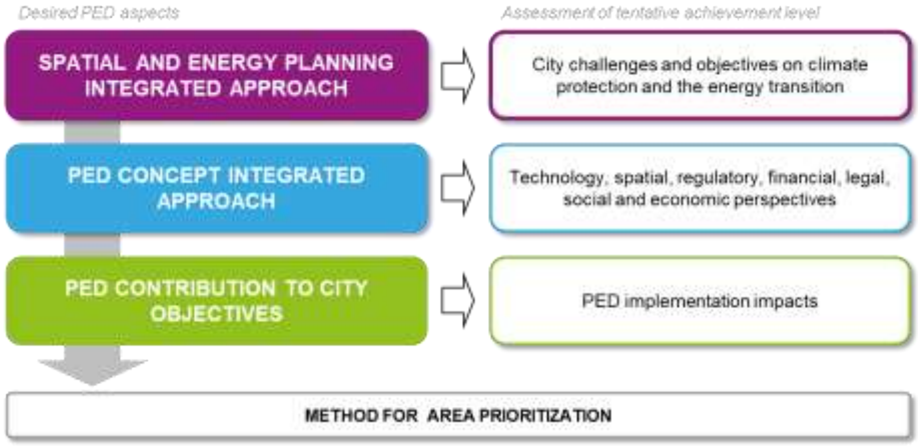

Figure 6 Method for PED area prioritization approach

All the process results in **a composite indicator**[5] for each area, which **allows comparing several areas between each other**.

Composite indicators, which compare potential PED area performance, are useful tools in policy analysis and decision-making processes for area prioritization. To obtain it, the method divided into several sub-steps:

STEP 2.1: Prioritization of the desired PED impacts

Aim: The goal of this stage was to prioritize the PED impact (highlighted in the (3) Questionnaire) by ranking the solutions/options respect to the city objectives. The ranking is performed according to their greater or lesser contribution of each impact to the city's objectives (that were agreed upon and stated in the (1) Initial survey).
Way of working: A pair-wise comparison exercise is proposed by applying an Analytic Hierarchy Process (AHP), which is an extensively used technique for multi-attribute decision-making. It considers both qualitative and quantitative aspects of a problem although with certain degree of subjectivity.

Each impact is compared in pairs, asking which of the two is the most important. The pairwise comparison assigns a level of importance i indicator relative to the j indicator. The relative results are represented in a pairwise comparison matrix (PCM) to obtain the weights for each PED impact.

In detail, the PCM is a $m\ x\ m$ real matrix, where m is the number of PED impacts highlighted by the city. Each a_{ij} element of the PCM represents the importance of the i indicator relative to the j indicator[6].

[5]OECD. Handbook on Constructing Composite Indicators - methodology and user guide. *JRC European Commission,* **2008**. ISBN 978-92-64-04345-9. Available online: https://www.oecd.org/sdd/42495745.pdf

[6] SAATY, 1980. The analytic Hierarchy Process. (McGraw Hill, New York)

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$$PCM = \begin{pmatrix} 1 & a_{12} & \cdots & a_{1j} \\ 1/a_{12} & 1 & \cdots & a_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1j} & 1/a_{2j} & \cdots & 1 \end{pmatrix} = (a_{ij})$$

Figure 7: Pairwise Comparison Matrix (PCM)

The relative importance between two impacts is measured according to a numerical scale from 1 to 5, as shown in Table 5.

Table 5 Importance scale definition

Value of a_{ij}	Interpretation
1	i and j are equally important
5	i is more important than j

In case of ATELIER cities, the pair-wise comparison matrix is based on the relevance criteria score established by the city working group from the municipality. The matrix is created by comparing each PED impact by the difference of relevance score values assigning values for each of the differences.

Desired PED Impacts	I1	I2	I3	I4	I5	I6	I7	I8
I1	1.00	5.00	1.00	1.00	5.00	0.20	1.00	5.00
I2	0.20	1.00	1.00	0.20	0.20	0.20	0.20	5.00
I3	1.00	1.00	1.00	5.00	5.00	0.20	1.00	5.00
I4	1.00	5.00	0.20	1.00	1.00	0.20	0.20	5.00
I5	0.20	5.00	0.20	1.00	1.00	0.20	0.20	1.00
I6	5.00	5.00	5.00	5.00	5.00	1.00	1.00	5.00
I7	1.00	5.00	1.00	5.00	5.00	1.00	1.00	5.00
I8	0.20	0.20	0.20	0.20	1.00	0.20	0.20	1.00

Figure 8 Pairwise Comparison Matrix (PCM) *(example)*

Once the PCM is created, the AHP method is applied to calculate eigenvectors which will be the first weight (W_1) of each PED impact to apply when evaluating potential PED areas in the following steps.

	I1	I2	I3	I4	I5	I6	I7	I8
W_1	0.0238	0.0409	0.0607	0.0843	0.1134	0.1515	0.2071	0.3182

Table 6 PED impacts weights with AHP method *(example)*

A second weight (W_2) will be calculated to prioritize areas that presents aspects or requisites that support the selected PED impacts achievement, and PED concept replication itself.

W_2 will be calculated to give more importance in terms of weight to those aspects of the area that support the achievement of those PED impacts that have the greatest potential contributing to city goals. For that purpose, a Matrix that relates impacts and city objectives (ICOM) is created, identifying whether the PED impact support the city objective or not.

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Table 7 Impacts and City Objective relation matrix (ICOM)*(example)*

			Desired PED Impacts							
		Selected?	**I1**	**I2**	**I3**	**I4**	**I5**	**I6**	**I7**	**I8**
City objectives	**O1**	No	0				0		0	
	O2	Yes	1	1	-	1	1	-	1	1
	O3	No				0				
	O4	Yes	-	1	1	-	-	-	-	1
	O5	No				0				
	O6	Yes	1	1	-	-	-	-	-	1
	O7	Yes	1	1	1	1	1	-	-	1
	O8	Yes	-	1	1	-	1	1	-	1
	O9	Yes	-	1	1	-	1	1	-	1
	O10	No			0			0		0
	O11	No						0	0	0
	O12	No			0			0	0	0
	O13	No	0	0			0			0
	O14	No	0	0		0	0	0		0

In the example provided in Table 7, the city identifies 8 PED impacts (I1-8) and 6 objectives (O2, O4, O6, O7, O8, O9) from the list provided in the initial Questionnaire (Step 2.1), and for those objectives, PED impacts that contributes to them were assigned with a “1” value, while PED impacts that do not contribute to the objectives chosen, were assigned with a “0” value. The more impacts selected that contribute to the city objectives, the better.

As a result of the ICOM performing, the W_2 is calculated per each PED impact:

Table 8 W_2 PED impacts weight *(example)*

	I1	**I2**	**I3**	**I4**	**I5**	**I6**	**I7**	**I8**
W_2	0.107	0.214	0.143	0.071	0.143	0.071	0.036	0.214

A final weight (w) that considers not only the prioritized impacts, but also their relation with the already stated city objectives, will be calculated providing the PED impacts ranking according to their greater or lesser contribution to the city's objectives (that were agreed upon and stated in the (1) Initial survey).

$$w = w_1 * w_2$$

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Table 9 Final weight (W) and ranking of PED impacts *(example)*

	w_1	w_2	w	FINAL WEIGHT	Ranking
I1	0.024	0.107	0.003	2%	8
I2	0.041	0.214	0.009	7%	4
I3	0.061	0.143	0.009	7%	5
I4	0.084	0.071	0.006	5%	7
I5	0.113	0.143	0.016	13%	2
I6	0.152	0.071	0.011	8%	3
I7	0.207	0.036	0.007	6%	6
I8	0.318	0.214	0.068	53%	1

STEP 2.2: PED area factors characterization

Aim: Once the PED impacts ranking is defined, a data collection for PED area characterization starts. The goal is to analyse the proposed area from technological, spatial, regulatory, financial, legal, social and economic perspectives.

Way of working: A template for collecting the information is provided (see ANNEX 2- POTENTIAL PED TEMPLATE).
The information collected for each PED area is grouped into the selected factors: spatial, Technological, Environmental, Social, economic and financial, Legal and regulatory, which will be compared and measured from 10 to 5.

Table 10 Importance scale definition

Factor score	Interpretation
10	It would be assigned to the area with a better factor value to support PED impacts and city goals achievement
5	It would be assigned to the area with a worse factor value to support PED impacts and city goals achievement

STEP 2.3: Composite indicator for PED area prioritization

Aim: During this step aims a **composite indicator** is built, to ease the PED area prioritization. The information collected in Step 2.3 for each suggested area, is analysed to compare the different aspects that facilitate the integrated approach required to replicate PED concept.

Following a Multi-Criteria Decision Analysis (MCDA) the composite indicator is built, measuring the multidimensional concepts that cannot be captured by a single indicator, but have to be into consideration when selecting a PED area.

Way of working:

A composite indicator is built from the technological, spatial, social and economic aspects analysed per area, considering the relative relevance of each answer provided for each factor of the different areas analysed. So that, at this stage the answers provided are scored according to a numerical scale as shown in Table 11.

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Table 11 Relevance scale definition

Score	Interpretation
10	This aspect of the PED area provides greater potential to become a PED, by supporting PED impacts and City objectives
5	This aspect of the PED area provides lesser potential to become a PED, by supporting PED impacts and City objectives in a fewer way

After scoring the different aspects of the PED areas, the weighting, normalization and aggregating processes are done following the theoretical framework.

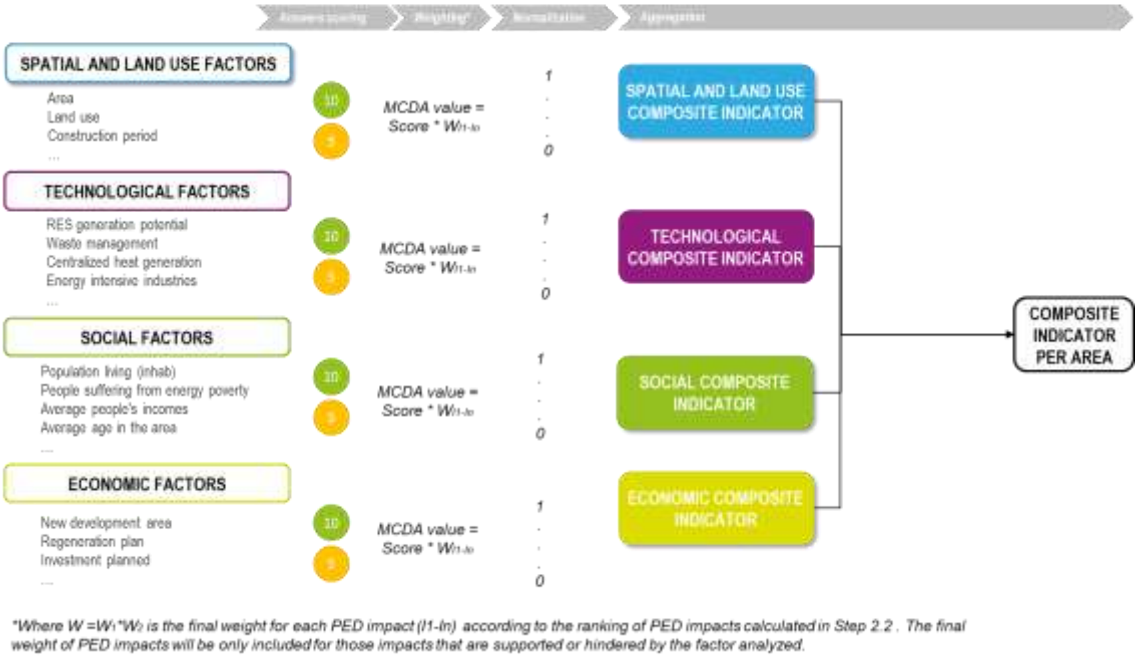

Figure 9: Composite indicator for PED area prioritization approach

Greater weight (w) was assigned to the area factors that are considered more significant for the PED concept replication (OECD, 2003). Each category identified in STEP 2.2, is weighted with a score (5 or 10) and normalized to the relative influence of that category towards the achievement of the impacts (if the characteristic can help in a positive way on the achievement of the impact (1) or not (0)).

For example, in the spatial and land use factors the “area in square km” or “the replicability potential” will have effects on the impacts of the PED. For example, the greater the area, in principle, the greater the positive impact can be to the city. If there are similar areas on the city, it can help to replicate the PED concept in several zones and thus help the city in the achievement of, for instance, zero energy imports.

As a result of this process a composite indicator is calculated per PED area, easing the selection prioritization of the area that has the greatest potential contributing to city goals.

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STEP 3: Detailed design of PED

Aim: Once the area is selected, detailed studies are performed to evaluate the achievement of the PED concept in the area in techno-economic terms. The aim is to give recommendations to stakeholders on how to deploy the PED concept in the area.

Ways of working: To do that, several tools (PED tool, City Energy Analyst software or CYPEtherm software, etc.) are used to assist the process. First of all, a model of the current status of the area is performed to evaluate its energy performance (i.e. the energy demand of the area). For new areas, unless there is already an architectural plan, the development of a model might not make sense as the area does not exist. Therefore, as an additional step for the cities of Bratislava, Copenhagen and Budapest, the climatic conditions of the city are evaluated to make recommendations on the passive design of the PED (i.e. the architectural design to make it more efficient and reduce the energy demand as much as possible). At the same time, cities using the PED tool[7] assess the potential solutions to be applied in the area and define scenarios to be studied in next steps. Using the baseline model results, several scenarios[8] are evaluated using several software models (PVGIS, python, excel, etc.). Some of the results for some cities are discussed with stakeholders to identify barriers and next actions. Cities also evaluate the possibilities to finance the PED.

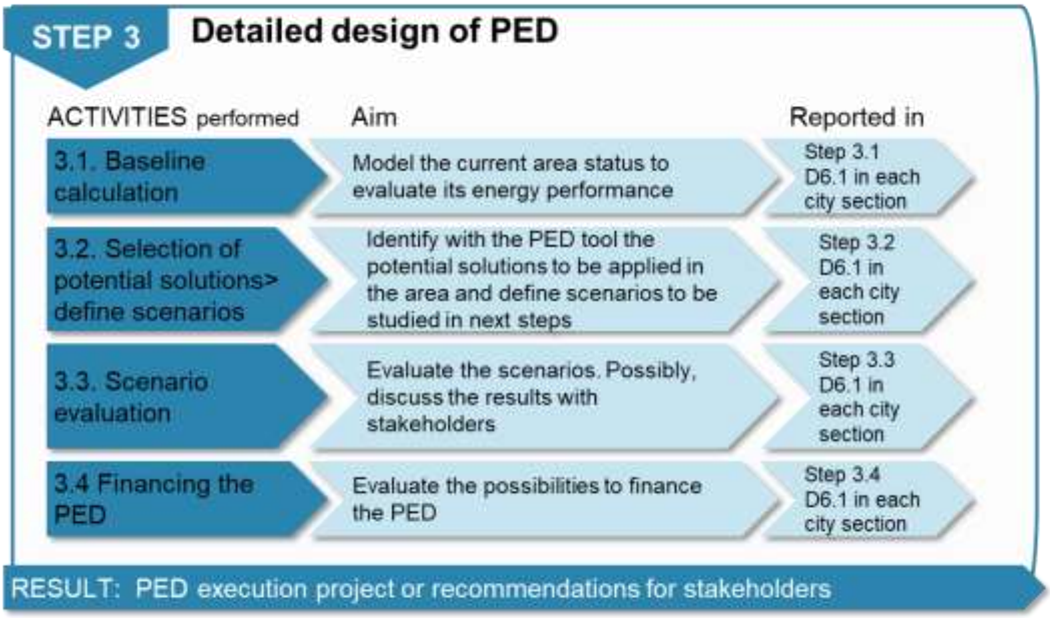

Figure 10 STEP 3 Detailed design of PEDs summary

Hereafter, each step is described in detail.

STEP 3.0: Climatic conditions evaluation

Aim: Some ATELIER cities decided new development areas for their PED design. As climatic conditions can impact human comfort and energy needs of buildings, it is essential to consider a bioclimatic analysis to understand the potential impacts climate can have on building design

[7] https://tools.cartif.es/ped-tool/ explained in D6.2

[8] Not all the technical possibilities are evaluated due to lack of time and resources. Mainly PV, heat pumps, biogas and deployment of DHN are evaluated, as they are the main technologies being applied in PEDs (reference: https://www.mdpi.com/2075-5309/11/3/130)

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and be able to reduce energy needs. The latter characteristic is vital for achieving a Positive Energy District in a feasible way.

Ways of working: To perform this analysis, Climate Consultant software was used. The software uses climate data from reputable sources, such as Energy+ (in epw format). By selecting the weather file for the city location, and by specifying the comfort conditions, bioclimatic charts are obtained, such as Psychrometric Chart, Comfort Chart, Solar Radiation Chart, and Wind Rose Chart. The results help to visualise and analyse the climate conditions relevant to human comfort and building performance. For example, you can identify periods of high temperature and humidity that may require cooling strategies or the potential for passive solar heating during certain seasons. A typical meteorological year file is considered to evaluate the climatic conditions. A future weather file (2050 forecasted weather file) will be used in T6.4, if needed.

STEP 3.1: Baseline calculation

Aim: Evaluate the energy efficiency of the current status of the district.

Ways of working: The baseline calculation consists of creating a 3D model of the district to estimate the energy needs and energy use of the current district status.

To create the 3D model envelope data is collected from each case study, such as 2D drawings of the buildings, U-values (windows, roofs, walls, floor), window-wall ratio, etc. The 3D model is created assuming:

- one node per floor (no internal divisions are considered) in the case of CYPE; one node per building in the case of City Energy Analyst
- domestic hot water dependency of the number of people in the building
- shadows of surrounding buildings and obstacles
- schedule of the building (for occupancy and heating/cooling schedules)
- meet city or ASHRAE comfort standards: 21º/18ºC for winter, 24/26ºC for summer (on/standby modes). Depending on the city these comfort variables might change.

Once the baseline is characterized, for Matosinhos a demand reduction is considered to meet the Passive standards.

STEP 3.2: Selection of potential solutions> define scenarios

Aim: assess the potential solutions to be applied in the area and define scenarios to be studied in next steps.

Ways of working: For each fellow city a selection of potential solution is performed using the PED tool developed by ATELIER and MAKING-CITY.

To do so, the analysis of resources is made in each city following a list of questions to determine the RES potential in their districts.

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Table 12 Questions related to technical restrictions of technologies

Questions related to technical restrictions of technologies
High solar energy potential generation in the area (kWh/kW peak – PVgis)
Local wind energy potential generation (W/m^2 at 10 meters height – Wind Atlas)
Geothermal energy potential generation (different sources are used)
Proximity to a river/sea: from which could be possible to harvest energy
Proximity to an industry/ice rink/waste water plant, etc.: from which could be possible to harvest energy (thermal/electric)
Proximity to a forest: from which could be possible to harvest forest waste
There is Gas grids access
There is a refuelling station near to the district
There is a centralized heating generation
There is RES production
Buildings already have ventilation or an air handling unit
Buildings already have heat pumps or splits
District heating connection available
Supply Tº of the DHN
Number of buildings connected
Substations available on the buildings
District network provides cooling
There is an electric substation nearby
There is an existing district heating or cooling network nearby
There is Virtual Power Plant in the district
There is an Energy Community in the district
There is a waste management (at level district) or waste water plant nearby
There are energy intensive industries in the district

Using the results of these analyses, the cities played with the PED tool to envision some technical solutions. With that selection at least 3 scenarios (combining: minimum 1-2 technologies, up to 5 technologies) is prioritised by the cities.

STEP 3.3: Scenarios evaluation and prioritization

Aim: evaluate the scenarios to come up with a set of recommendations for stakeholders.

Ways of working: Different energy models are used to evaluate the scenarios. For each scenario Key Performance Indicators (KPIs) are calculated in STEP 3.4 for each scenario using the following formulas:

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Table 13 KPIs evaluation in the scenarios

Impacts desired[9]	Calculation
Improve air quality	$GHG\ PED = DE_{bs,c} \cdot GHG_c - DE_{PED,c} \cdot GHG_{PED,c}$
Reduce bills	$Costs\ Saved = \sum OPEX_{bs} - \sum OPEX_{PED}$
Positive Energy Balance	$BALANCE\ PED_{nren} = PE_{nren,imp} - PE_{nren,exp}$
Affordable	$CAPEX = \sum I_i$

Furthermore, cities evaluate in a qualitative way the co-benefits[10] per scenario.

To evaluate scenarios different models are used. Specifically *oemof.solph* package[11] is used to combine electric and thermal technologies to decide which investment is best. Part of the linear programming is validated with TRNSYS (the thermal part) to check that the results are consistent (e.g. supply temperatures are being met). Only the scenarios and combination of measures within a scenario are performed. A comparison of scenarios is performed to see what is best in terms of economic aspects, primary energy and GHG emissions, calculating the indicators above mentioned.

The characteristics of the model are the following:

Characteristics	Definition
Temporal Resolution	Hourly, but it can do years too (depending on the granularity of the data)
Geographic Coverage	District (1 node per group of buildings)
Sectoral Coverage	supply side (using what is called “transformers” and “sources”), demand side(sinks), and storages
Demand Response	It can be used, but not considered it
Accessibility	open-source
Data Resolution	Hourly
Estimated Data	Efficiency data for the technologies is assumed. Efficiencies can be time-series data (e.g. COP estimated for each hour of the year depending on Tºs) or a constant over time

[9] Bs: indicates baseline, c: carrier, ren: renewable, total: renewable+non-renewable, nren: non-renewable, imp: imports, exp: exports. PE= Primary energy, DE= deliver energy

[10] The positive effects that a policy or measure aimed at one objective might have on other objectives, irrespective of the net effect on overall social welfare. (IPCC, 2018) For example: increased property value, better air quality and health, improved land use management, greater biodiversity, enhanced stability of the urban infrastructure; improved participation, interaction, and awareness among citizens; healthier and more active lifestyles (public health and wellbeing), better education, more social cohesion, less poverty, etc.

[11] OEMOF is free, open and documented framework in python for energy system modelling. It contains several open source packages for linear programming: *solph*; to model thermal energy components as an extension of solph: *oemof.thermal*; generate load profiles: demandlib;, power output of wind turbines: windpowerlib; power output of pv: pvlib, etc. DOI:https://doi.org/10.1016/j.simpa.2020.100028

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STEP 3.4: Financing the PED

Aim: Implementing new initiatives, like PEDs, often require significant upfront investment and new business models. Financial instruments can help attract funding and investment from various stakeholders and sources (EU funding, regional funding, etc.) to support the development of an innovative project. Furthermore, PEDs can involve some level of risk, especially when incorporating new technologies, and financial instruments can help distributing the risks among different stakeholders, ensuring no single entity bears with all the burden. The aim of this step is to evaluate the possibilities to finance the PED in each city.

Ways of working: Several financing options studied in D6.2 were presented to cities, as examples of possibilities to fund their PED: e.g. EPC, energy community business model, investment platform, etc. Each financing option comes with its own characteristics, responsibilities (users versus developers) as well as requirements. Table 14 shows an overview of the possibilities presented to cities.

From those possibilities, cities, based on their area selected, were asked to think which options are more feasible for them and why. Cities could also add new financing possibilities that they know about. This financial instrument can be part of their Tendering Procedure or in their stakeholder process, to ensure a successful implementation.

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Table 14 Financing options for PEDs

Type of model / Stakeholder:	Energy Performance Contract (EPC) - Shared savings	Energy community business model	Investment platform (TNO)	European, National, Regional funds
Description	This is a form of creative funding for capital enhancement that permits the upgrading of funding energy upgrades from cost reduction. In Energy Performance Contracting (EPC), and Energy Saving Company (ESCO) is assigned the responsibilities of executing an energy efficiency or a renewable energy project. The production of energy or saving in the project finances the initial investment of the project that is to be carried out.	A private or public energy company launches a citizen-funded project, in which people can join by: - Offering their roofs. - Offering investment (which can be funded with a loan by a bank or by their own funds). Roofs are prioritised in terms of order of arrival. Plus, the energy company checks the techno-economic suitability of the roof and launches the installation. Energy company also manages the energy flow.	Through an investment platform the municipality, the financial sector and other public, private and civic investors can work together on initiatives within the district. They can for example use the platform to finance the development of an interconnected energy system on district level to support renewable energy sources. The aim of the platform is to align, structure, speed up and increase investment decision making of stakeholders, public, private and civic, at the district level.	A grant is a direct monetary assistance to an entity to pursue a specific project or programme. Depending on its stipulations, it can be used to fund solutions to identified problems within a community and can come from federal, state, regional and international resources. **Partial Grant plus Partial Self finance :** As the name suggests, with this financing source, the project capital is financed partially through a grant and the remaining is financed using the municipal budget. Many grants require the municipality to contribute a certain amount to establish ownership.
Developer(s)	The developer (energy service company or equipment manufacturer)	The developer (private or public energy company) manages the energy flows of	To get to effective investments there is a need for insights on	The grants can have many restrictive stipulations which need

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	does the installation and ensures energy savings through an energy performance contract. The ESCO is compensated in regard to the performance revealed and delivered towards the agreed energy saving.	the community and charges for the energy consumed from the grid to its users. The revenues come from that purchased energy and the reimburse energy associated to the excess of energy injected to the grid of the roof owners.	stakeholders, projects, budgets and possible financial partners at district level. This makes it essential to better align investments by companies, governmental bodies, individuals and their collectives in order to achieve the necessary volumes. For example, the platform could agree that all parties invest the same money and revenues or costs savings are equally shared. They could agree to invest depending on buildings' footprint or building consumption, and costs savings could be shared according to the % of investment. It could be a similar option as	to be met to meet eligibility. Therefore, projects need to be designed to fit the requirements of the grants.
User(s)	Clients do not have access to finance. They get benefits from increase of comfort. The cost savings are split according to previously agreed upon percentage based on cost of the project and risks taken by the ESCO, and for a previously agreed time span based on the length of the contract.	Once the installation is made, roof owners benefit from a cost energy reduction. Capital repatriation of the roof takes place on the one hand through the savings in electricity purchase from the network, and on the other hand through the excess electricity payment, both managed by the energy company. After no longer than 12.5 years the photovoltaic system becomes the property of the roof owner. The more energy savings, the sooner the repatriation takes place. The investors receive an interest (higher than the bank) from the amount of money invested.		

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4. PED design in Bratislava

In this section, the steps defined in section 3.2 are applied to the city of Bratislava. Starting with (Section 4.1) the city context and identifying the strengths, weaknesses, opportunities and threats of Positive Energy Districts; followed by the prioritization of one of the preselected areas in proposal stage (Section 4.2) and finalising with a PED detailed design for the selected area in section 4.3. The output is a set of recommendations for stakeholders to deploy PEDs in that area.

4.1. STEP 1: City's environment for PED implementation

Context

Bratislava is the **capital** and largest city of Slovakia, although it is still one of the smaller capitals of Europe (475k inhabitants[12]; together with Tallin, Luxembourg or Ljubljana). Bratislava is in the south-western Slovakia, occupying both banks of Danube River and the left bank of Morava River.

The city is **administratively divided** into 5 districts, which are further divided into **17 city boroughs**. Bratislava City has then two levels of governance, at city level and at borough level. This leads to the municipality not having access to all data. To get the data might require to ask each district for it, which may be a long and complicated process.

Bratislava has a **density of 1,169 people per km^2** (2020), and a **GPD** of 25,450 M€ in 2018, which is much higher than in the rest of the country.

Bratislava is located in the North Temperate Zone and has a **moderately continental climate** with average annual temperature of around 10.5 °C. The average temperature is 21 °C in the warmest month, and −1 °C in the coldest month, and it has four distinct seasons and precipitation spread rather evenly throughout the year. It is often windy with a marked variation between hot summers and cold, humid winters. The city is in one of the warmest and driest parts of Slovakia.

Bratislava city has experience in **similar projects** to ATELIER, such as H2020 Resilient Cities and Infrastructures (RESIN), H2020 Advancing resilience of historic areas against climate-related and other hazards, FP7 EN European cities serving as Green Urban Gate towards Leadership in sustainable Energy - EU GUGLE, Central Europe EU ERDF Funds - Enabling Private Owners of Residential Buildings to Integrate them into Urban Restructuring Processes (EPOUrban).

Conditions to allow a Positive Energy Balance

Energy certification is mandatory for all new buildings or after a general refurbishment (deep renovation). This includes residential buildings as well, but only under those two premises.

There is lack of information with respect to the **peer-to-peer exchange**, it is not mentioned in the legislation. There is a new law on energy efficiency of buildings, but it does not mention the energy exchange.

[12] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Main_indicators_for_capital_city_metropolitan_regions,_2014_Cities16.png

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Citizen energy communities in the cities for power or heat generation are unlikely, they are only possible for some condominiums that can disconnect from the central system and use their own boiler, but in general terms, Slovakia's legislation does not allow disconnecting from the central heating system (legal barrier that will/should change). The new government elected in February 2020 announced a plan with strong support for renewable energy sources, with an aim to reduce bureaucracy, make the support schemes more transparent and the application process less complex.

Self-consumers and renewable energy communities will be entitled to install their own equipment to produce heat from RES to provide heat for their own consumption, enable the storage of heat produced from RES and the sale of excess production. They will be subject to non-discriminatory fees and payments to participate in the fixed costs associated with the operation of the district heating system including storage. The right of renewables self-consumers and RECs to set up a heat generation plant in a building to cover their own heat consumption, to use energy storage, and to sell excess heat will only be exercised at the level of the whole building consumers (feed-in tariff costs represent around 20% of the final electricity price). But all this is not yet consolidated, since there are no funds linked to it.

For now, it is not possible to inject **hydrogen** in the gas grid. There are some ideas about how to use hydrogen, they are establishing a new research centre to investigate how to use gas pipes to transform it, but it will take long. There is also a hydrogen academy.

Regarding the **District Heating regulation**, it is mandatory to connect to the District Heating Network, although it is not that strict for new buildings (new buildings close to a DHN have to connect, but those which are not close to a DHN can have their own heating system). At the moment it is not possible for Energy Communities to create their own DHN, but it might be possible in the future.

Conditions to allow Renewable Energy Production

There is an amendment to a law to reform the support of **electricity production from RES**. The new rules introduced a new feed-in premium tariff (which guarantees a premium above the market price) through green auctions for solar installations above 100kW and other installations above 500kW, instead of the existing feed-in-tariff system. For smaller installation, the **feed-in-tariff** will be still available but not as generous as it was in 2009-2010 when most of the new solar plants were installed. The amendment has also introduced a local source up to 500kW and obligation of distribution to connect these sources to the national grid on the condition that 90% of electricity is consumed at the place of installation, but shall not receive any feed-in-premium or feed-in-tariff. Furthermore, to solve the stop status, the amendment transferred obligation to pay the tariffs from the distribution companies to the Short-term Electricity Market Operator (OKTE) which is a stated-owned entity.

There is also legal burden on the installation of specific technologies. **PV panels** need permissions and lot of paperwork (administrative work) to be able to install them. For self-consumption, it is possible to export energy but up to 10% of their installation capacity (90% need to be self-consumed), which in reality is not working. PV panels are usually installed with batteries. In addition, there is only one electricity company in the residential market. There is also a limit on the capacity to be installed for self-consumption. The permit is not required for certain activities, such as the production and supply of electricity by electricity generation installations with a total installed capacity of up to and including 1 MW, the production and supply of gas from biomass and other activities.

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Conditions to allow Efficient buildings/ Building stock demand

Bratislava has an **old building stock**, which needs refurbishment plans to regenerate it. Buildings from late 70's are connected to the District Heating, but older ones have individual boilers. There is legislation to renovate buildings but at different levels, the main amount of buildings is residential and since they are private, it is difficult to engage and involve owners. For residential buildings it is recommended to renovate them, but not mandatory. This means that the building stock is not as efficient as it should be.

Renovation of buildings is set for a total of 29,000 apartment building units and 22,000 family houses annually. The majority of renovated buildings followed the minimum energy performance requirements valid at the time of carrying out the construction works. First renovation requirements for buildings were 20cm envelope insulation, but this also depends on the building category.

New buildings should fulfil the requirements set for ultra-low energy construction and achieve the global indicator for energy class A1. Heat recovery systems with a minimal efficiency of 60% for the ventilation spaces is further required. The requirements for the global indicator for primary energy are set depending in the category of the building. New public buildings must fulfil **nZEB requirements** from 2019 on.

RES and heat recovery are mandatory in new buildings in Slovakia. At least 50% of the energy used in nZEB should be covered by RES. Implementing heat recovery systems or units with efficiency higher than 60% is also required.

There is a very low rate of public social housing in Bratislava.

Family houses have specific funds for energy saving renovations, for improving the envelope. There are also subsidies for systems replacement (old gas boilers by heat pumps, for PV installation, etc.); as well as the EU structural funds. With the new plan there will be a new subsidy plan as well.

Conditions to allow Liveability

Bratislava initiated a **project on urban mobility** worth 246 million euros. The main activities under the initiative will include: new **tram** line linking the city centre with Petržalka, the most densely populated area of Bratislava; expansion, modernization and upgrading of the already-existing tram system; raising awareness of public transportation advantages; acquisition of new trolley buses; construction and development of new infrastructure including cycling routes and strategic PR facilities.

Conditions to allow PED implementation

Regarding the planning affecting the PED implementation, at national level, to 2030 (aligned with EU targets that Member States had to transpose into their national regulation), there is a target on GHG emissions reduction and a share of RES for the energy consumption. It is also highlighted the relevance of the electricity interconnectivity.

SEAP was targeted to 2020, with a **CO_2 reduction** by 20% compared to 2005 baseline levels, the renewal of housing stick and the increase of the energy efficiency of the DH systems. Bratislava also aims to develop the SECAP in the coming years, including both mitigation and adaptation measures to climate change effects.

SWOT analysis results

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

Bratislava's inputs are summarized in a SWOT table to identify which internal factors help or harm the PED implementation, as well as which external factors (National, EU level, etc.) creates opportunities and threats to the Bratislava context.

What can be conclude is:

- Although Bratislava has the highest GDP in their country, one of the main limitations is the access to funding, which is limited in the city, but there are many opportunities at EU level.
- There is a favourable regulatory environment for decentralized energy generation, but at the same time DHN is mandatory in some cases, which implies to involve always this stakeholder for PED purposes. There are also limitations in terms of energy communities.
- The feed-in tariff system through green auctions incentivizes solar installations and renewable energy generation. Exemptions for small-scale electricity and gas production could simplify the permitting process for energy generation installations.
- There is an increase of building renovation, but still the building stock is old. New buildings have a mandatory certification and ambitious energy performance standards..
- There is a high administrative complexity, and therefore governance problems.
- There are opportunities for hydrogen (Except for injection to the gas grid) and sustainable mobility projects.
- Lack of regulations for P2P exchange, PV barriers and understanding of the PED concept.
- Monopolies in some energy sectors

Therefore, PED implementation has the potential to leverage its strengths, and capitalize on opportunities, but an effective coordination of stakeholders and district departments in the city, regulatory adjustments, and community engagement will be crucial in realizing PEDs.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

	HELPFUL	HARMFUL
INTERNAL FACTORS (City context)	STRENGHTS	WEAKNESSES
	Highest GDP in the country	Possible complicated processes due to the city administratively division on 17 districts
	In process: self-consumers and renewable energy communities entitled to install own equipment to produce heat from RES (for own consumption, storage and sale of excess production)	Little possibilities to form citizen energy communities, and not possible to create their own DHN
	Ideas about the use of hydrogen, research centre to investigate about it	Not possible to inject hydrogen in the gas grid
	Renovation of buildings: 29,000 apartment building units and 22,000 family houses annually	Mandatory to connect to the DHN
	Project on urban mobility: new tram, update existing tram, new trolley buses, better infrastructure including cycling routes, etc.	Old building stock. Buildings older than 1970 have individual boilers
		Low access to funding opportunities
		Low rate of public social housing
EXTERNAL FACTORS (National, EU level)	OPPORTUNITIES	THREATS
	Energy certification is mandatory for all new buildings and after a deep renovation	Lack of regulation/legislation for peer-to-peer energy exchange
	Feed-in tariff system through green auctions for solar installations	Slovakia (in general terms) does not allow to disconnect from the central heating system
	Permit not required for the production and supply of electricity (by electricity generation installations with a capacity installed until 1 MW), or for the production and supply of gas from biomass	Legal burden for the installation of PV panels (permits)
	RES and heat recovery are mandatory in new buildings in Slovakia	Only one electricity company in the residential market
	New buildings should fulfil nZEB requirements from 2019 on	Limit on the capacity to be installed for self-consumption
	New buildings are required to have a minimal efficiency of 60% for the ventilation spaces	Not mandatory the renovation of residential buildings (only recommendation)
	At least 50% of the energy used in nZEB should be covered by RES	
	Specific funds for energy saving renovations for envelope of family houses	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

	Subsidies for systems replacement	

Table 15. Bratislava SWOT analysis results

4.2. STEP 2: Selection of suitable area to design a PED

As said in section 3, from the preselected districts in proposal stage, a prioritization exercise is performed.

Bratislava identified two potential districts for the implementation of their PED:

- Potential district #1: OLO Bazová
- Potential district #2: Petržalka - Janíkov dvor

The former one is a brownfield area, partially occupied by Municipal cleaning and gardening maintenance company, major part of the buildings abandoned, refurbishment necessary.

The second location is greenfield area next to the future public transport junction with new tram line on the edge of suburb Petržalka. New tram line will connect the location with the rest of the city at the end of the year 2023. Area is also partial sector of the new urban study procured by the city of Bratislava. This urban study is still in process of creation.

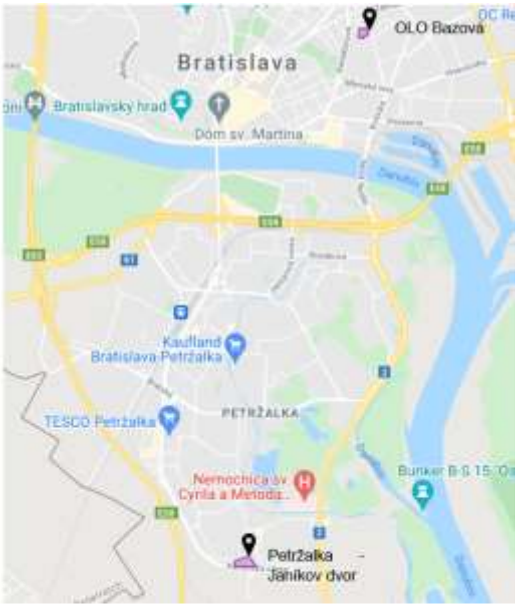

Figure 11: Bratislava pre-selected PED areas

Now the process of the methodology explained in *STEP 2: Selection of suitable area to design a PED* is followed to prioritize one of the two for performing the next steps (towards a PED detailed design).

STEP 2.1

To start assessing the districts, first (STEP1.2) the desired objectives or impacts to be achieved by the PED implementation are identified. The impacts are identified and the pairwise comparison is performed, which results in:

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Table 16 Bratislava Impacts Prioritisation

		A	B	C	D	E	F	G	H
RER (Renewable Energy Ratio)	A	**1.0**	5.0	0.2	0.2	0.2	0.2	0.2	5.0
Improve air quality	B	0.2	**1.0**	0.2	0.2	0.2	0.2	0.2	0.2
Reduce bills	C	5.0	5.0	**1.0**	0.2	5.0	5.0	5.0	5.0
Achieve zero energy imports	D	5.0	5.0	5.0	**1.0**	0.2	5.0	5.0	5.0
Positive Energy Balance	E	5.0	5.0	0.2	5.0	**1.0**	5.0	5.0	5.0
Efficient buildings	F	5.0	5.0	0.2	0.2	0.2	**1.0**	5.0	0.2
Affordable	G	5.0	5.0	0.2	0.2	0.2	0.2	**1.0**	0.2
Liveable	H	0.2	5.0	0.2	0.2	0.2	5.0	5.0	**1.0**
	ADDING VALUE	26.4	36	7.2	7.2	7.2	21.6	26.4	21.6

Then, the impacts are compared with the city objectives, which results in:

Table 17 Bratislava Ranking to assess PED characteristics (PED vs City Priorities)

FINAL WEIGHT (considering CITY PRIORITIES)	**Ranking**	
5%	**6**	RER (Renewable Energy Ratio) factor
3%	**8**	Improve air quality
19%	**2**	Reduce bills
13%	**4**	Achieve zero energy imports
31%	**1**	Positive Energy Balance
9%	**5**	Efficient buildings / Building stock demand
3%	**7**	Affordable
17%	**3**	Liveable

This means the characteristics of the area that allow to achieve these impacts will have a resulting composite indicate that gives more score (a weight) to these characteristics than other ones (e.g. the indicators will give more score to areas that have renewable energies and high energy efficiency as both characteristics allow to achieve a Positive Energy Balance).

STEP 2.2

Using the City context template, city level details about the renewable energy source (RES) potential are asked in step 1.1 (such as maps, GIS data, etc.). This data potential at city level is used to analyse the RES potential at district level and compare the two areas. For Bratislava, as there was not sufficient data at city nor district level, a detailed analysis has been performed searching in the different open data platforms (sEEnergies, PVgis, Wind Atlas, geoDH map, etc.). A summary of the results is presented in the following table:

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Characteristics	PED 1	PED 2
High solar energy potential generation in the area (kWh/kW peak – PVgis)	1164.28	1171.65
High wind energy potential generation (W/m2 at 10 meters height – Wind Atlas)	67	91
Geothermal energy potential generation	YES	YES
There is a river/sea close from which could be possible to harvest energy	YES	YES
There is an industry/ice rink/waste water plant, etc. from which could be possible to harvest energy (thermal/electric)	NO	NO
There is a forest from which could be possible to harvest forest waste	NO	NO
There is Gas grids access	YES	YES
There is a refuelling station near to the district	YES	YES
There is a centralized heating generation	YES/NEEDS REFURBISHMENT	NO
There is RES production	NO	YES
Buildings already have ventilation or an air handling unit	NO	NO
Buildings already have heat pumps or splits	NO	NO
District heating connection	YES	YES
Supply Tº	75ºC supply/50ºC return in summer, in winter 115ºC supply/55ºC return	90ºC supply/70ºC return
Number of buildings connected	buildings 1-4	YES
Substations available on the buildings	Substation with heat exchanger and tanks in building No.1 - needs reconstruction	-
district network provides cooling	NO	NO
There is an electric substation nearby	NO	YES
There is an existing district heating or cooling network nearby	YES	YES
There is Virtual Power Plant in the district	NO	NO
There is an Energy Community in the district	NO	NO
There is a waste management (at level district) or waste water plant nearby	YES	YES
There are energy intensive industries in the district	NO	NO

Both areas identified have access to a nearby district heating network according to sEEnergies Open Data platform. This has been confirmed by the city. In fact, PED area 1 is already connected, but it needs refurbishment according to the city.

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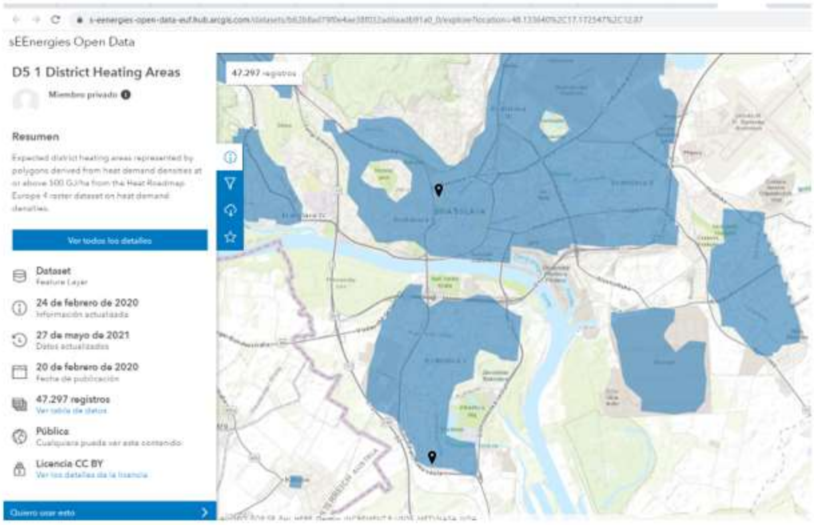

Figure 12: District heating areas in the city of Bratislava (sEEnergies Open Data platform)[13]. The points indicated in the map are the PED areas

No industry points close to the areas have been identified. There is only one industry with waste heat available according sEEnergies Open Data platform (called Slovnaft, a.s., and located near the airport).

Figure 13: Potential waste heat sources (industry) (sEEnergies Open Data platform)[14]. The points indicated in the map are the PED areas

Nevertheless, in the PED area 2 there is one waste water plant (called Slovenský Vodohospodársky podnik petržalka), that according to sEEnergies Open Data platform, it could potentially provide their excess heat.

[13] https://s-eenergies-open-data-euf.hub.arcgis.com/datasets/b62b8ad79f0e4ae38f032ad6aadb91a0_0/explore?location=48.133640%2C17.172547%2C12.87

[14] https://s-eenergies-open-data-euf.hub.arcgis.com/datasets/a6a1e8e95514413a90bbb2e40515fdb2_0/explore?location=44.450426%2C17.567450%2C4.70

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Figure 14: Potential waste heat source: Waste water plants (sEEnergies Open Data Platform)[15]. The points indicated in the map are the PED areas

According to geoDH map, there is geothermal energy potential. The red contour delimits a hot sedimentary aquifer, with potential to harvest energy at 2000m at a temperature greater than 50ºC. Furthermore, according to the portal Geoplasma, Bratislava PED areas are both suitable for: borehole heat exchangers, and groundwater heat pumps.

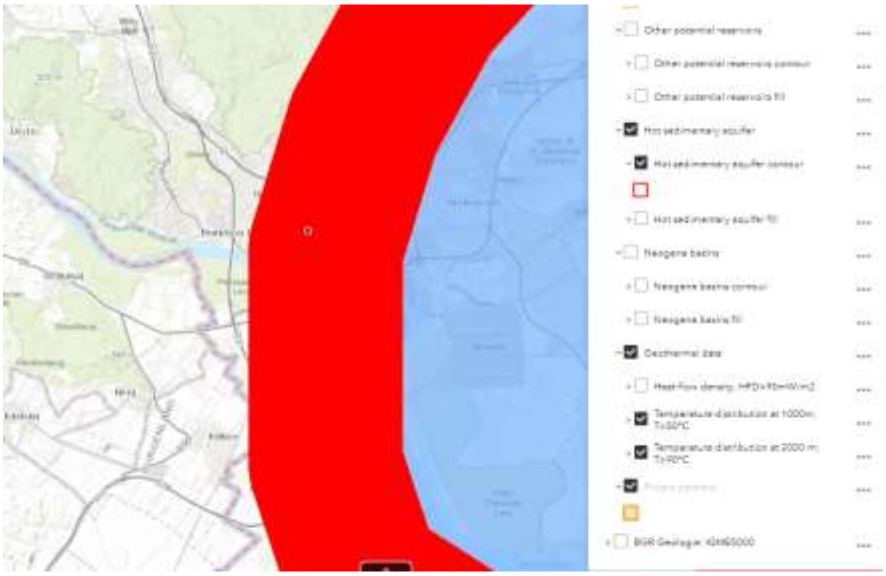

Figure 15: Geothermal potential (https://map.mbfsz.gov.hu/geo_DH/)

15s-eenergies-open-data-euf.hub.arcgis.com/datasets/2357e5fcfb744d2f8f842cd7171a90a0_0/explore?location=48.135375%2C17.102720%2C11.88

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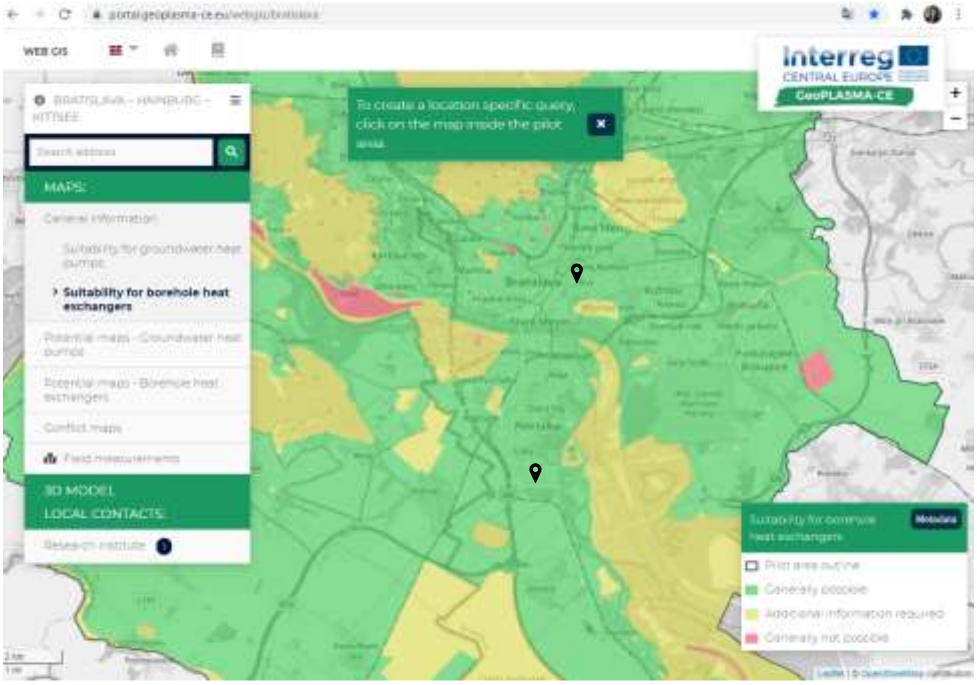

Figure 16: Suitability for borehole heat exchangers (https://portal.geoplasma-ce.eu/webgis/bratislava). The points indicated in the map are the PED areas

Using PVgis the PV potential is obtained for the optimal tilt and azimut for a location in the middle of the PED areas. For PED area 1 a potential of 1164.28 kWh/year/kWpeak installed is obtained, with a tilt of 38º and azimut of -1. For PED area 2 a potential of 1171.65 kWh/year/kWpeak installed is obtained, with a tilt of 38º and azimut of -1.

In Wind Atlas, the wind potential is obtained for a location in the middle of the PED areas, and at a height of 10 meters (to allow mini wind turbines). For PED area 1, a potential of 67 W/m^2 is obtained for a height of 10 meters and a wind velocity of 3.41 m/s. For PED area 2 a potential of 91 W/m^2 is obtained for a height of 10 meters and a wind velocity of 3.73 m/s.

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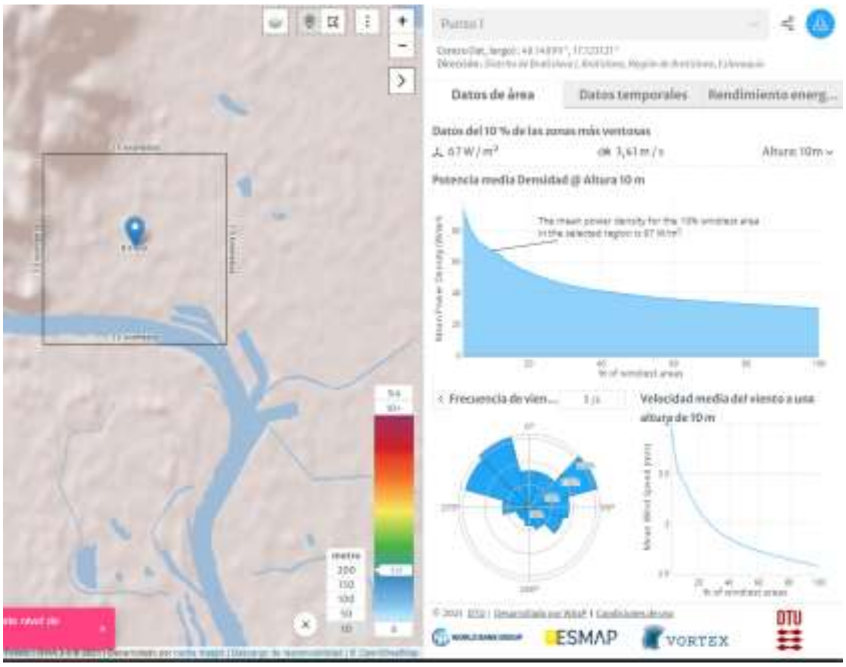

Figure 17: Wind potential in PED area 1

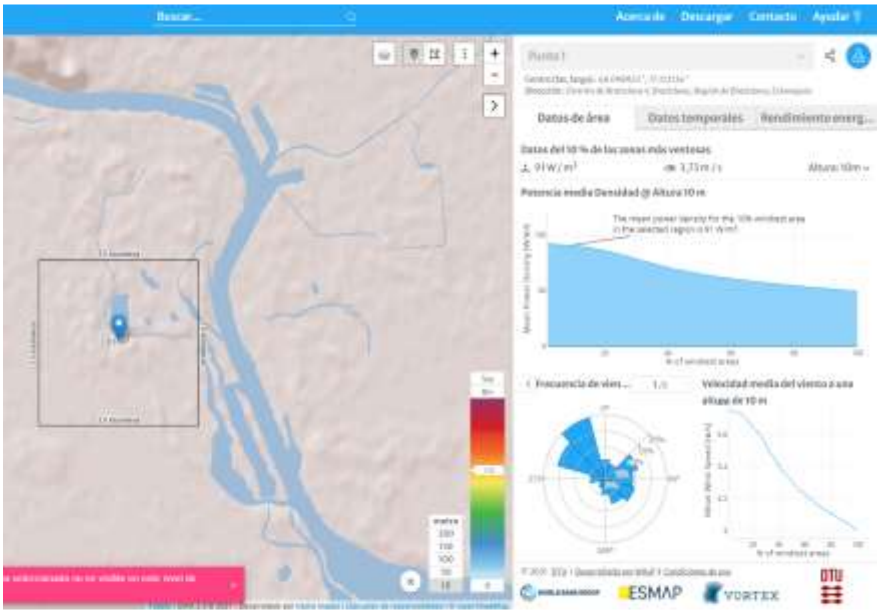

Figure 18: Wind potential in PED area 2

Lastly according to ChargeMap, in PED area 2 there are 4 charging points (with a power of 16-30 kW) and in PED area 1, there are 4 Fast charging points (with a power greater than 30kW), and 3 accelerated points (with a power of 16-30 kW).

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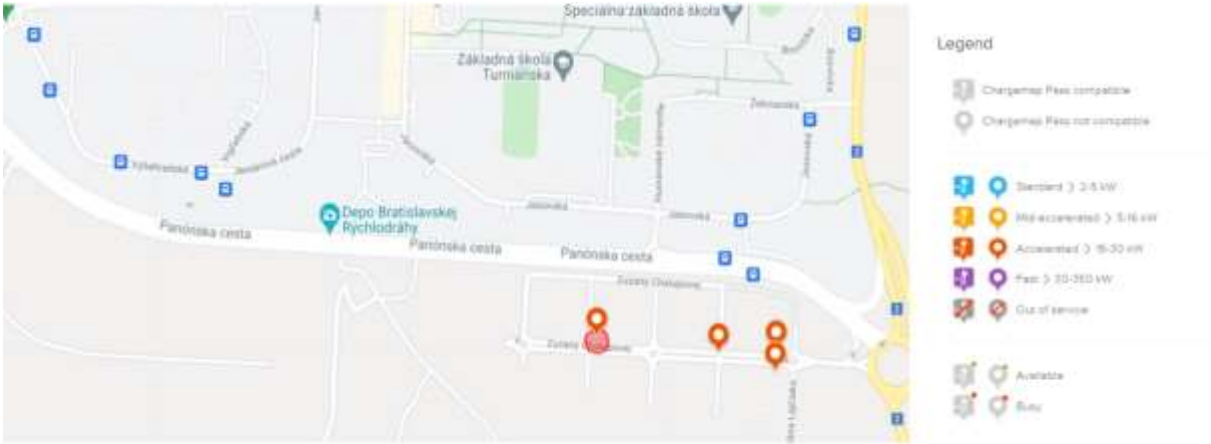

Figure 19: Charging points in PED area 2.

Figure 20: Charging points in PED area 1

All of these characteristics, as well as spatial, social and economic characteristics[16] are weighted using the resulting scores from STEP 2.1 in next step.

STEP 2.3

Considering spatial, technological, social and economic factors, a **composite indicator** that ease the PED area prioritization is obtained for each of the areas. The process is validated by the city. PED area 1 obtained a final score of 0.57, whereas PED area 2 obtained a final score of 0.76. This is due to the fact that, PED 2 is greater in size (roof, km2, land) with higher RES potential and, potential to be connected with a DHN. Summary of the results are shown in Figure 21.

[16] The requested information is not displayed due to confidentiality reasons.

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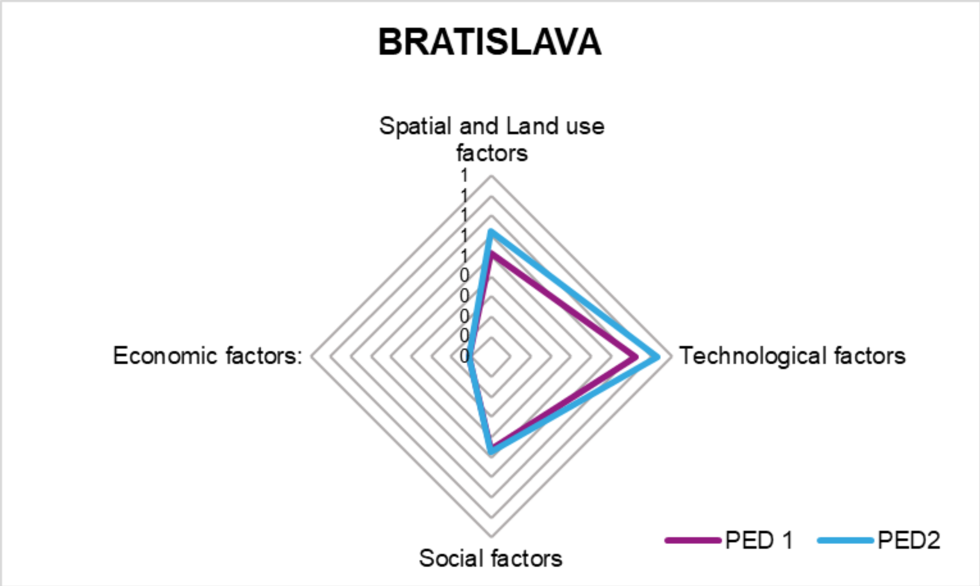

Figure 21: Final selection of PED and summary of scores, and final weights.

4.3. STEP 3.1: Detailed design of PED

STEP 3.0: Bioclimatic design

In order to support the PED design in new development areas, an evaluation of the climatic conditions has been done by collecting and analysing the main climatic variables (temperature, humidity, wind, rain...) using the software Climate Consultant.

Based on the main climatic data, the specific characteristics of each season (Winter, Spring, Summer and Autumn) have been extracted. This data will inform the implementation of the heating and cooling strategies for each season.

The execution of these strategies attempts to achieve comfort in accordance with the subsequent standards: the comfort temperature is deemed to oscillate between 20,3ºC-24,3ºC in winter, and 20,3ºC-26,7ºC, in summer. Also, it is considered the necessity for shading when the dry bulb temperature is above 23,8ºC and simultaneously the global radiation is more than 325,5Wh/sq.m. Wind protection strategies are incorporated when wind´s speed is above 8,5m/s or temperature is at least 11,1ºC below minimum comfort value for dry bulb temperature, to maintain heat gains in the buildings.

Local analyses of the current climatic conditions

GENERAL STRATEGIES FOR PASSIVE URBAN DESIGN
JANUARY - MARCH
1.ENERGY NEEDS:
Temperature: The minimum temperatures recorded reach temperatures below zero degrees, especially in February when the minimum is around -20ºC. Hence, it is essential to provide enough heat to cover the demand, from January through March. (see Figure 121: Dry bulb diagram) Since there is not much sunlight, during this time of year shading is not required. In March global radiation increases enough to exceed 400Wh/sq.m., which would reduce heating demands if correctly used. (see Figure 122: Diurnal average diagram)

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Wind: The wind often blows from northwest in January and March, and from northeast in February, with an average speed of 2,7m/s. (see Figure 126: Wind wheel_JAN-MAR)

2.SOLAR PASSIVE GAINS

Due to the short amount of daylight hours and low solar radiation received in this period of the year, the possible solar gain will be minor and it should be optimized to reduce heat demand. For this purposed, it should be taken into account that the angle of incidence of sunlight is around 23,5º in winter, facilitating sun incidence. The incidence of sunlight in the south façade varies over the months, although it does receive sunshine for nearly the whole day. As well as, the sun shines on the east façade from morning until noon and the west façade from midday until sunset. The north one, however, does not receive sunlight.

3.STRATEGIES

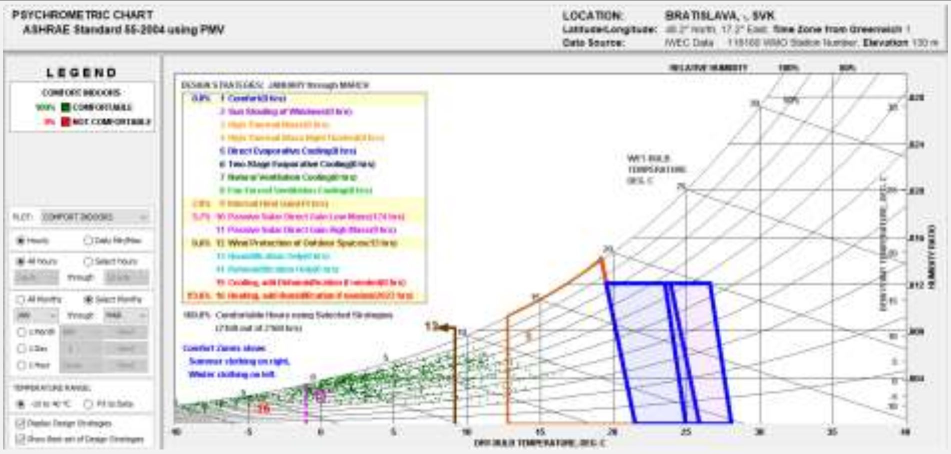

Figure 22: Psychometric chart without any strategy JAN-MAR

It would be necessary to incorporate a heating energy source in the buildings and increase solar capture during these months as much as it would be possible, due to the cold temperatures and limited sunshine, using them to provide heat.

As there is low probability of overheating and any passive solar gain is advantageous, the primary façade of the structures should be facing south and have large windows on it, even if windows can be unshaded and facing in any direction.
In addition, it would be essential to incorporate measures to preserve that warmth after sunset, such as thermal inertia enclosures, to allow accumulating energy during the winter.

In the benefit of archiving 100% of the time to be comfortable, the design strategies implemented should focus on gaining internal heat, passive solar direct gain low mass, wind protection of outdoor spaces, and, as a special important measure, to provide heating and humidification if needed.

Among the strategies for archiving it are:
Place transparent surfaces/ glass surfaces in the south to maximize sun exposure.

- Implementing a more efficient heating system.
- Adding more insulation in the façades and roof, to avoid thermal bridges.
- Designing buildings without excessive floor areas, which would waste heating and cooling energy.
- Using low mass materials that are firmly sealed in well-insulated structures to enable solar gains to heat in the morning.

APRIL – JUNE

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1.ENERGY NEEDS:

Temperature: The average temperature in spring is over 14ºC. There is a considerable increase in the temperature range compare to previous months of the year. Although in April, the coldest month of spring, when the temperatures still drop to 0º, they also rise above 25ºC; and in June they even reach 30ºC. (see Figure 121: Dry bulb diagram)
As the sunlight hours increase, also does the temperature and radiation; being over 400Wh/sq.m all the springtime.
In April, shading is not required, as the average temperature is still 10ºC in this month. If during sun hours, the heating gains can be used to compensate for the drop-in temperature at night, reducing or eliminating the need for heating input.
On the other hand, from 11:00 hours to 16:00 in May and June, it would be necessary to shade specially in the south façade, when the risk to overheating increases. (see Figure 122: Diurnal average diagram)

Wind: The wind often blows from the northwest throughout the second trimester of the year, with an average speed of 3 m/s. (see Figure 127: Wind wheel_APR-JUN)

2.SOLAR PASSIVE GAINS

The incidence of the sunlight on the façades generates enough solar passive gains. If used, it can generate a relevant thermal contribution to the heat balance.
During May and June, the irradiation is high, and shading is especially necessary in the south façade, which receives a lot of sunlight. The sun shines on the east façade from dawn until noon, and then on the west façade from midday until sunset. The north façade receives some light but it is still a small in relation to the rest.

3.STRATEGIES

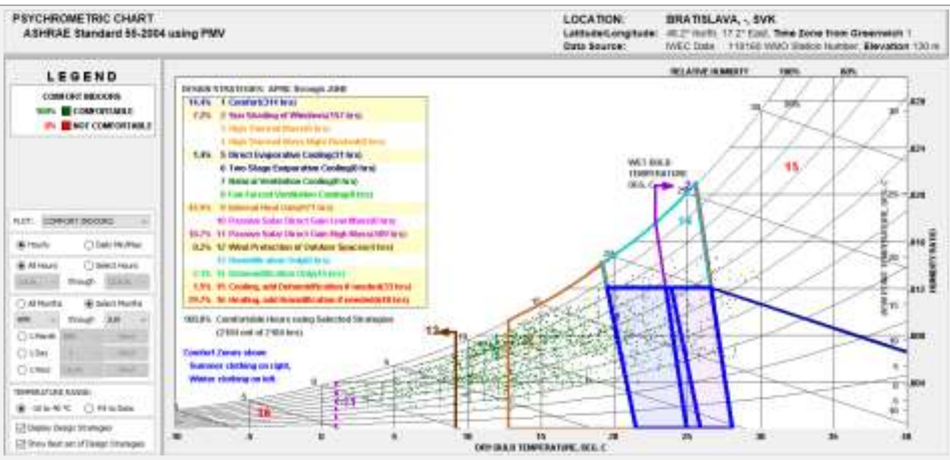

Figure 23: Psychometric chart without any strategy APR-JUN

It is still crucial to take advantage of the daylight illumination, even if in Spring the temperatures increase and daytime lengthen. For example, in April, the temperatures are still quite cold at night, and storage temperature during the day, may be useful to reduce heat demand. Solar passive gains during the most heated hours would balance the temperatures´ drop; which can be accomplished incorporating enclosures with thermal inertia.
This should be reconciled with the necessity of providing enough shading in May and June; when average temperature reach over 25ºC, involving adapting fixed shading systems to the different incidence angle of sunlight or using mobile systems.

Regarding sunlight, sun incidices on the south, east, and west façades when natural light is required. East solar gains are great for comfort. Even the north façade would receive some indirect sunlight in the morning. Although the north façade of the building should not have

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barely any windows since they would get very little morning sunlight, and it would not be efficient.

In the benefit of archiving 100% of the time to be comfortable, the design strategies implemented should focus on sun shading of the windows, direct evaporating cooling, gaining internal heat, passive solar direct gain high mass, wind protection of outdoors spaces, dehumidification, and providing heating or cooling and humidification if needed.

Among the strategies for archiving it are:

- Using high mass interior surfaces (slab floors, high mass walls, stone fireplace...) to store winter passive heat and summer night “coolth”.
- Using more efficient windows (double or triple pane).
- Sunny wind-protected outdoor spaces can extend living areas.
- Locate dense planting or exterior structures such as garages or storage areas on the side of the buildings, facing the coldest wind to help insulate.

JULY – SEPTEMBER

1.ENERGY NEEDS:

Temperature: During summer, temperatures are high. In July and August, maximum temperatures are above 30 degrees. Average can oscillate between 20ºC and 25ºC. Therefore, it will be very important to preserve the cool of the night and to avoid overheating, reducing the cooling necessity. (see Figure 121: Dry bulb diagram)
Due to the high summer heat, it would be necessary to provide shading from 9:00 to 19:00 in July and August. In addition, since the temperatures and the radiation decreased in September, so does the necessity for shading and cooling demand; when shading would be required on the most heated hours. (see Figure 122: Diurnal average diagram)

Wind: The wind often blows from the north-west throughout the third trimester of the year, with an average speed of 2m/s. After this table, there is more information about implications of wind (see Figure 128: Wind wheel_JUL-SEP)

2.SOLAR PASSIVE GAINS

The high temperatures require reducing the amount of solar passive gains to the minimum possible, as they would be enough to compensate the little drop in temperature at night. The incidence in the façades would be larger than the previous months, although with longer daytime and higher incidence. Nevertheless, the shade system should allow the winter sun to enter. For this purpose, the angle of incidence of sunlight is relevant, being in summer around 70º.

3.STRATEGIES

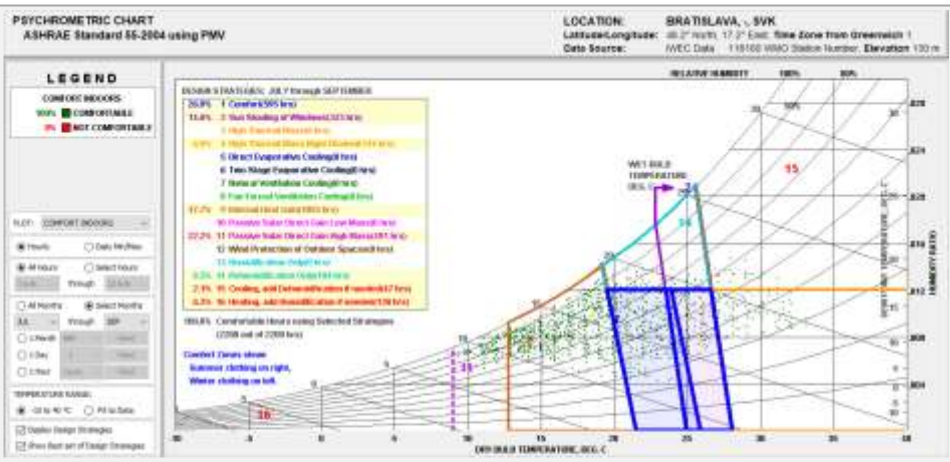

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Figure 24: Psychometric chart without any strategy JUL-SEP Due to the high temperatures, it would be necessary to provide cooling during daytime, which can be reduced implementing shading and ventilation that allows to keep night coolth and reduce solar gains. It has to be taken into account that the south, east, and west facades of the buildings receive direct sunshine during the day, and in the mornings, even the north façade gets some indirect light. As a result, windows facing east are adequate for comfort and require less shading. In the benefit of archiving 100% of the time to be comfortable, the design strategies implemented should focus on sun shading of the windows, high thermal mass, night flushed, gaining internal heat, passive solar direct gain high mass, dehumidification, and providing heating or cooling and humidification if needed. Among the strategies for archiving it are: • Using high mass interior surfaces (slab floors, high mass walls, stone fireplace...) to store passively. • Low pitched roofs with wide overhangs works well in temperate climates. • Designing windows location to prevail breezes, incorporate shading elements and generate natural ventilation. • Sunny wind-protected outdoor spaces can extend living areas.
OCTOBER – DECEMBER
1.ENERGY NEEDS
Temperature: The temperatures decrease until below zero degrees, with maximum temperatures barely around 20ºC. Like so, there is a demand for warmth throughout this time of the year. (see Figure 121: Dry bulb diagram) As the sunlight hours and the temperatures and radiation decrease so much, it would not be necessary to shade at all during autumn months. (see Figure 122: Diurnal average diagram)
Wind: The wind often blows from northeast, with an average speed of 2,3m/s. (see Figure 129: Wind wheel_OCT-DEC)
2.SOLAR PASSIVE GAINS
During these months the temperature and radiance decrease, so the solar gains should be optimized, taking into account the incidence on the various façades as follows. The length of time the sun shines on the south façade varies over the months, it does receive sunshine for nearly the whole day. As well as, the sun shines on the east façade from morning until noon and the west façade from midday until sunset. The north one, however, does not receive sunlight.
3.STRATEGIES

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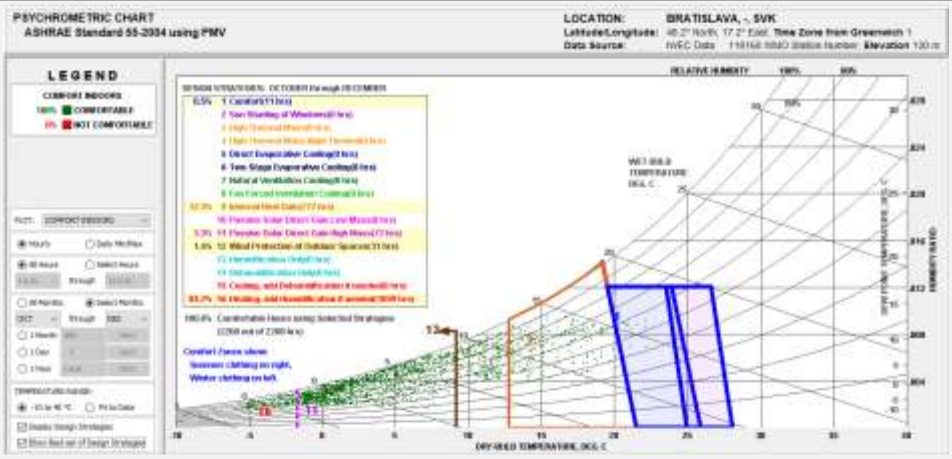

Figure 25: Psychometric chart without any strategy OCT-DEC

From October to December, the lowest temperatures drop below zero and sunshine hours are reduced, with a radiation below 400 Wh/sq.m even in the central hours of the day. Therefore, it is necessary to make the most of the daylight hours, to reduce the heating demand from the buildings, even if the incorporation of a heating source would be required.

Consequently, the primary façade should face south and have big windows on it in order to maximize the sunshine. While they would receive less sunlight, windows might also be added to the east and west façades to offer respectable capitations. Thermal inertia enclosures would be required to enable energy to build up during the course of the fall.

In the benefit of archiving 100% of the time to be comfortable, the design strategies implemented should focus on gaining internal heat, passive solar direct gain high mass, wind protection of outdoor spaces and, as a special important measure, to provide heating and humidification if needed.

Among the strategies for archiving it are:

- Facing most of the glass area to the south, in favour of maximize winter sun exposure.
- Using high mass interior surfaces (slab floors, high mass walls, stone fireplace...) to store passively.
- Adding more insulation in the façades and roof, in order to avoid thermal bridges.
- Sunny wind-protected outdoor spaces can extend living areas.

SUMMARY OF STRATEGIES

Based on the previous analysis on Bratislava´s climate and taking into account the specific opportunities of the Potential district for PCED, Petržalka - Janíkov dvor, several measures and best practices are proposed to consider the climate performance of the existing area and bioclimatic design of new buildings.

The main factors that need to be addressed are urban form, building density, surfaces, vegetation, and heat released by human activity.

Predominant wind comes from the north-west during winter, with a temperature between 0ºC and 21ºC. As the actual urban form is quite compact, the most exposed area would be the one indicated in the following map (indicated with number 1 in Figure 26). This imply higher thermal losses in these building blocks, and should be consider for future constructions to avoid it. In

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addition, it has been located the main communication routes (highway and railway) that define the southeast limit of the district. Finally, some alternative measures have been proposed (permeable parking area, urban carbon sink, pollinator spaces) to improve comfort.

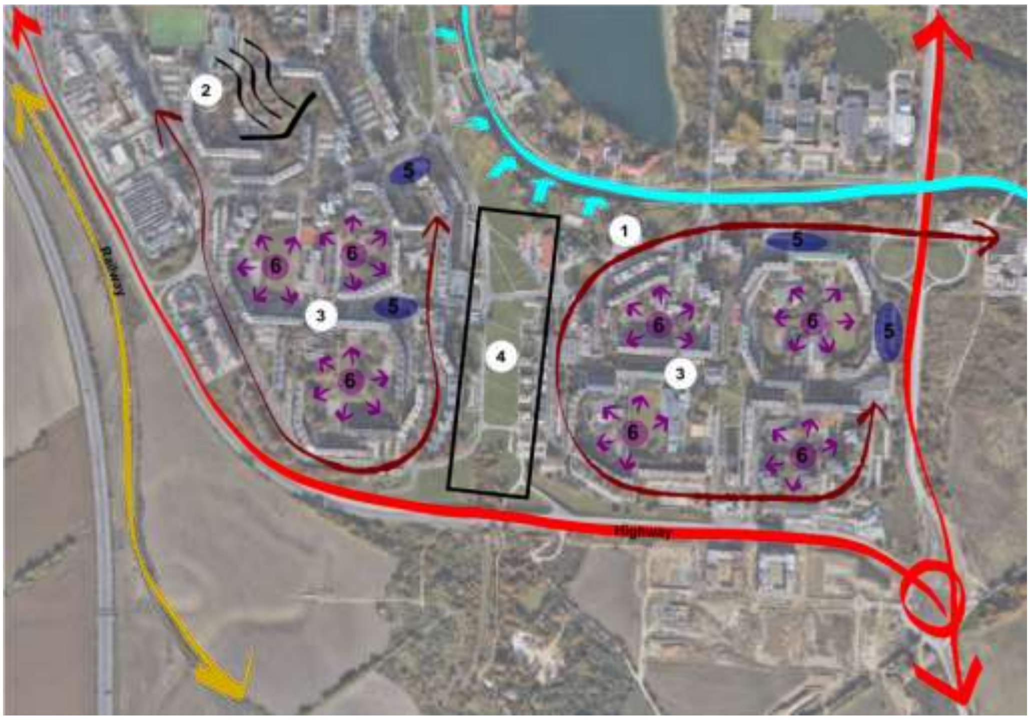

Figure 26 Microbioclimatic analysis

Figure 26 depicts the following areas (indicated with a number):

1. Building´s exposed façade to main winds
2. Main wind direction (Winter, Spring, Summer)
3. Existing buildings, where rehabilitation measure can be implemented to reduce energy demand
4. Area for new development
5. Permeable parking area
6. Urban carbon sink

Strategies for new buildings construction:

- **Buildings´ orientation and shape:**
  Shadow impact: The building floorplans should be organized to allow winter sun to enter daily usage zones with specified functions that correlate with solar orientation in order to maximize solar capacity during the colder months. It is also vital to provide shade elements that protect these regions from summer sun.
  For that purposed, shading should take into account the angle of incidence of sunlight (around 70º in summer and 23,5º in winter). Windows or other openings should face south or south-southeast within 30 degrees and should not be shaded by other structures or trees between 9 a.m. to 3 p.m. during cold months of autumn and winter, although the openings should be covered to prevent overheating in the spring and summer (Department of Energy, U.S., 2023).

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Figure 27 and Figure 28 depict shadows in the Petržalka - Janíkov dvor district on the winter solstice (4:00 p.m. European Time) and on the summer solstice (3:30 p.m. European Time), respectively, using the orientation data from (European Solar Test Installation; CM SAF and National Renewable Energy Laboratory, 2022). For that representation, it has been considered the shadows cast by the existing structures on the ground surface.

Table 18. Orientation data. Source: (European Solar Test Installation; CM SAF and National Renewable Energy Laboratory, 2022)

Date	Azimuth	Altitude
December 21st (winter solstice)	229,9º	7,8º
June 21st (summer solstice)	223,8º	59,5º

Figure 27. Building´s shadow on the winter solstice at 4:00 p.m. European Time

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Figure 28. Building´s shadow on the summer solstice at 3:30 p.m. European Time

Because there is a significant quantity of vegetation in the area, particularly in the internal space between the buildings, the position of the vegetation and shadows cast by it have also been taken into account, as shown in Figure 29 and Figure 30.

On the one hand, existing vegetation has a significant impact on protecting interior block areas during the summer by allowing shaded passages with a little effect in winter.

On the other hand, the central region has less shadow and is largely devoid of vegetation. If new buildings are to be built there, it would be advisable to locate the new blocks nearer to the east side of the central area, so that they can benefit from the existing buildings´ shading during summer mornings, when temperature are higher.

Figure 29 Building´s shadow (including existing vegetation) on the summer solstice at 4:00 p.m

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Figure 30. Building´s shadow (including existing vegetation) on the summer solstice at 3:30 p.m. European Time

Wind impact: Wind protections are necessary when there are winds of higher speed than 8,5m/s. As in Bratislava wind does not usually exceed of 6,5m/s, wind protections are not required. Although it can be used as a measure to improved comfort, especially in most windy months (APR, MAY, JUN), or reduce wind chill/improve thermal sensation in cold months.

Figure 31 Mean Wind Speed. Source: (DTU, World Bank Group, ESMAP, VORTEX,, 2023)

For this purpose, building´s orientation should not expose too much of the interior to the main cold winds from the north-west. Buildings should be planned with floorplans that allow for cross ventilation and apertures to gentle breezes, especially the warm

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south-east summer winds. It is also important to note that there are in the market several models of high-performance windows with smart glazing, regulated by sensors or electrochromic technology, which improve isolation at the same time they maximized natural ventilation as it is regulated by sensors.
In the following link there is a tool for dimensioning natural ventilation and another one for calculating Air Change Rate for a specific building, that can help improve the bioclimat quality of the buildings once defined its shape (Window Master, 2023).

In addition, the building´s entrances can be protected from cold winds by structures such as wing walls, wind barriers, fences, outside structures, or natural features. In case of using vegetation as windbreaks, they should face the prevailing winds from the northwest, and should be positioned with at least 45 degrees from each corner on façades with windows, to avoid reducing passive solar gain. To be effective, windbreaks must be semi-permeable, ideally filtering around 50% of the wind to reduce its strength (myperfectplants.com, 2023). Solid barriers are unsuitable; leading to damaging eddies of wind on each side.

The distribution of the buildings in Petržalka - Janíkov dvor, which creates interior spaces protected from the main winds, avoids wind tunnels, even if some turbulent winds can be created. It also implies that in summer the heat abosrobed by sun radiation is trapped between buildings, rising the direct radiation to the building's façades.

- **Use high mass materials:**
  Another strategy may be to use high mass materials for the interior surface and walls of the structure. These materials could retain both winter solar gain and summer night time "coolth". The most effective high mass walls employ direct drywall or plaster in the outside insulation and reveal mass on the interior.
  A common strategy to increase indirect heat gain is the incorporation of Trombe walls. They are south-facing walls of 20cm-40cm thick with an exterior sheet of glass that creates an air chamber to take advantage of the greenhouse effect to raise the temperature that has been accumulated in the wall. It works so the heat that was absorbed on an 8-inch concrete wall's exterior at noon will be transferred inside to the living area by 8 p.m (Dnyandip K., Manish K., & Jyotirmay).
- **Use sensors and controllers:**
  One strategy is incorporating sensors to reduce the energy consumption, as they automatically regulate heating/cooling system, shadowing and ventilation to the users' behaviour.
  Multiple companies produce these technological solutions, although not so many companies offer specialized installers, as a correct installation that secure reliable data a main point for the correct functioning of the monitoring system. One recurrent problem when installing these devices is an adequate commissioning of the whole chain linked to a monitoring system, as the obtain data should be easy to use for the users and HVAC system (POLIMI; REGEA, 2023).

Also, in the following reference (INFINITE building renovation, 2023) there are some broader insites on the technologies that can be implemented on new and existing buildings to improve efficiency.

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<u>Other interventions to take into account in the urban design for the new district:</u>

Urban carbon sinks: The buildings´ distribution creates interior space between the blocks, which are already gardened. These areas are shaded during the summer by the existing trees, and they are a suitable area to incorporate some measures to enhance its capacity to capture carbon emissions (South Pole; CARTIF, 2023). For this purpose, it is important to select the vegetation pieces among the native ones, as they require less maintenance. Incorporating spaces for pollinators within the city is also a relevant action, as it has a great impact on its biodiversity. The pollinator modules aim to develop water and food-rich areas for pollinators and refugies in the cold months. They should consider the distance between modules and other green infrastructure to facilitate their movement.

Permeable parking area: The heat island effect is caused mainly by the great number of impermeable surfaces in cities, which absorb solar energy, hamper the retention of water, and diminish the underlying water reservoir.

In the district, there are several parking areas with large extensions of concrete soil, such as the one in the following image. Although some of them already include vegetation to some degree, they can be improved by incorporating green or hard drainage pavements (LGI; TECNALIA).

Figure 32. Parking in the west area of Petržalka - Janíkov dvor

Incorporating permeable pavements that allow appropriate drainage would reduce the overall temperature, improve soil health, decrease storm water runoff and flooding, as well as mitigate the heat island effect. There are different permeable pavements to choose from to use in parking areas, such as concrete pavers, permeable interlocking pavers, and porous asphalt.

STEP 3.1: Baseline calculation

No baseline calculation has been possible as the area does not exist and the stakeholder engagement is still on-going.

STEP 3.2: Selection of potential solutions> define scenarios

The city of Bratislava selected several potential solutions to define the scenarios at district level. Evaluating as well the co-benefits that could be obtained for each solution.

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Define technologies of each scenario based on PED tool results

if **manufacturers** are considered **within the city**, you can consider these as co-benefits. Otherwise,

IMPACTS / CO-BENEFITS:		SCENARIO 1 - self sufficiency						
		Technology 1	Technology 2	Technology 3	Technology 4	Technology 5	Technology 6	non-technical
		Photovoltaics	Heat pumps ground/ water	FPC - Solar thermal panels	geotermal energy - ground heat exchangers	Electric storage - short	Thermal storage - seasonal VS SHORT	energy community
Climate resilience	Climate adaptation	High	Medium	Low	Medium	none	Medium	none
	Climate mitigation	High	High	Medium	High	High	High	none
Local economy, entrepreneurship and innovation	Local economy enhancement	none	none	none	none	none	none	High
	Financial savings for citizens	High	Medium	Medium	Medium	none	High	High
	Increase employment rate and jobs	none	none	none	none	none	none	High
	Decrease future maintenance costs	High	High	High	High	none	High	High
Social inclusion and education	Social cohesion (gender, minority groups)	none	none	none	none	none	none	High
	Enhance citizen participation, connectivity and community	none	none	none	none	none	none	High
	Improve access to information, Social capacity building	none	none	none	none	none	none	High
	Raise awareness/ behavioural change	none	none	none	none	Medium	none	High
Health and well-being	Improve air quality	High	High	High	High	none	High	High
	Reduce noise pollution	High	High	High	High	none	High	High
	Reduce hot stops/ urban islands in the city	Medium	none	none	none	none	none	none
	Enhance attractiveness of the city	High	High	High	High	none	High	none
	Promote healthier and more attractive lifestyles	High	High	High	High	none	High	Medium
Biodiversity	Reduce ecological footprint	Low	none	none	none	none	none	none
	Greater biodiversity	none	none	none	none	none	none	none
Resource management and efficiency *(circular economy)*	Waste efficiency	none	none	none	none	none	none	none
	Water efficiency	none	none	none	none	none	none	none
	Food efficiency	none	none	none	none	none	none	none
	Sustainable land use	High	High	High	High	none	High	none

Figure 33 Overview of co-benefits for scenario 1 Bratislava

STEP 3.3: Scenarios evaluation and prioritization

The PED in Bratislava is being created on greenfield, which led to the need to examine several urban-architectural solutions.

It is not possible in such a short period, as the duration of the Atelier project, to prepare an urban competition in the municipality that would lead to the proposal of a concept on the selected PED area. Therefore, we decided to cooperate with FA STU, the Institute of Urbanism and Spatial Planning. In cooperation with students – future architects, several student projects of PED in Janikov Dvor were created, and the lengthy process from public procurement to the selection of the winning design was not necessary.

Concept, learning objectives and methods of the new course "Positive Energy Districts: Development and Renewal Principles"

The new course of study consists of two parts, theoretical and practical. This combination is suitable during the study of architecture, as it offers students the opportunity to test their theoretical knowledge on a concrete example. In the theoretical part, students attend two four-hour blocks of lectures, in the practical part two three-hour blocks of tutorials of assigned exercises.

During the first trial semester of the project, the method of combining lectures and exercises was chosen. The students started with a project design according to the general sustainable criteria they had learned during the previous mandatory courses of study (Urbanism 1, Urbanism 2). Subsequently, the emerging design was continuously verified and modified according to the acquired theoretical knowledge they gained from lecture blocks.

Evaluation of students' initial knowledge was based on a questionnaire. The content preparation of the lectures reflected the results of a questionnaire filled in anonymously by the students during the first organizational meeting for the course.

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Questions:

1. What does sustainability at the scale of city districts mean to you.

2. How would you define a positive energy district.

3. What advantages do you think positive energy districts would bring?

4. When does a building count as an energy efficient for you? Try to quantify its energy consumption.

5. What energy standard of buildings is prescribed by the legislation?

6. What climate initiatives is Slovakia, or cities in Slovakia, involved in? A total of 27 students completed the questionnaire.

Lectures: The topics of the lectures were designed to cover a general introduction to the subject, the principles of PED design, introduction of applicable technologies and examples of good practice.

The lectures were presented in two four-hour blocks (on two different dates), due to the still current pandemic situation - in a hybrid format. Each block was followed by questions from the students.

The themes of the lectures covered the following topics: Climate change solutions in cities Introduction to Positive Energy Districts Energy efficiency of buildings Seestadt Aspern, a climate-neutral district in Vienna, The Energy Balance in Detail Climate-sensitive Architecture

Exercises: As part of the elective course exercises, students were given the task of designing a PED project. The area to be worked on was part of the largest Central European prefabricated housing estate in the south of Bratislava/Petržalka (with more than 100 thousand inhabitants) - namely a part of the greenfield Janíkov Dvor, with an area of approx. 10ha.

The exercises took place in the form of consultations, in two three-hour blocks.

The students formed a total of 9 teams: 1x 1 student, 6x 2 students and 2x 3 students.

Background to the assignment:

- presentation of the area to be addressed

- vector documents

- .dwg file of the designed area and .dwg file of the whole Petržalka district

- balance table of energy demand and production of the assessed area, excel file

- PED tool (Cartif)

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Excursion: the area covered by the exercises, Janíkov Dvor/Petržalka

At the beginning the students listened to a lecture about Petržalka and its development concepts. Afterwards, they took a guided tour of the area. After the tour, they independently explored the area and during the tour they focused mainly on the following topics, which were given to them in advance:

- Structure of the area, amenities and functional relationships
- Built-up area, paved and green areas, public spaces
- Options for optimising energy production
- Mobility in the territory, passenger transport/public transport and alternatives
- Elements of original and newly designed architecture
- Photo documentation

Final presentation and evaluation of student projects

Students presented their projects in the form of a 10-minute PowerPoint presentation and two printed posters in B1 format - 700x1000 mm. Each team was followed by feedback from the jury: a total of 9 teams, 19 students in total, completed the course. All 9 projects were evaluated positively.

Selection of student projects

Team Jozef Červenák, Róbert Rozniak: The students decided to design the longitudinal masses of the development according to the pattern of existing residential buildings. In the direction of the expressway, the longitudinal masses transition into point apartment buildings, thus connecting to the planned urban fabric beyond the expressway. The aim of the design of the residential housing was to support housing in the area while densifying the existing development.

The main public open spaces were created in the northern part of the site and a public space with shops and event space was proposed on site.

An extensive green roof is proposed on each building. Outdoor spaces are connected to each residential building. The design promoted electric mobility and green transport for the residents of the site. Screening of glazed areas is important for the buildings. The site design considers water retention on the site and each building has solar panels on the roof to use solar energy.

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Figure 20 Visualization and urban design, Students: Jozef Červenák, Róbert Rozniak

Team Alžbeta Gazdová, Richard Čeklovský, Veronika Bertová: The analysis prepared by the students showed that there is a large amount of vegetation in the area, which represents large unused areas. The proximity to nature and woodland is ideal for densifying the area with greenery, which could reduce the heat in the centre of the district. A streetcar line project could also address the traffic problem, which would divert car traffic and create space for pedestrians and cyclists.

The project focuses on the above-mentioned strengths of the area, where the students tried to use as many ecological aspects as possible in combination with the idea of designing community housing.

The main idea of the project is the element of water. The water channels flow on and below the surface of the ground, where they flow into the retention basins. The purpose of bringing water into the land is to provide a more suitable climate and space for various biotopes. The project also links the green structures of the proposal, such as forest belts, community gardens and green roofs, to their functional use.

The average annual wind speed on the territory of Janik's Court is 18 Km/h, as the northern side is not built up with any buildings. The students used the potential of the wind for wind turbines, which are located on the roofs of buildings. Traffic problems were solved by the students by placing a garage directly at the exit of Panonská cesta, the facade of which would consist of transparent photovoltaic panels.

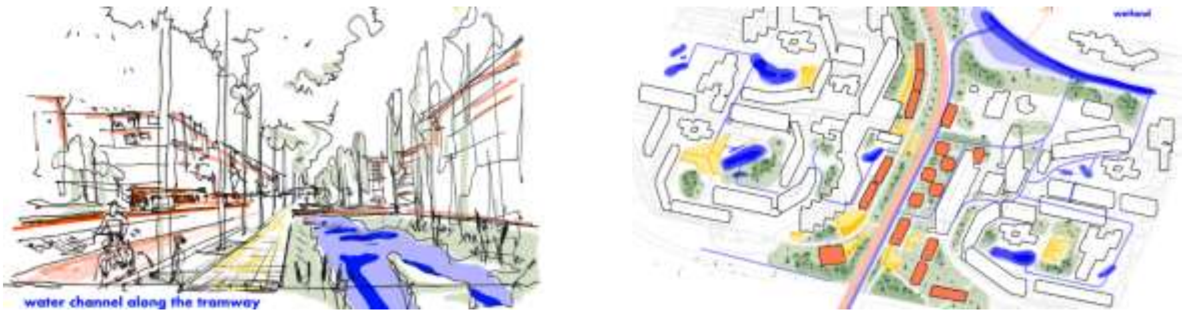

Figure 23 Visualization and urban design, Students: Alžbeta Gazdová, Richard Čeklovský, Veronika Bertová

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Team Daniela Poliačiková, Michaela Sisková, Simona Suchánková: The students decided to analyze the territory of Petržalka in the overall context and compare sustainable solutions of different types of residential blocks.

The main aspect of sustainable energy concept of this project is the use of solar energy with the help of photovoltaic cells and heat pumps. In flat terrain, where there is constant wind, it is also possible to use wind energy, which would be located near the border between Slovakia and Austria. An example is also selected typical blocks of Petržalka, where the graphs may show the energy needed from other sources, while we also include the use of a heat pump in the calculations. In this way, instead of vegetated roofs, "sunny roofs" and a "wind city" are created on the edge of Petržalka.

Block1+Block2: New pavilion producing its own green energy for the whole block of buildings. Photovoltaic cells are placed on the roof of the pavilion, thereby freeing up the space below for various activities for the residents of the block. The round shape of pavilion of block1 gives the environment a new expression, both ecologically and aesthetically. The shape of pavilion of block2 was inspired by blocks - cubes, whose block represents the production of energy for one entrance of an apartment building.

Block3: A great example of a block that, with the addition of photovoltaic cells on the roof, can produce enough energy to eliminate the need for an additional separate building creating new green energy.

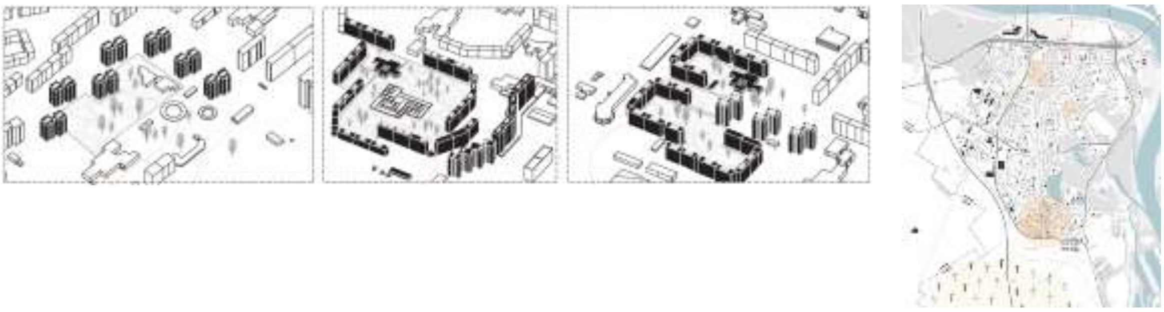

Figure 24 Visualization and urban design, Students: Daniela Poliačiková, Michaela Sisková, Simona Suchánková

Team Samuel Skýva, Rebeka Markovicsová: The students produced a detailed analysis of the area, identifying the current deficiencies of the area. Their proposal focused on the addition of missing public and semi-public spaces. The study area lacked playgrounds, sports fields, parks and community gardens. It was a large area without dense development, with pavements and terraces in a state of disrepair. There was a lack of insulating urban greenery, landscape architecture elements, urban furniture and polyfunction and active parterres.

Within the framework of the architectural concept, the students mainly processed four sustainable concepts.

Green roof: Prevents the building from overheating. It supports biodiversity and at the same time reduces the greenhouse effect. It absorbs rainwater, which is then used for utility purposes.

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Vertical gardens: In the summer months, greenery serves as a natural shade, and on the contrary, in the winter months it does not prevent sunlight from penetrating into the apartments.

Retention tanks: Instead of draining rainwater from the public sewer, the water is retained under the building and subsequently used for a utility function that would otherwise have to be performed by the water supply.

Photovoltaic panels: As an edge of intensive greenery, the roof area of the building is also used as an area for photovoltaic panels, which are the supporting element of the energy neutral/plus building.

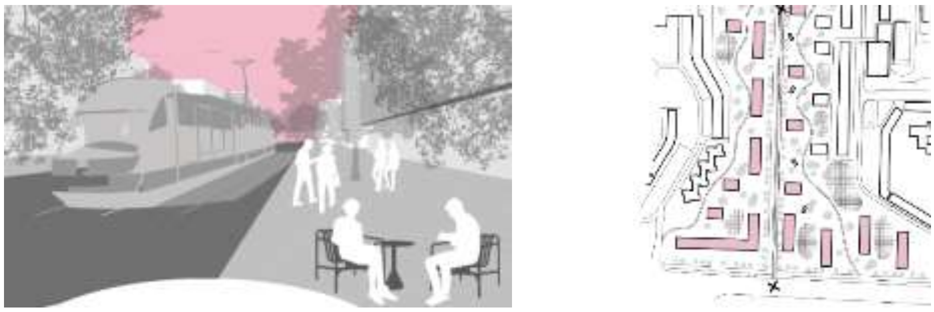

Figure 26 Visualization and urban design, Students: Samuel Skýva, Rebeka Markovicsová

Team Darina Izakovičová, Karolína Horváthová: This concept consists in the renaissance of Petržalka‘s former plans and urban planning concepts of vertical segregation of pedestrian traffic from car traffic. After analysis, the students found that the neighbourhood is made up mostly of apartment buildings with terraces, which currently form a barrier in the space. They decided to reactivate them and at the same time prevent the creation of a barrier by the tram line.

Basically, students create three hierarchical levels of public spaces - the boulevard with the cultural zone are the main bearer of functions not only for leisure use, which have the importance of another sub-centre of Bratislava, with a target group of city-wide importance. The second level - sports zone, community gardens, administration are primarily intended for the given community, living or working in this area of Petržalka, with the possibility of all-day use. The third level is traffic and static traffic, which students place separately from pedestrian routes and residential areas, they move parking from areas with other potential uses to terraces, underground garages, and a parking garage on the edge of the zone. Activities in the open spaces overlap in time and thus the environment is used almost constantly.

There are two typologies of buildings in the design, stick houses and point houses. Stick apartment buildings are oriented to the E-W cardinal directions. They have terraced green roofs with the possibility of using the roofs for obtaining solar energy. Point high-rise buildings of administration and amenities have green roofs with the possibility of using areas for obtaining solar energy, as well as the vertical areas of the southern facades of these buildings with the possibility of installing panels. Most of the paved surfaces are replaced by turf paving. The proposal focuses on creating gaps between buildings and overgrown greenery between individual structures with water-retaining permeable surfaces.

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Figure 27 Visualization and urban design, Students: Darina Izakovičová, Karolína Horváthová

Based on the consultations of experts and professors, one student project was selected that showed a strong realizable potential, included sustainable concepts in the design and was based on a detailed analysis of the real needs of the residents in the given area. This student project will be elaborated in detail in the next phases of the Atelier project as PED Janikov dvor in Bratislava.

Project of students Daniela Hrabovská and Viktor Polák was choosen as an architectural-urbanistic study of PED for Janikov Dvor.

Concept and socio-community character of the project

The design was preceded by an analysis of the Petržalka area. The students focused on a phenomenon they called "the heart of Petržalka". They found that in this territory, sociologists examined the internal and external view, it is the internal view of Petržalka residents that is significantly better than the external view of residents of other parts of Bratislava. (In the internal view Petržalka residents evaluate Petržalka, in the external view - Petržalka is evaluated by residents of other city districts.)

People who live in Petržalka have a habit of perceiving this place as better than it really is. The internal view of Petržalka residents is significantly better than the external view of residents of other districts of Bratislava.

Despite the positive evaluation of the housing estate, most Petržalka residents expressed that they prefer to spend their weekends and their free time elsewhere rather than in the housing estate.

For the PED design, this meant that the residents of Petržalka are very sensitive to any change that should take place in relation to the spatial structure of the housing estate. It is therefore important, to work in this area with a high level of participation of the local residents, to inform them about all the steps and explain to them how it will affect them - improve their everyday life.

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Architectural-urban design

The goal of the architectural-urban design is to create a new residential-mixed-use neighbourhood with a human scale that will have all basic amenities within walking distance. By locating the residential block structure with reference to the existing buildings, the students clearly define and differentiate the public, semi-public and semi-private character of the spaces. The main public space is the axis around the tram line with a longitudinal park. The courtyards of the residential buildings create a community - quieter space for residents to spend leisure time.

Close to the main public spaces are buildings with an active ground floor - amenities. Detached amenity/administration buildings are located in the nodal areas of the tram line and roadway intersection. The proposal contemplates the construction of a parking structure to the south, which is located within the block structure.

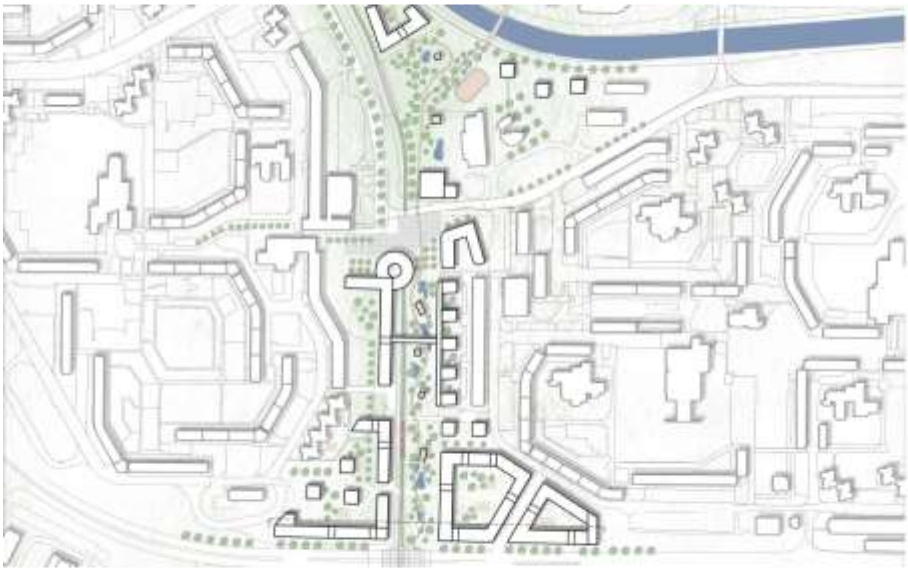

Figure 25 Urban design, Students: Daniela Hrabovská, Viktor Polák

Public spaces

The project contributes to improving the quality of public spaces - by strengthening and improving local pedestrian footpaths (desire lines), creating community gardens in the newly created courtyards and designing a nodal space in contact with the tram line, with amenities.

The tramway itself is a catalyst for action in the public realm. Therefore, different territorial characters appear along the radial. The area around the tramway is also suitable for the routing of blue-green infrastructure, there can be a longitudinal park with climate change measures.

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Figure 26 Visualizations, Students: Daniela Hrabovská, Viktor Polák

Energy concept

Within the project, the students explored the possibility of using various sources of local renewable energy, like solar, wind, heat pumps and waste incineration. The design of the neighborhood is dominated by the function of housing in combination with commercial spaces. They use solar integrated technologies to cover their energy needs. Further, the district uses waste-to-energy recovery, rooftop wind turbines, and ground source heat pumps. The student design includes aspects of e-mobility and works with the possibility of forming an energy community.

Since the students have explored almost all the possibilities of using renewable energy sources, in the next step the reality of the proposed solutions will be verified and consulted with experts in the Innovation Atelier. The student project is understood as a basic structure, which will be further elaborated in detail, and energy concepts that realistically correspond to the conditions of the area will be used.

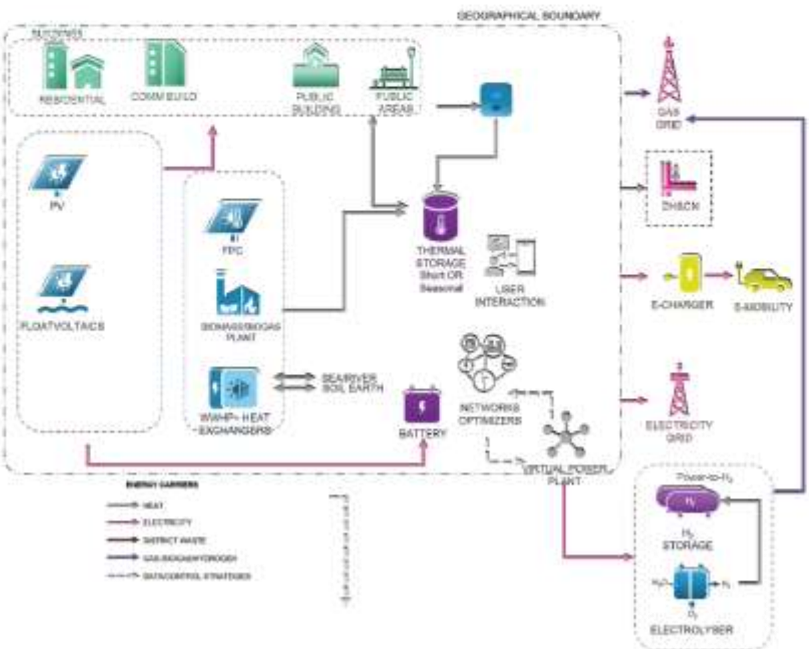

Figure 27 Energy concept, Students: Daniela Hrabovská, Viktor Polák

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STEP 3.4: Financing options

From the options presented in Table 14 and considering the selected area of Janikov Dvor located in Petrzalka, district owned by Bratislava municipality, several things need to be considered. First of all, Bratislava suffers from shortage of housing possibilities. The urban concept is based on rental flats and amenities supporting compactness of urban structure, good mix of functions to reach better energy balance with better division of energy consumption.

For the concept of rental housing will be possible financing through State Housing Development Fund (SHDF), and also a technical infrastructure. Other amenities will be covered by private investments. SHDF is a major tool to finance several types of housing interventions governed by the state (e.g. building social housing, renovating the municipal stock, supporting the construction and thermal insulation of family houses). PED Janikov Dvor is located in an area where is already planned development. The new area called Petrzalka City has got several private investors, which could be involved in the future to became partners also in Janikov Dvor. Bratislava doesn't have developed a legislation environment for energy communities, there are some pioneer's activities in Slovakia, which could serve as an example also for Janikov Dvor in the future. Other financial options are less likely. Janikov Dvor is a greenfield so the Energy Performance Contract (EPC) - Shared savings, are not possible to use there. The model is suitable for existing building stock. Investment platform is unknown although interesting model, still rather complicated, without a similar experience.

Conclusions

Thanks to this process Bratislava was able to gather some insights for designing a tendering procedure that considers the necessary features to achieve and implement a PED in their area. For instance:

- To reduce the need for space cooling, it is recommended to insulate buildings as much as possible, to take advantage of natural cooling during the night and to use controllable external shading. To reduce the water energy demand, is to preheat the cold-water mains with waste heat (e.g. heat exchanger to extract heat from the grey water from the shower). Other bioclimatic conditions can be considered for the design as in STEP 3.1a. Urban design is considered in STEP 3.3.
- To reduce electricity needs, efficient lighting and appliances should be prioritized. Stand-by modes should be avoided when possible, using smart plugs to cut off power when not needed.
- In terms of energy systems, students explored the possibility of using various sources of local renewable energy. Photovoltaics, heat pumps, solar thermal panels and thermal and electric storage could be considered by the IA stakeholder group.
- To reduce transport emissions, it is recommended to use clean mobility principles as much as possible and to create a sustainable urban e-community. In some contexts, it can be possible to use e-vehicles batteries to discharge it and use it within the boundaries. Otherwise it will always be a load (consuming electricity from the PED).
- State Housing Development Fund (SHDF) seems the most feasible option. Private funding could be unlocked, but the Investment Platform is a concept unknown and energy communities are not regulated.

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5. PED design in Budapest

In this section, the steps defined in section 3.2 are applied to the city of Budapest. Starting with (Section 5.1) the city context and identifying the strengths, weaknesses, opportunities and threats of Positive Energy Districts; followed by the prioritization of one of the preselected areas in proposal stage (Section 5.2) and finalising with a PED detailed design for the selected are in section 5.3. The output is a set of recommendations for stakeholders to deploy PEDs in that area.

5.1. STEP 1: City's environment for PED implementation

Context

Budapest is the **capital** and the largest city of Hungary. It is the country's principal political, cultural, commercial, industrial, and transportation centre. The city covers an area of 525 km^2 and is home to 1.7 million people (which mean a **density of 3,238 people per km^2**). It is located at an easily traversable crossroads of the European continent. It is at Budapest where the waterways of the Danube cross the traditional transportation routes leading from Western Europe eastbound (towards Asia) and to the Southeast (towards the Balkans).

Budapest has a peculiar dual self-government system. It has **23 districts**, which means that in addition to the Budapest Municipality (the local government of Budapest) each of the 23 districts have their **own government** (the so-called district governments) with elected mayors and a body of representatives. Both the City and the Districts are local governments, not subordinated to one another, each having specific duties and powers, specified by law. This could difficult some processes since the City government does not have the power (and data or information) in some fields.

Budapest has a mild and **wet continental-climate** with sunny summer and cold winter. The city sees lots of daylight averaging 9 to 11 hours every day, with average temperature in the warmest month (July) of 21.1 °C. Winter months are cold and dull, with average temperature in the coldest month (January) of -1.4°C. Precipitation is at 609.6mm annually and is equitably distributed all year round. July got the most amount of rainfall, while January the least.

Conditions to allow a Positive Energy Balance

Starting from January 2012, in all existing and residential and non-residential buildings need to be **certified** when sold. The owner must present a valid Energy performance certificate (**EPC**) to the buyer when the sale contract is agreed upon. For rentals, the EPC is mandatory since 2015. The reference value of the EPC scale is the nZEB requirement on total primary energy performance.

In Budapest the peer-to-peer energy exchange, understood as "*my neighbour can use the energy produced by me*", is not allowed by the current regulation.

In Hungary, the legislative framework enabling and promoting **energy communities and collective self-consumption** is under development. The Hungarian National Energy and Climate Plan (Hungarian government, 2020), mentions a three-step community integration to support the goals of climate neutrality by 2050. A main priority is to extend the **net metering** (or an equivalent incentive programme) to apartment blocks, this lays the groundwork to **establish communities** within the transforming zones in a second-level goal. The option of managing "village heating plants" as energy communities is mentioned as a third step. Also, **small-scale district heating zones** are mentioned in the context of renewable energy

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communities. As regards the establishment of renewable energy communities, the question of **vulnerable consumers** and the security of supply is assigned a priority; the legal environment should allow even a miniature-scale district heating zones to fulfil these two criteria.

Regarding the use of **hydrogen**, there is no explicit prohibition for hydrogen production facilities, but the legislation states that hydrogen production facility (or similar facility) can be located only in "industrial area" zone.

District heating represents approximately 30% of the capital heat market (this 30% is owned by FOTAV: Budapest DH Works Private Co). It operates nine separated District Heating zones and four block-heating. Most of the substations supply a building or section. It is planned to improve connections among the different heat zones so that new customers could join the district heating system. It is not mandatory to connect to the DHN.

It is not possible in Budapest that an energy community creates a **DH company**, it is needed to comply with the regulation for DH.

Conditions to allow Renewable Energy Production

Regarding electricity regulation, there is **restrictive legislation for wind energy**, the areas of renewables most likely to develop are solar and geothermal, but there are capital requirements of seismic and drilling activities which lead to few geothermal projects. **Solar power** seems to be the most promising segment of the renewable generation sector as it is easy to install and well-known technology.

There is **limit to the capacity to be installed** in the residential sector. Besides the limitations due to the regulatory environment, issues have been raised, whether the electrical grid of the city would be able to handle a large uptake in PV installations and use. However, according to the preliminary results of a municipal project, these speculations seem to be incorrect. And it would only occasionally lead to some issues (and more likely from EV charging stations, not PV panels). In addition, questions have been raised, on how the installation of PVs around the city would affect the 'city-view' or 'city landscape'. Budapest is currently working on a strategy to harmonize regulations and find a common ground with all stakeholders on how and where PVs can be installed.

There is **legal burden** on the installation of solar panels due to the current regulatory environment, restricting the possibility of feeding-back excess energy. Coupled with restricting regulations on the sharing of the generated energy between households, businesses, etc.

Conditions to allow Efficient buildings/ Building stock demand

The **building stock** in Budapest is mostly old, especially in the historical centre of the city, with building from even the 18th century. There is a refurbishment plan recently adopted, called the Renewal of Historical Urban Fabric (Historikus Városi Szövet Megújítása), which details a city-scale strategy on the renovation and maintenance of Budapest's historical building stock.

There are no reliable statistics available on the number of existing nZEB. According to the Hungarian Passive House Association, there are approximately 100 to 300 existing nZEB. Most of them are single-family houses or public buildings, which have been renovated with the support of the Environmental and Energy Efficiency Operative Programme.

The requirements of **nZEB** were widely introduced in 2019 for new public buildings and in 2021 are being introduced for all new buildings. The nZEB threshold of the specific primary energy

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consumption for residential buildings is 100 kWh/m^2*year; but in case of installed air-conditioning it rises to 110 kWh/m^2*year.

Within the **nZEB requirements** is that at least 25% of the energy needs of the building should be covered from RES. Regarding primary energy factors, some cases are defined at national level for district eating, if the level of co-generation is at least 50% but the source of heat is biomass, wood pellets, agricultural pellets, biogas, other renewable, landfill gas or sewage sludge, then the primary energy factor is e=0.5, under 50% co-generation e=0.76; while for off-peak grid electricity the primary energy factor is e=1.8. Nevertheless, nZEB requirements are not planned to become mandatory for retrofits.

There are no distinctions in the requirements for social housing and residential housing. The discount is regulated by the municipality, and it is not in the electricity bills but they can apply for support to municipality.

Some of the district municipalities have **programs for energy saving renovations** for its 33 districts; but at single municipality level there are not programs.

Conditions to allow PED implementation

For the planning affecting the PED implementation, at national level to 2030 (aligned with the EU targets that Member States had to transpose into their national regulation), there is a target on GHG emissions reduction, on increasing the share of RES in energy production, and highlights the relevance of electricity interconnectivity.

A national tender was published in 2020 aimed to create more **pilot energy communities** and communal-generation and use of energy projects (CSC projects). The provided subsidies will enable small regional entities to participate and are expected to generate useful information to support the definition of a suitable framework.

At Budapest level, to 2030 there is a target to increase the energy efficiency and the share of RES, and reduce GHG emissions. In addition, the Climate Strategy of Budapest (to 2030 with vision to 2050) aims at reducing GHG emissions, and contains mitigation and adaptation measures.

SEAP to 2020 had the target of **reduction GHG emissions by 20%** compared to 1990 levels. The planned SECAP will target the **GHG emissions reduction to 40%** by 2030.

SWOT analysis results

Budapest inputs are summarized in a SWOT table to identify which internal factors help or harm the PED implementation, as well as which external factors (National, EU level, etc.) creates opportunities and threats to its context.

What can be conclude is:

- Budapest has a high city density, which allows to have a greater impact (more people per km2). But, the building stock is old. Fortunately, there are programs for energy saving renovations in the district municipalities. Also, when buildings are sold (since 2012) or rented (since 2015) they need to have a certification (more data is available).
- New buildings have a mandatory certification and ambitious energy performance standards
- Close to monopolies in some energy sectors (e.g. only one significant company for DH). Nevertheless, DH represents only 30% of the heat market.

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- There is a favourable regulatory environment for decentralized energy generation, except for solar PV. There are also limitations in terms of energy communities, for instance, they cannot create a DH company. Hydrogen production facility can only be located in “industrial areas”. Geothermal activities require capital requirements for considering the seismic and drilling activities
- There is a high administrative complexity, and therefore governance problems.
- Frameworks for collective self-consumption and energy communities are being developed, and there are national tenders to pilot energy communities.

Therefore, PED implementation has the potential to leverage its strengths, and capitalize on opportunities, but an effective coordination of stakeholders and district departments in the city, regulatory adjustments, and community engagement will be crucial in realizing PEDs.

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	HELPFUL	HARMFUL
INTERNAL FACTORS (City context)	**STRENGHTS**	**WEAKNESSES**
	High city density	Dual self-government with 23 districts with own government with divided power and duties (could difficult some processes)
	Impossible to export energy to the power grid, but in autumn of 2023 new regulations should lift the ban and feedback should be possible again	Not allowed the peer-to-peer energy exchange Hydrogen production facility can only be located in “industrial areas”
	District heating represents approx. 30% of the capital heat market	There is only one company for the DH (FOTAV)
	Planned to improve connections among different zones of the DH to join more customers (not mandatory)	Not possible for an energy community to create a DH company
	No legal burden for the installation of any technology	Capital requirements of seismic and drilling activities for geothermal energy
	Refurbishment plans adopted	Limit to the capacity to be installed in the residential sector
	Programs for energy saving renovations in the district municipalities	Old building stock
EXTERNAL FACTORS (National, EU level)	**OPPORTUNITIES**	**THREATS**
	Energy certification is mandatory for all buildings when sold (since 2012) and for rentals (since 2015)	nZEB requirements are not mandatory for retrofits
	Energy communities and collective self-consumption legislative promoting framework under development in Hungary	
	Next legislative framework will allow the small-scale DH zones in Hungary	
	nZEB requirement: at least 25% of energy needs covered by RES	
	National tender for pilot energy communities	

Table 19. Budapest SWOT analysis results

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5.2. STEP 2: Selection of suitable area to design a PED

As said in section 3, from the preselected districts in proposal stage, a prioritization exercise is performed.

Budapest identified two potential districts for the implementation of their PED :

- Potential district #1: Fehérdűlő
- Potential district #2: Mocsáros dűlő

These two areas are selected as they are the only major, contiguous free development areas of Budapest which are still in the hands of the municipality and allow for the conceptualization of a newly built PED area.

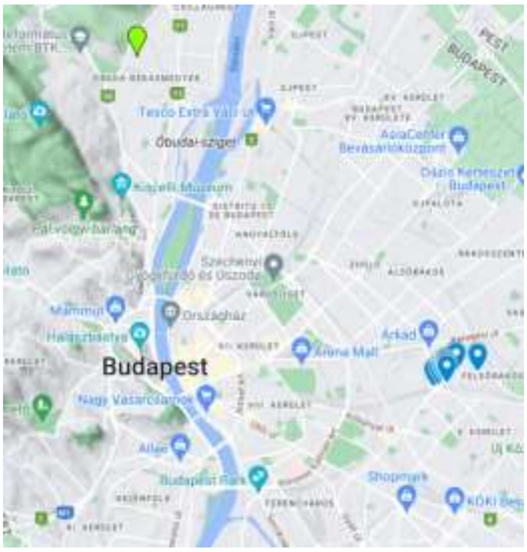

Figure 34: Budapest pre-selected PED areas

The process of the methodology explained in *STEP 2: Selection of suitable area to design a PED* is followed to prioritize one of the two for performing the next steps (towards a PED detailed design).

STEP 2.1

To start assessing the districts, first (STEP1.2) the desired objectives or impacts to be achieved by the PED implementation are identified. The impacts are identified and the pairwise comparison is performed, which results in:

		A	B	C	D	E	F	G	H
RER (Renewable Energy Ratio)	A	**1.00**	0.20	5.00	5.00	0.20	0.20	0.20	0.20
Improve air quality	B	5.00	**1.00**	5.00	5.00	5.00	5.00	5.00	5.00
Reduce bills	C	0.20	0.20	**1.00**	5.00	0.20	0.20	0.20	0.20
Achieve zero energy imports	D	0.20	0.20	0.20	**1.00**	0.20	0.20	0.20	0.20
Positive Energy Balance	E	5.00	0.20	5.00	5.00	**1.00**	0.20	5.00	0.20
Efficient buildings	F	5.00	0.20	5.00	5.00	5.00	**1.00**	5.00	5.00
Affordable	G	5.00	0.20	5.00	5.00	0.20	0.20	**1.00**	0.20
Liveable	H	5.00	0.20	5.00	5.00	5.00	0.20	5.00	**1.00**
	ADDING VALUE	26.4	2.4	31.2	36	16.8	7.2	21.6	12

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Then, the impacts are compared with the city objectives, which results in:

FINAL WEIGHT (considering CITY PRIORITIES)	Ranking	
5%	**6**	RER (Renewable Energy Ratio) factor
35%	**1**	Improve air quality
3%	**7**	Reduce bills
1%	**8**	Achieve zero energy imports
10%	**4**	Positive Energy Balance
18%	**3**	Efficient buildings / Building stock demand
6%	**5**	Affordable
23%	**2**	Liveable

STEP 2.2

Once the PED impacts ranking is defined, a data collection for PED area characterization starts. Using the City context template, city level details about the renewable energy source (RES) potential are asked in step 1.1 (such as maps, GIS data, etc.). This data potential at city level is used to analyse the RES potential at district level and compare the two areas. For Budapest, as there was not sufficient data at city nor district level, a detailed analysis has been performed searching in the different open data platforms (sEEnergies, PVgis, Wind Atlas, geoDH map, etc.). A summary of the results is presented in the following table:

	PED 1	PED 2
High solar energy potential generation in the area (kWh/kW peak – PVgis)	1232.97	1246
High wind energy potential generation (W/m2 at 10 meters height – Wind Atlas)	29	55
Geothermal energy potential generation	YES	YES
There is a river/sea close from which could be possible to harvest energy	YES	YES
There is an industry/ice rink/waste water plant, etc. from which could be possible to harvest energy (thermal/electric)	YES	NO
There is a forest from which could be possible to harvest forest waste	NO	NO
There is Gas grids access	YES	YES
There is a refuelling station near to the district	NO	NO
There is a centralized heating generation	NO	NO
There is RES production	NO	NO
Buildings already have ventilation or an air handling unit	YES	NO
Buildings already have heat pumps or splits	NO	NO
District heating connection	NO	YES
Supply Tº	-	-
Number of buildings connected	-	-
Substations available on the buildings	-	-

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district network provides cooling	-	-
There is an electric substation nearby	YES	NO
There is an existing district heating or cooling network nearby	YES	NO
There is Virtual Power Plant in the district	NO	NO
There is an Energy Community in the district	NO	NO
There is a waste management (at level district) or waste water plant nearby	NO	NO
There are energy intensive industries in the district	NO	NO

Both areas identified have access to a nearby district heating network according to sEEnergies Open Data platform. This has been confirmed by the city. PED area 2 is already connected, and PED 1 could be potentially connected.

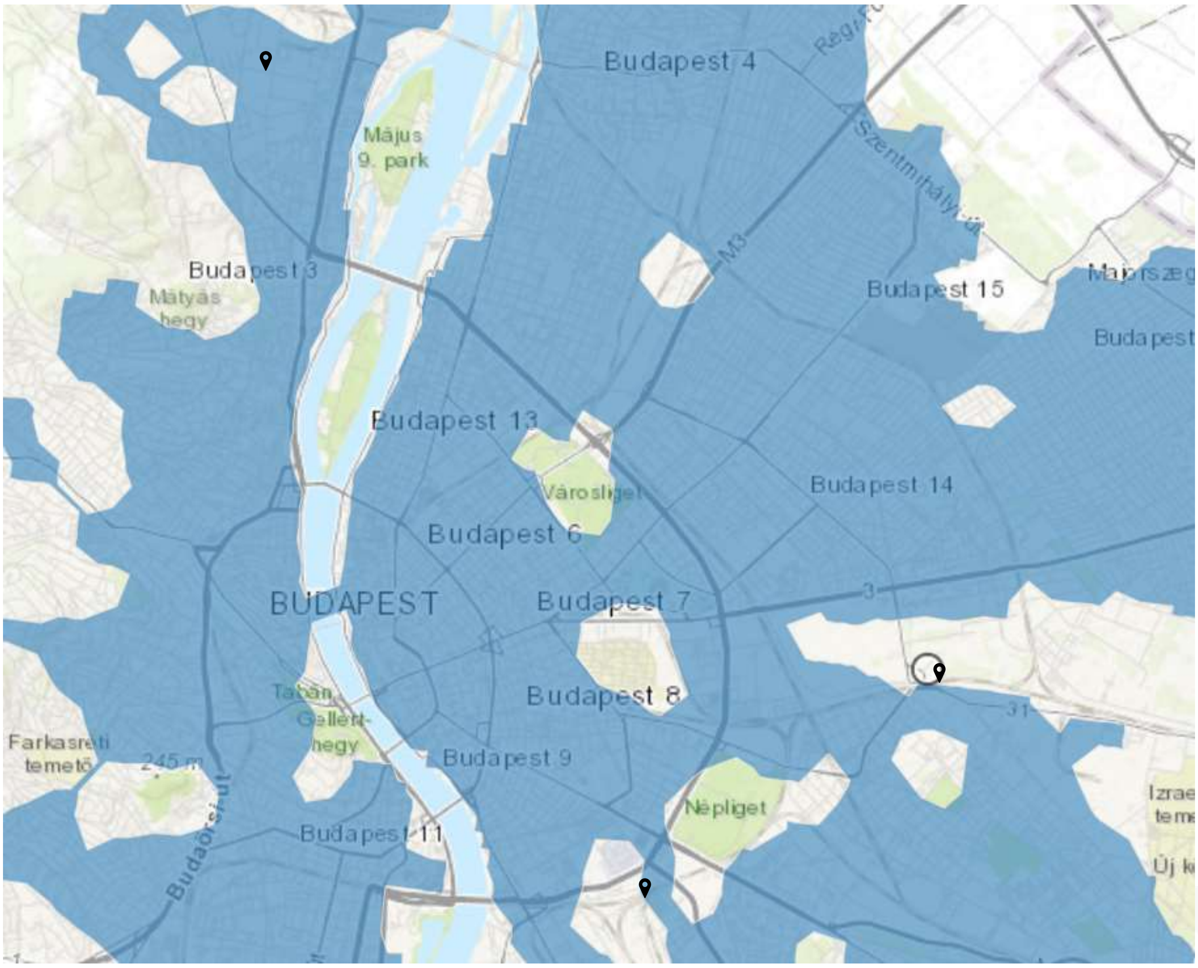

Figure 35: District heating areas in the city of Budapest (sEEnergies Open Data platform)[17]. The points indicated in the map are the PED areas

Potential waste heat sources (industry, waste water treatment plants, among others).

[17]https://s-eenergies-open-data-euf.hub.arcgis.com/datasets/b62b8ad79f0e4ae38f032ad6aadb91a0_0/explore?location=47.499720%2C19.055080%2C11.11

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No industry points close to the areas have been identified.

Geothermal potential

According to geoDH map, there is geothermal energy potential at 50ºC at 1000 m depth, and 90ºC at 2000m depth. The red contour delimits a hot sedimentary aquifer, with potential to harvest energy at 2000m at a temperature greater than 50ºC. Furthermore, Budapest PED areas might be suitable for direct exchange (especially if coupled with NZEB) and ground source heat pumps. Another study indicated that temperature range goes from 40 to 70ºC (https://europeangeothermalcongress.eu/wp-content/uploads/2019/07/264.pdf)

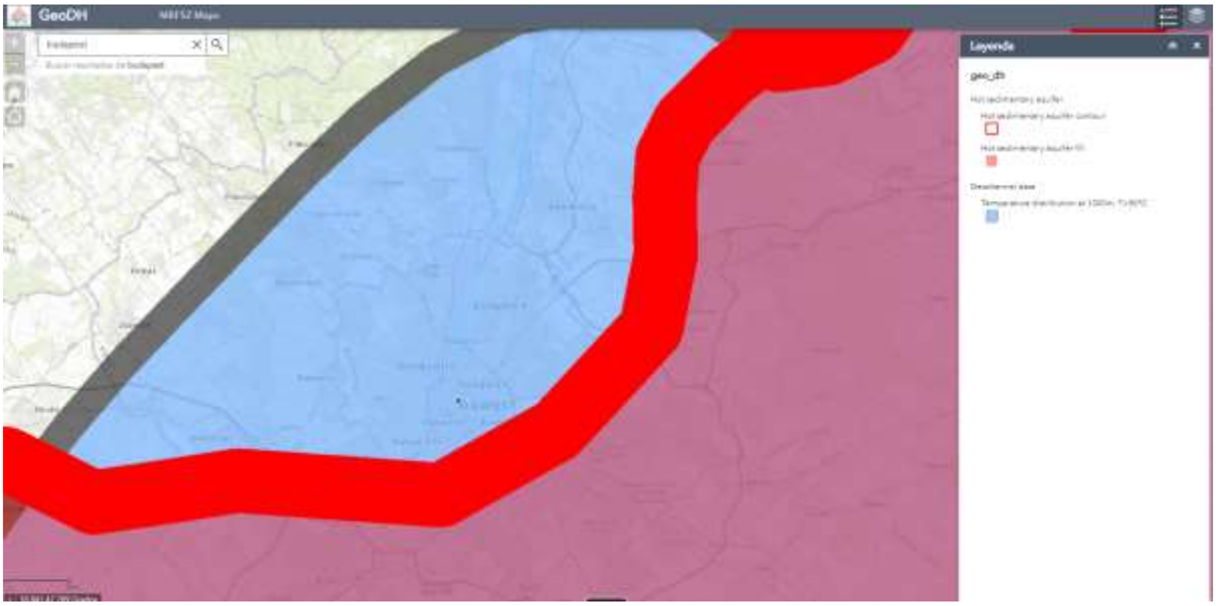

Figure 36: Geothermal potential (https://map.mbfsz.gov.hu/geo_DH/)

Analysis at district level (PED areas):

Using PVgis the PV potential is obtained for the optimal tilt and azimut for a location in the middle of the PED areas. For PED area 1 a potential of 1237 kWh/year/kWpeak installed is obtained, with a tilt of 39º and azimut of -2. For PED area 2 a potential of 1246 kWh/year/kWpeak installed is obtained, with a tilt of 39º and azimut of -3.

In Wind Atlas, the wind potential is obtained for a location in the middle of the PED areas, and at a height of 10 meters (to allow mini wind turbines). For PED area 1, a potential of 29 W/m^2 is obtained for a height of 10 meters and a wind velocity of 2.5 m/s. For PED area 2 a potential of 55 W/m^2 is obtained for a height of 10 meters and a wind velocity of 2.7 m/s.

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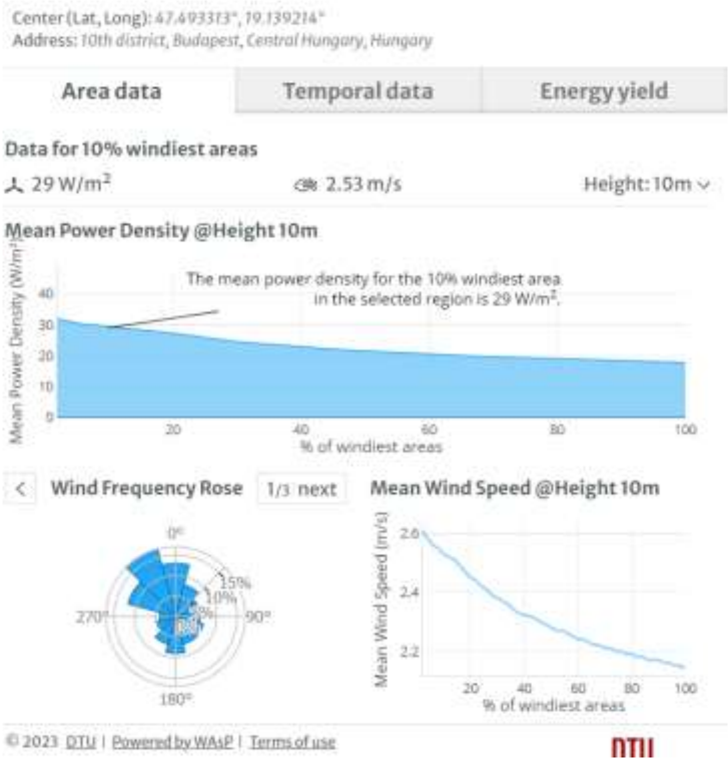

Figure 37: Wind potential in PED area 1

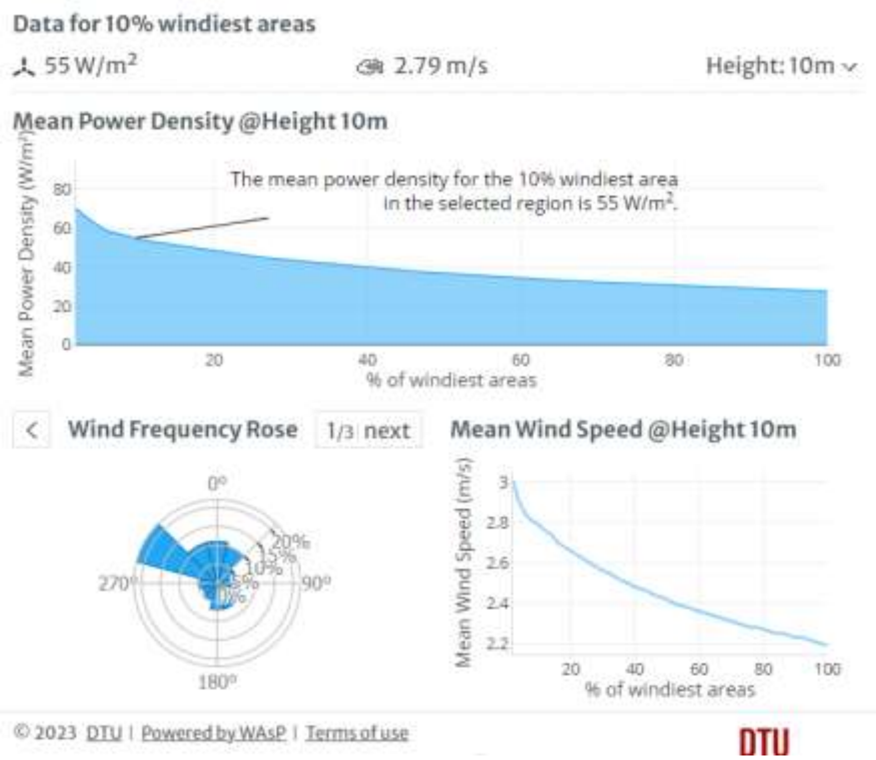

Figure 38: Wind potential in PED area 2

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Lastly according to ChargeMap, in PED area 2 there are 2 recharging points (with a power of 16-30 kW) and in PED area 1, there are plenty of accelerated recharging points (with a power of 16-30kW).

Figure 39: Charging points in PED area 2.

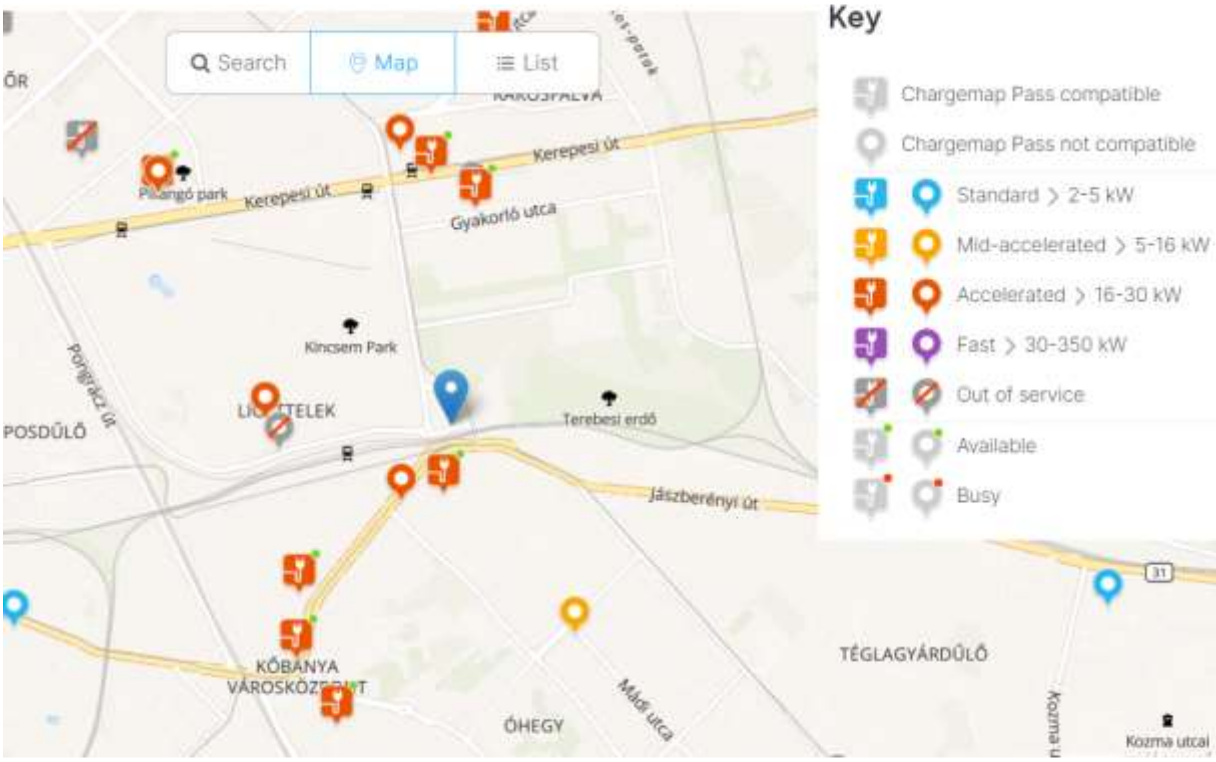

Figure 40: Charging points in PED area 1

All of these characteristics, as well as spatial, social and economic characteristics are weighted using the resulting scores from STEP 2.1 in next step.

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STEP 2.3

Considering spatial, technological, social and economic factors, a composite indicator that ease the PED area prioritization is obtained for each of the areas. The process is validated by the city. PED 1 resulted in higher composite indicator than PED 2. This is due to the fact that, PED 1 has, in principle, higher RES potential compared to that of in PED 2 and it is a new development area preferred by the municipality. Summary of the results are shown in Figure 41.

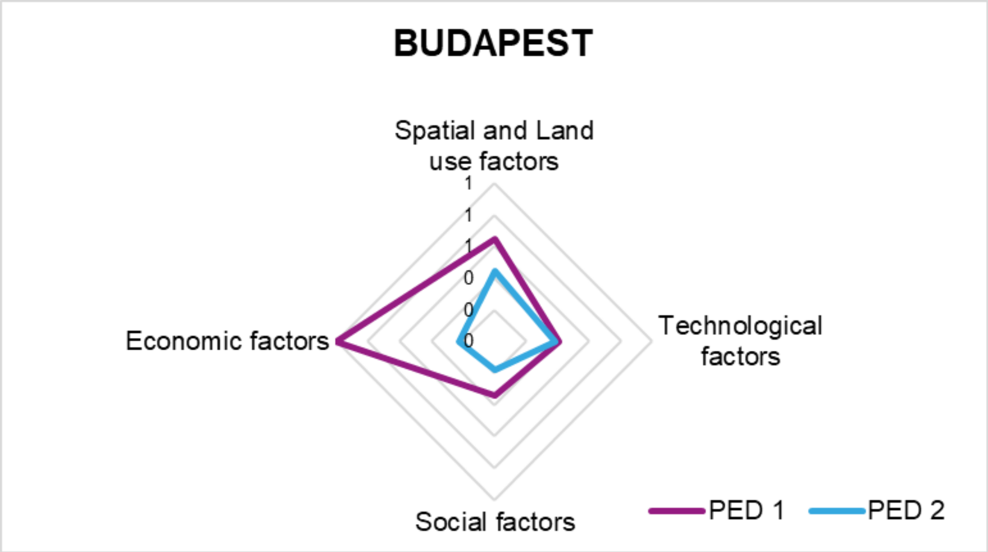

Figure 41: Final selection of PED and summary of scores, and final weights- Budapest

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5.3. STEP 3b: Detailed design of PED

STEP 3.0: Bioclimatic design

Using the program Climate Consultant, an assessment of the climatic conditions was conducted to assist PED design in new development regions. The key environmental variables (temperature, humidity, wind, rain ...) were collected and analysed. The execution of these strategies attempts to achieve comfort in accordance with the comfort standards previously detail in STEP 3.0: Climatic conditions evaluation (Bratislava).

Local analyses of the current climatic conditions

GENERAL STRATEGIES FOR PASSIVE URBAN DESIGN

JANUARY - MARCH

1.ENERGY NEEDS:

Temperature: The minimum temperatures recorded reach below zero degrees, oscillating between -5ºC and -10ºC. Therefore, providing warmth is really necessary from January through March (see Figure 137: Dry bulb diagram)
Since there is not much sunlight, during this time of year shading is not required. In March global radiation increases enough to exceed 400Wh/sq.m., which would reduce heating demands if correctly used. (see Figure 138: Diurnal average diagram)

Wind: Within the course of the primary trimester of the year, wind´s main direction varies through the months, with an average speed of 2m/s. (see Figure 142: Wind wheel_JAN-MAR)

2.SOLAR PASSIVE GAINS

There is little radiation during these months and hence it has to be taking the most advance of it. The south façade receives sunlight for nearly the whole day, albeit the amount of time sun shines on it fluctuates over the months. Although, the north one is not sunny at all. Additionally, the sun from dawn until noon lights the east façade, while from noon until sunset it lights the west façade.

3.STRATEGIES

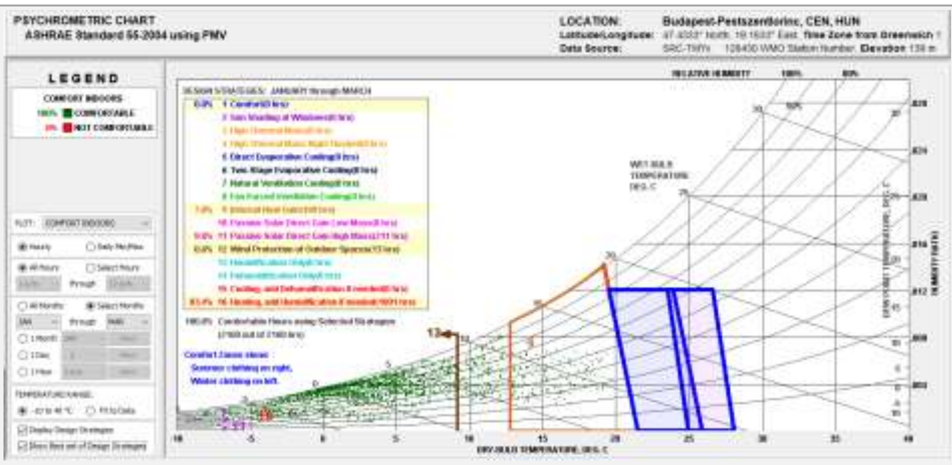

Figure 42: Psychometric chart without any strategy JAN-MAR

Providing heating sources is necessary and maximizing daylight hours is essential from January through March, as the overnight lows are below zero.
Due to the cold temperatures and short amount of daylight, it would be required to improve solar capacity during these months. Therefore, even though windows can be unshaded and

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facing in any direction, the main façade of the structures should be facing south with large windows on it since there is little risk of overheating and any passive solar gain is beneficial. It will be necessary to include thermal inertia enclosures in order to allow energy to accumulate throughout the winter. Also, buildings floorplan should be organized to allow winter sun penetrates into daytime use spaces with specific function that coincide with solar orientation to optimized solar captations. In the benefit of archiving 100% of the time to be comfortable, the design strategies implemented should focus on gaining internal heat, gaining passive solar direct gain high mass, wind protection of outdoor spaces and, as a especially important measure, to provide heating and humidification if needed. Some methods for archiving it include: • Facing most of the glass area to the south, in favour of maximize sun exposure. • Using better glass in the windows (double or triple pane). • Implementing a more efficient heating system. • Adding more insulation in the façades and roof, in order to avoid thermal bridges. • Designing buildings without excessive floor areas, which would waste heating and cooling energy.
APRIL – JUNE
1.ENERGY NEEDS:
Temperature: The average temperature in spring is over 16ºC, with a continuous rise through the months, reaching almost 35ºC in June. Although the minimum temperatures in April barely drop under 0ºC, the maximum ones rise above 25ºC. (see Figure 137: Dry bulb diagram). As the sunlight time and temperatures increase, shading starts being necessary. During April mean temperature is 13ºC, heat during most sunlight hours should be used to compensate the minumums during the night. But, during May and June minimum temperature rises and shading starts being necessary during the afternoon. (see Figure 138: Diurnal average diagram).
Wind: The wind often blows from the northwest throughout the second trimester of the year, with an average speed of 2m/s (Figure 143: Wind wheel_APR-JUN)
2.SOLAR PASSIVE GAINS
During April is still necessary some solar gains, although the shadowing necessity increases over the months of May and June, especially in the south façade. While the light hardly touches the north façade, it shines in the south façade for long periods. From sunrise until noon, the sun illuminates the east façade, and from that time until sunset, it is the west façade.
3.STRATEGIES

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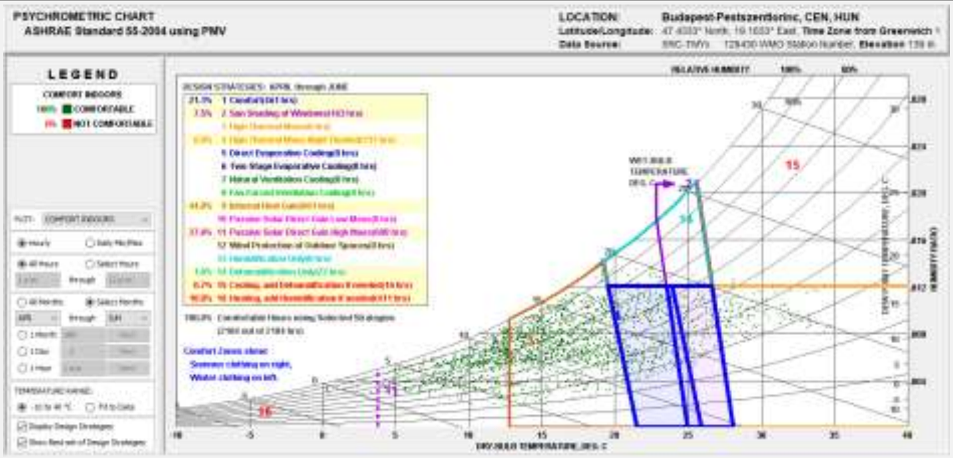

Figure 43: Psychometric chart without any strategy APR-JUN

It is important to make the most of the daylight hours, even if the lowest temperatures only fall below zero in April. As the number of daylight hours increases in the spring, it will be required to provide some shade during the hottest times of the day. The building should not have any windows on the north façade since they would hardly receive any sunshine in the morning. Additionally, thermal inertia enclosures can be used to storage energy.

In the benefit of archiving 100% of the time to be comfortable, the design strategies implemented should focus on sun shading of the windows, night flushed high thermal mass, gaining internal heat, passive solar direct gain high mass, dehumidification, and providing heating or cooling and humidification if needed.

Some methods for archiving it include:

- Using high mass interior surfaces (slab floors, high mass walls, stone fireplace...) to store passive.
- Keeping tight well-insulated buildings to maximize heat gain from lights, people, equipment, and lower heating needs.
- Sunny wind-protected outdoor spaces can extend living areas.
- Incorporating blinds, heavy draperies, or operable window shutters to reduce heat losses during night time.

JULY – SEPTEMBER

1.ENERGY NEEDS:

Temperature: The maximum temperatures recorded are above 30 degrees, and the mean temperature is between 20 and 25 degrees. Therefore, it will be very important to preserve the cool of the night and to avoid overheating, reducing the cooling necessity (see Figure 137: Dry bulb diagram).
During this time of year, it is necessary to provide some covering over the apertures and provide cooling through breezes and cross ventilation. In July and August, it would be essential to shade from 10:00 until 20:00, and in September, from 12:00 until 18:00, as the maximum temperature remain quite high. (see Figure 138: Diurnal average diagram)

Wind: The wind generally comes from the north in July and August, and from the west in September, with an average speed of 1,67m/s. (Figure 144: Wind wheel_JUL-SEP)

2.SOLAR PASSIVE GAINS

Since there are such high temperature, the solar gain should be reduced to the minimum. For this purpose, the openings should be facing the less illuminated façades, or should incorporate shadowing that would not affect during winter.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

Although the sun seldom touches the north façade, the south façade is hardly ever in the shade. From sunrise until noon, the east façade is illuminated by the sun, and from that time until sunset, it is the west façade

3.STRATEGIES

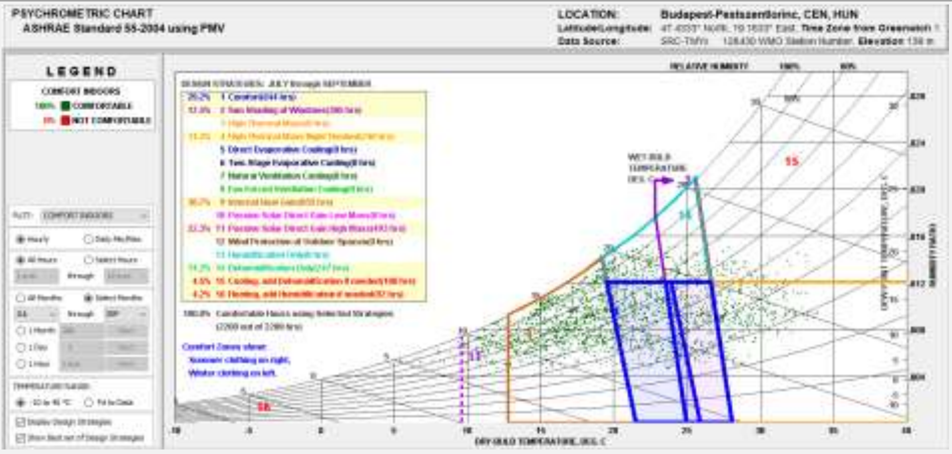

Figure 44: Psychometric chart without any strategy JUL-SEP

During summer, it will be essential to provide shading and cooling during the most heated hours, due to the high temperatures. The south, east, and west façades of the buildings receive direct sunshine throughout the day. East capitations are hence suitable to offer comfort. The south façade, however, receives the greatest sunlight. Therefore, its windows will require extra shading to avoid overheating. Overhands and moveable sunshades are a couple of the solutions that may be employed. Moreover, some blinds, thick drapes, or moveable window shutters could be added to provide shade and prevent heat loss at night.

In the benefit of archiving 100% of the time to be comfortable, the design strategies implemented should focus on sun shading of the windows, night flushed high thermal mass, gaining internal heat, passive solar direct gain high mass, dehumidification, and providing heating or cooling and humidification if needed.

Some methods for archiving it include:

- Using high mass interior surfaces (slab floors, high mass walls, stone fireplace...) to store passively.
- Low pitched roofs with wise overhangs works well in temperate climates.
- Designing windows location to prevail breezes, incorporate shading elements and generate natural ventilation.
- Incorporating low screened porches and patios to the buildings, in order to provide more comfort facilitating cooling and ventilation in warm weather and prevent insect problems.

OCTOBER – DECEMBER

1.ENERGY NEEDS

Temperature: The minimum temperatures recorded reach below zero degrees, achieving even below -10ºC in December. Throughout the whole time in October, November and December, there is a significant demand for warmth (see Figure 137: Dry bulb diagram).
Since there is so low temperatures and little sunlight, there is no need for shading during this period of the year. (see Figure 138: Diurnal average diagram)

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Wind: The wind predominantly comes from the south during October and November, and from the West in December, with an average speed of 2m/s. (Figure 145: Wind wheel_OCT-DEC)

2.SOLAR PASSIVE GAINS

During these months the temperature and radiance decrease, so the solar gains should be optimized. Before and after mid-day, the south façade receives sunlight, whereas the north façade virtually never receives any. From sunrise until noon, the sun illuminates the east façade, and from that time until sunset, it is the west façade.

3.STRATEGIES

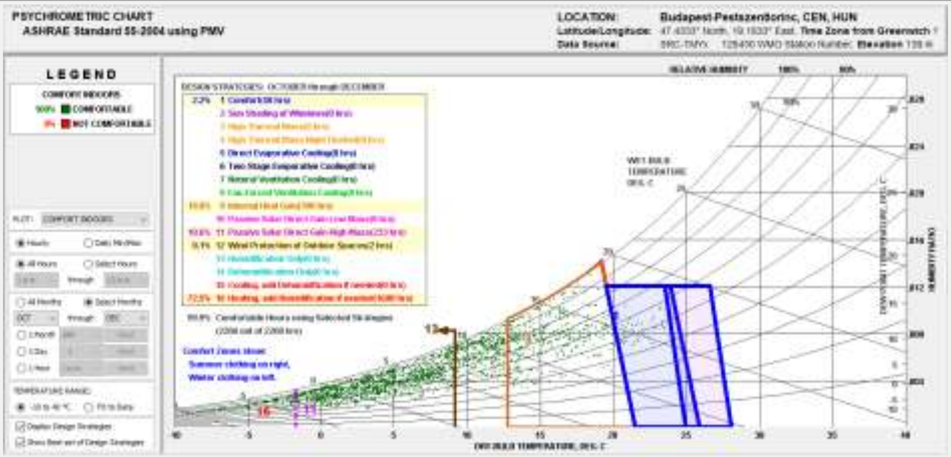

Figure 45: Psychometric chart without any strategy OCT-DEC

Using the daylight hours is essential from October through December to accumulate warmth, when the lowest temperatures are below zero. As a result, the primary façade of the structures should face south and have big windows on it to better use the sunshinet, as long as they are equipped with properly shading elements for the warm months of the year. While they will be less effective, windows on the east and west façades might also give respectable capitations.

Due to the cold temperatures and short amount of daylight, it would be required to improve solar capacity during these months. It would be necessary to include thermal inertia cages in order to allow energy to accumulate throughout the fall.

In the benefit of archiving 100% of the time to be comfortable, the design strategies implemented should focus on gaining internal heat, passive solar direct gain high mass and, as an especially important measure, to provide heating and humidification if needed.

Some methods for archiving it include:

- Facing most of the glass area to the south, in favour of maximize winter sun exposure.
- Adding more insulation in the façades and roof, in order to avoid thermal bridges.
- Using better glass in the windows (double or triple pane).
- Locate garages or storage areas on the side of the building facing the coldest wind to help insulate.

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STEP 3.1: Baseline calculation

The selected district will consist of a residential area (blocks 1–4), a workplace area (blocks 5; 7-8; 10-13 and 15-16), and an economic area (14 blocks). The proposed design of PED in Fehérdűlő was created to offer the optimum version in accordance with the sustainable new districts manual of Budapest. The parameters and ratios of the envisaged development only slightly fall short of the maximum possible dimensions permitted by the effective building regulation.

When the structural design of the area was worked out, the main objectives were to create block sizes that ideally matched the requirements of pedestrian traffic and public areas of widths corresponding to the network role of the area. The planning area is divided into two areas of two different main functions. The area along Gyógyszergyári út will accommodate residential buildings, while in the area south of it will be one of building complexes for work-related functions /offices, research and development facilities, education, accommodation (e.g. student hostel) type buildings etc. /. A public park will be developed in the centre of the area (block 9) at the border line between the area for residential functions and the area for work-related functions.

Figure 27 Fehérdűlő PED Area

The residential area (blocks 1–4) has a built-up ratio of 40%. For the most part, buildings of ground floor plus 6 upper floors, connected by ground floor wings. The ground floors of the buildings will accommodate community functions, commercial and service facilities. The

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minimum distance between building masses is 21 metres, therefore the air space ratio between opposite façades is always greater than 1:1. The coordination of building heights with building mass distances enables adequate sunlight to enter the spaces between buildings. The shapes of the buildings will be sufficiently varied to avoid monotonous streetscapes. Parking facilities will be constructed under ground level everywhere – in two-storey underground car parks under the buildings – ensuring a parking place for every apartment.

The workplace area (blocks 5; 7-8; 10-13 and 15-16) consists of buildings of ground floor + 5, 6, 7 or 8 upper floors, of varied mass shapes. In the case of any institution that needs a larger area (e.g. the campus of an educational institution) adjacent blocks can be merged. Parking facilities will be constructed under ground level everywhere – in two-storey underground car parks under the buildings – providing parking capacities reflecting the dominance of public transport. The planned open accessibility between blocks will guarantee vital, vibrant urban spaces.

The economic area (block 14) accommodates commercial, logistics or other economic activities that do not interfere with the use of the surrounding blocks. The building masses may be undivided, so unbroken hall spaces of great ceiling heights can also be created. The office spaces and the halls associated with handling and service providing functions should be ground floor + 2 upper floor buildings and the built-up ratio should be kept below 30% to make sure that green spaces can also be created in the area in addition to paved handling spaces.

The property in the ownership of a church (block 6) will continue to be an institutional area and may be utilised in accordance with the owner's requirements.

Figure 28 overview of 3D model of the PED development prepared in accordance with the recommendations set forth in the Sustainable New Districts Manual

The energy supply and efficiency modelling has been worked out on the basis of the built-up area ratio, the buildable floor area and the related air cubic metre numbers and the planned functions. Planning does not cover the design of buildings' detailed mass and façade forms (e.g. shading systems, glass to solid façade surface area ratios) or the internal layout systems.

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Our initial condition is that all of the buildings appearing in the plan meet the domestic energy efficiency requirement (the "nearly zero" requirement specified in Decree 7/2006 TNM, issued by the competent minister without portfolio) and those laid down in the Manual.

AREA STATISTICS – based on "XXI.sz." variant

block number	area of block of land (m2)	zone	maximum permitted ratio to/ area on which buildings can be constructed on the site (%, m2)		general floor area ratio (m2/m2)	total floor area that can be constructed (m2)	building height	function (apartment: gross 80 m2/apart.)	useful area (m2) / number of apartments	proposed parking spaces (No.)	number of P floors
1	12 181	Ln	40	4 872	2,4	29 234	variable F+1 - F+8	apartments	24 400 / 305units	305	2
2	12 181			4 872		29 234		apartments	24 400 / 305units	305	2
3	12 181			4 872		29 234		apartments	24 400 / 305units	305	2
4	12 181			4 872		29 234		apartments	24 400 / 305units	305	2
5	21 402	Vi	40	8 561	2,4	51 365		office+research	25 682	643	2
6*	47 841		30	19 136	1,0			church function			
7	18 508		40	7 403	2,4	44 419		office+research	22 210	556	2
8	18 550			7 420		44 520		office+research	22 260	557	2
9	10 310							office+research		0	0
10	10 930			4 372		26 232		office+research	13 116	328	2
11	7 814			3 126		18 754		office+research	9 377	235	2
12	13 191			5 276		31 658		office+research	15 829	396	2
13	13 191			5 276		31 658		office+research	15 829	396	2
14	12 163	Gksz	30	3 649	0,9	10 947		comm.	7 663	192	2
15	8 661	Vi	40	3 464	2,4	20 786		office+research	10 393	260	2
16	13 181		60	7 909	3,0	39 543		office+research	19 772	495	2
Total:	234 156			95 082		436 820				1220+4058	

Figure 29 Area statistics for optimum version of the Manual

The location of the planning area within Budapest, and consequently its accessibility, are both favourable, since it is located in the vicinity of (at a distance of 700 m – 1200 m from) one of Budapest's five designated intermodal subcentres, i.e. Örs vezér tere. The circumferential route – running along the roads Nagy Lajos király útja, Fehér út and Kőrösi Csoma Sándor út – connecting the elements of the centre system of the region is located along the western border of the area. The area's southern side bordered by the route of the planned extension of the road Keresztúri út until as far as the ring road Hungária körút. There is a metro terminal and a commuter train (HÉV) terminal at Örs vezér tere, and several tram lines run along Fehér út.

The Municipality of Budapest proceeded the study of PED design through BFVT Kft., a municipality owned company to deliver the task of studying the area and the urban form of the buildings as well as the scenarios to perform positive energy balance for the proposed new development.

As a result, the planned situation (baseline) of the buildings would be the following:

The study of PED development was worked out through detailed elaboration of one block of each type (Residential Block No. 1 and Office Block No. 5.). The overall aggregated information for the entire area can be generated by the multiplication of the functional units, based on the principle of similarity. No development (construction) is planned to take place in Block No. 6 (church-owned area) therefore this area is not presented in the aggregated energy balance. In case the development as per the BDR is implemented in accordance with the requirements laid down in the Manual in this area as well, or if it becomes part of an energy community, its

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energy requirement and the possibilities for energy generation in this area can also be taken into account in the energy balance.

A residential block's need for thermal energy generating capacity of the required heating system is 691 kW according to the heat loss calculation, which can be reduced to 437 kW by using heat regenerators in the ventilation systems. The estimated total annual amount of thermal energy required for the heating of a residential block is 1,296 MWh/a, which can be reduced to 708 MWh/a with the use of heat regenerators. A total of 732,000 kWh/a thermal energy is required for supplying a residential block's domestic hot water requirement.

An office block's need for thermal energy generation capacity of the required heating system is 1,477 kW according to the heat loss calculation, which can be reduced to 809 kW by using heat regenerators in the ventilation systems. The estimated total annual amount of thermal energy required for the heating of an office block is 2,030 MWh/a, which can be reduced to 1,106 MWh/a with the use of heat regenerators. A total of 436,485kWh/a thermal energy is required for supplying an office block's domestic hot water requirement and an annual 277 MWh electricity is required for lighting.

Summary of baseline results:

kWh/m²	Thousand m²	Cooling	Heating	DHW	Lighting	Ventilation+ Appliances	Total El.	Total DHN	Total Gas
Residential	19.49	0[18]	53.10 kWh/m2/a (per 1m2)	39.42 kWh/m2/a (per 1m2)	-	-	-	-	-
Offices	75.59	0[19]	30.78 kWh/m2/a (per 1m2)	12.14 kWh/m2/a (per 1m2)	7.70 kWh/m2/a (per 1m2)	-	277 MWh/a	-	-
Public space	139.0	-	-	-	58 MWh annual	-	58 MWh annual	-	-
Parking	Number of parkings: 5278	-	-	-	-	-	-	-	-

Figure, Summary of Baseline results

Assuming the heating and DHW covered by the DHN that is nearby, it would have accounted in 1,150.7 MWh/a of heat delivered by the DHN. With primary energy factors of 2.5 for Grid electricity [20]and assuming a DHN factor from the ISO52000 standard (which is 1.2), the total non-renewable primary energy is 2.2GWh/a. This corresponds to tonnes of CO2eq[21].

[18] A daytime warming during a heat spell of several days are of a scale which is perfectly offset by the inertia of the building's thermal mass, or can be adequately controlled by intensive ventilation during the cooler early morning hours, or can be compensated by the PCM plaster on the walls of interior walls or can be adequately controlled by a combination of the above without additional energy input, which is the goal to be achieved.

[19] The situation is somewhat different in the case of office buildings from what was written above in regard to residential buildings, however, mandatory application of the above methods – primarily, shading – is recommended in this case as well. Office buildings have significantly higher proportions of glazed surfaces, therefore the tasks of shading are even more important here. However, unlike in the case of residential buildings, virtually all office buildings have ventilation systems in place in general. The heat of the extracted air can be an excellent heat source for DHW production.

[20] https://epbd-ca.eu/wp-content/uploads/2022/10/Implementation-of-the-EPBD-in-Hungary-2020.pdf

[21] Assuming 243 g CO2eq/kWh for GRID from https://www.nowtricity.com/country/hungary/#:~:text=In%202022%20the%20average%20emissions,C

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STEP 3.2: Selection of potential solutions> define scenarios

In new buildings: Within the nZEB requirements is that at least 25% of the energy needs of the building should be covered from RES. The city of Budapest selected several potential solutions to define the scenarios at district level. In view of the project's location, conditions and circumstances as well as its planned utilisation, the following may be taken into account as potential renewable energy sources in the area to be developed:

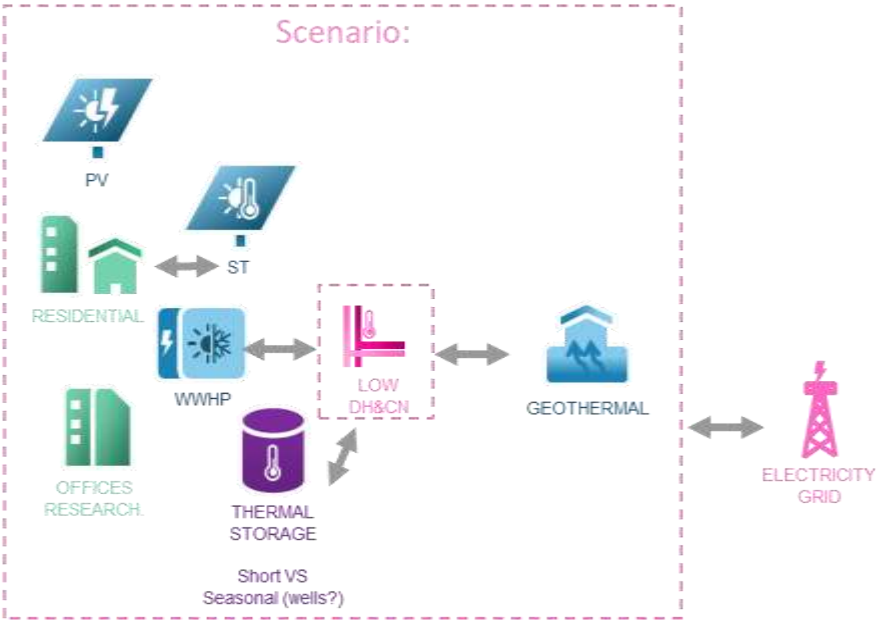

Figure 31 Overview of solutions

- **Geothermal**

Geothermal was considered at the beginning. From the company studies, 10-11 MW of thermal energy could come from geothermal, 765 kW geothermal energy can be extracted from the area designated for one residential block, and 1,336 kW geothermal energy can be extracted from the area designated for one office block.
However, according to the geological study of the area prepared by HGD Kft, drilling will be difficult due to thick limestone sediments. Data measured in nearby drill holes south of the area show that underneath a few metres of soil, surface sediments or filling there is a 30–60 metre bedded limestone formation comprising medium heavy and heavier beds as well. Below that, calcareous, and variably heavy-textured clayey and sandy layers are to be found in alternation to a depth of about 200 metres; in the south-eastern part sandy marl and tuff can also be found down to the same depth.
Lower thermal conductivity values (1.5-1.7 W/mK) were measured in HGD Kft's drill holes at Gyömrői út, and their probe tests in similar formations (probes were installed to a depth of 70–80 m in the Tinnye Formation and below that, to 100 metres, in the Lajta Limestone) which is explained by the poorer water permeability of the more cemented heavier limestone beds. In view of the above test results and other information (other projects, heat flow map) similar 14-15 °C base temperatures, and a similar approx 3 °C/100 m temperature gradient may be expected in the area under review. No deep geothermal – thermal well – solution was assessed for the area.

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oal%20usage%20was%209.4%25. And 200 g CO2eq/kWh (assuming the benchmarking from https://erranet.org/download/benchmarking-district-heating-hungary-poland-lithuania-estonia-finland-2/?wpdmdl=33352&refresh=64e4817e628a01692696958).

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- **Heat pumps**

Utilising ambient air by heat pumps. The outdoor units of an **aerothermal heat pump** must be installed outdoors. Due to the required large air flow such machines may be rather noisy. A central unit requires a considerable area and since such units are installed on the ground they increase the built-up area ratio, or on rooftops, in which case they occupy area where solar panels could also be installed.

In the case of office buildings, they are usually mounted on rooftops but they always require a supplementary heating unit. The amount of thermal energy that can be generated with such machines depends solely on their physical dimensions. The thermal energy source is theoretically unlimited.

In residential buildings it may be of relevance in the form of **split air conditioner** installed individually in apartments. These may be a viable alternative primarily in residential units, units with separate specific purposes, for light-structure (or equivalent) units with low heat requirements. Their power factor depends on the outdoor temperature whose applicable average value is c_k=0.3. With 1 kW auxiliary power they can generate an average of about. **3.5 kW heat flow** can be generated.

Since **technological waste heat** is utilised, the thermal energy so recovered must be taken into account as renewable energy in the assessment of the building's energy efficiency.

- **District Heating**

The existing district heating network is far, but it could be studied to deploy a low DHCN. BKM's District Heating Division is currently preparing a geothermal small power plant project in the south-eastern part of Budapest (within about 10 km from the site), which is expected to start supplying hundreds of thousands of GJ thermal energy into the district heating system a year, within two years from now, whereby it will improve the renewable energy source ratio of the Capital City's district heating system.

- Solar energy

The total area on which construction is permitted on the basis of the applicable permitted maximum built-up area ratio applying to the block of land: 95 082 m^2. Installation experience shows that up to 30% of the roof surfaces can, at best, be used for the installation of solar panels. In view of the above data, the estimated maximum solar power generation capacity that can be put in place in the area:

on the plots of land on which residential blocks are to be constructed:
P_{HMKE}= 4 872 m^2 * 30% * 0.25kW_p/m^2 = 365.4 kW_p

on the plots of land on which office are to be constructed:
P_{HMKE}= 8 561 m^2 * 30% * 0.25kW_p/m^2 = 642.1 kW_p

on the entire development area:
P_{HMKE}=95 082 m^2 *30%*0.25kW_p/m^2 = **7 131 kW_p.**

The estimated total electricity that can be generated on the whole of the development area:

on the plots of land on which residential blocks are to be constructed:
Q_{HMKE}= 365 kW_p * 1.232 $MWh/m^2/a$ = 450 MWh/a

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on the plots of land on which office are to be constructed:
Q_{HMKE}= 642 kW_p * 1.232 $MWh/m_2/a$ = 791 MWh/a

on the entire development area: Q_{HMKE}= 7 131 kW_p * 1.232 $MWh/m_2/a$ = **8 785 MWh/a.**

The maximum size of a household-sized small power plant is – according to the Electricity Act – 50 kW_p. Accordingly, a total of 142 maximum-size HSPP can, in principle, be installed on the roof surfaces.

Installation of solar panels on facades/walls
The estimated total electricity that can be generated on the whole of the development area on the buildings' façades:

on the plots of land on which residential blocks are to be constructed:
Q_{HMKE}= 2 507 kW_p * 1.232 $MWh/m_2/a$ * 0,62 = 1 915 MWh/a

on the plots of land on which office are to be constructed:
Q_{HMKE}= 6 296 kW_p * 1.232 $MWh/m_2/a$ * 0,62 = 4 809 MWh/a

on the entire development area:
Q_{HMKE}= 8 803 kW_p * 1.232 $MWh/m_2/a$ * 0,62 = **6 724 MWh/a.**

The maximum size of a household-sized small power plant is – according to the Electricity Act – 50 kW_p. Accordingly, a total of 176 maximum-size HSPP can, in principle, be installed on the façades. The actual size of the sufficient area depends primarily and essentially on architectural solutions therefore the architect and the power engineer need to collaborate in the initial phase of the design process.

- DHW production with solar collectors

During 50–70% of the year the DHW requirement can met by operating a **solar collector system**. During the remaining 30–50% of the time some alternative for generating thermal energy. Solar collectors can be installed even on surfaces that are suitable for the installation of solar panels only to a limited extent (e.g. being shaded during certain periods), therefore their use should be considered in combination with solar panels. The estimated auxiliary power requirement of the operation of a solar collector is approx. **0.4 $kWh/m_2/a$.**
On an annual average, on every 1 m_2 of sun-exposed surface,

- 815 kWh/thermal energy can be generated by solar collectors,
- 308 kWh/a electricity can be generated by solar panels.

The part of 60% of the DHW requirement of the development area, which can be supplied by operating solar collectors:
On the plots of land on which residential blocks are to be constructed:
Q_{DHWc}= 962 MWh/a * 0.6 = 577 MWh/a
On the plots of land on which office are to be constructed:
Q_{DHWc}= 436 MWh/a * 0.6 = 262 MWh/a

- Utilisation of solar radiation with transparent structures

The magnitude of solar gain per 1 m_2 of transparent structure (glazed window/door) is regulated in the TNM Decree. The size of the transparent surface exposed to solar radiation can be estimated for office blocks as follows. Heated air volume: V = 107 865 m_3. Of the A/V = 0.325 m_2/m_3 calculated in another way the building's cooling surface is 35 056 m_2. Let's assume that 50% of the total cooling surface is transparent and its elements are

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evenly distributed in the four directions, there is a total cooling surface of 35 056/2/4 = 4 382 m_2, rounded to 4 400 m_2 in each direction. Some 30% of the total annual solar radiation of 1 544 MWh/a, that is, approx. 500 MWh can be utilised during the heating season. This amount equals 25% of the 2 030 MWh/a total annual heat requirement for heating. In the case of a heat regenerator it can cover nearly half of the total annual heat requirement of 1,106 MWh which is a very considerable amount of energy.

In the case of the residential block, the ratio of transparent structures is about 10-15%. According to the calculation based on the above method shows that some 280 MWh solar thermal energy can be utilised during the winter period, equalling about 30% of the total annual thermal energy of 708 MWh required for heating (with the help of heat regenerators). Regardless of the amount of the extractable heat energy, this can only be taken into account as a supplementary heat source

- Storage possibilities

Creating some storage capacity is indispensable for smoothing out the fluctuations. The installation of storage capacity is also justified by the prevailing regulatory environment because newly notified HSPPs cannot, for the time being, temporarily feed back into the grid, according to the government's communication.

The obligation of storage capacity installation is of relevance in the licensing of solar power generators over 50 kW because this is prescribed in the currently effective version of MAVIR's Operational Regulation for all solar panel systems of capacities exceeding 50 kW; a remotely controllable battery energy storage system must be put in place on a mandatory basis for up to 30% of the capacity of the installed solar panels for two hours.

The possibility of annual balance settlement is expected to be terminated in the near future and replaced by a system in which the party towards which the electric current momentarily flows, pays for it.

- **Energy communities**

Energy communities are not supported at the moment, e.g. they need to connect with existing DHN (they cannot promote a new one). It is NOT possible to export energy. The regulatory background for energy communities has not yet been worked out. Although Act LXXXVI of 2007 (Electricity Act) introduced the concept of energy communities from 01.01.2021, however, the detailed rules that would enable energy sharing have not been adopted. The regulatory test environment is expected to be launched in 2023.

Scenarios to study combine: PV, solar thermal, and heat pumps (ground-coupled) connected or disconnected from DHN.

STEP 3.2.1: CEA calculation

After the completion of the PED concept and the urban and architectural plans by BFVT (urban development company of the municipality), the concept was presented to local stakeholders (2022.december). This concept included both an energy generation potential and energy demand calculation. Still, to back up the results with further calculations, we attempted to use the City Energy Analyst software.

However, due to issues we were unable to resolve, we had to rely fully on the calculations of BFVT to define the PED area and verify that it can function as a PED. Since their calculations were made according to local regulations and manuals, by professionals, we are confident in the results and scenarios generated (presented in the next paragraph).

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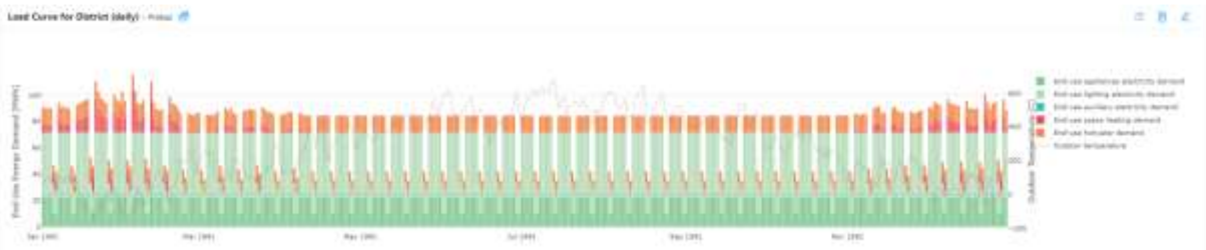
Issues we ran across:
- the software was unable to calculate with parking space that were part of a building complex, but instead of having additional floors above it, had public spaces
- due to the complexity of building geometry, we separated building blocks, which (we presume) might have led to some of the issues
- lack of mechanical engineer or other professional who can understand and manage the nuances of the software.
- unable to identify the issue when we managed to generate a final result.

Load curve for whole district:
The sudden drops on weekends can be explained by the fact that the majority of functions on the area are offices. However, the distribution of demand between heating and lighting are impossible to be correct, but we were unable to find the source of the issue.



Load curve for selected building:

STEP 3.3: Scenarios evaluation and prioritization

A total of sixteen possible technology scenarios are compared in relation to each usage function. The recommendations of the technology catalogue recommended in the ATELIER project were taken into account in the preparation of the various scenarios from an engineering aspect. The indicators of energy requirement calculations relating to the two types of building blocks were summarised in a table in a breakdown by renewable energy utilisation scenario. The **indicators** are the quantities of the auxiliary power required for the utilisation of renewable energy. The data in the last – evaluating – column of the table show the quantities of the surplus electricity generated from renewable energy sources but not used, which can be transferred to other energy consuming systems (not shown in the table) (the negative figures, in red, show the quantities that need to be taken from other sources, e.g. the public grid). It is clear from the evaluating column that there are several alternatives in the case of both types of building blocks which show a positive balance in the case of the energy requirements calculated on the basis of the TNM Decree.

The calculations were based on general consumer behaviour and internal parameters specified in accordance with the TNM Decree. The figures in the table can be used in terms of their scales/magnitudes and mutual relative proportions.

According to the building energy efficiency study scenarios 11 and 12 in each table provides a positive energy balance through solutions that are easy to implement. **The study also points out that scenario 12 ensures autonomous supply.**

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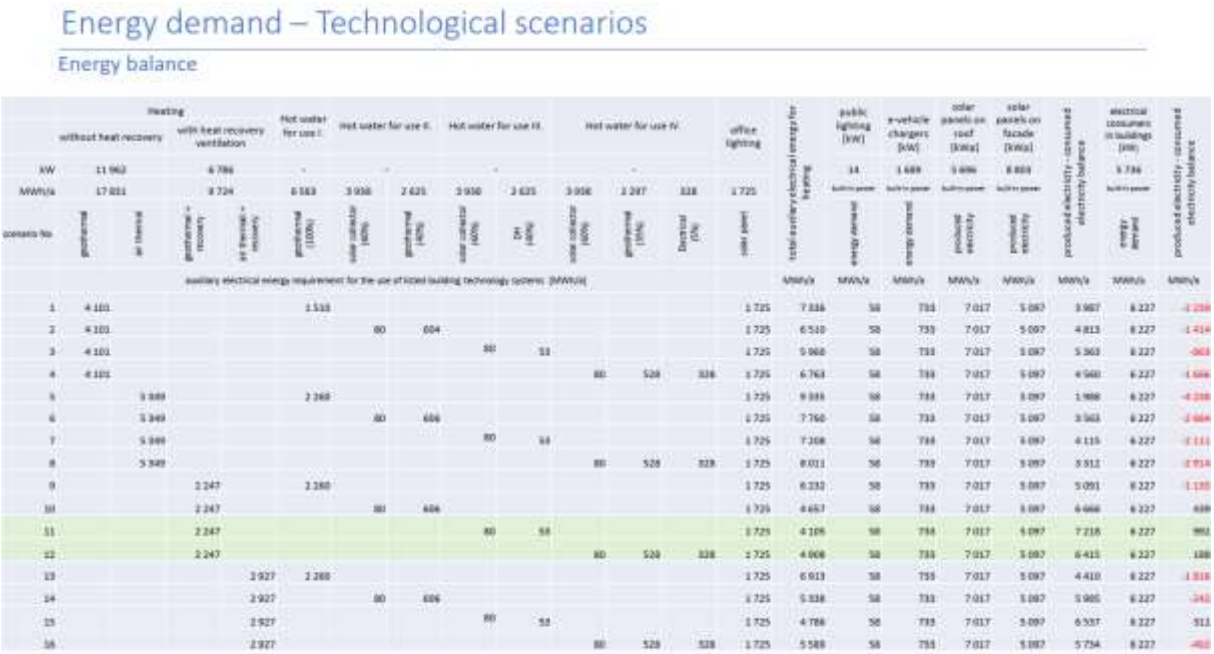

The two scenarios that achieve PED are scenario 11 and 12, which are summarized in the following figure:

Figure 46 scenarios 11 and 12 summary.

Further possibilities for improving the energy balance

- On the consumption side:
  - application of innovative solutions for the utilisation of the waste heat and technological heat output (a combination of usage functions, in the optimum proportions, enables making the optimum choice of the available building services engineering technologies)
  - utilisation of the heat gain from solar radiation with the help of the transparent structures
  - emphasis on use of shading structures

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    - influencing consumer habits and behaviour, awareness raising, information, IoT systems, collecting, processing and making available, of production/consumption data, applications, smart controlling etc.
- On the production side:
    - increasing the number of geothermal probes, integrating consumers in external areas into heat supply
    - large scale use of solar panels on façades
    - maximising the solar panels/solar collectors on rooftops, minimising the area occupied by other building services engineering installations
    - mounting of solar panels as shading structures on top of other suitable structures in the planning area.

- Limitations
    - there is no major source of waste heat in the vicinity that can be taken into account (industrial technological heat, biogas, waste output that can be used for the generation of energy, wastewater treatment plant, major watercourse etc.)
    - the area's geological conditions are not favourable – exploratory drilling is necessary
    - construction parameters cannot be significantly reduced, matters of economic efficiency
    - land use for combined functions is necessary, however, residential function is only feasible in a small proportion in the area chosen for the project
    - returns on investments are difficult to calculate as a consequence of the frequent changes in the domestic energy policy and regulatory environment
    - what with the termination of balance settlement there will be a need for the installation of electrical storage capacities
    - a renewable energy community will have to be created, but its legal framework has not been worked out yet

To conclude, the amount of energy, calculated in accordance with Decree 7/2006. (V. 24.) issued by the Minister without Portfolio on the determination of the renewable energy contribution and energy efficiency of buildings, determines if it is possible to achieve a positive energy balance for the proposed development. With all other energy consumers (loads in buildings, electric car chargers, street lighting) also in place, solar power generation capacities need to be maximised and innovative building services engineering/architectural solutions will have to be applied if the implementation of the PED is to be a feasible concept on the chosen site of implementation.

STEP 3.4: Financing options

From the options presented in Table 14 and considering the selected area of Fehérdűlő, the most feasible option is having an Energy Performance Contract (EPC) for shared savings through an Energy Service Company (ESCo) because this way the coordination would be in professional hands from the beginning, and it would grant higher potential to succeed the positive energy balance. This contract should go through the new Climate Agency that would act as a ‘Super’ ESCo, which the City of Budapest will initiate in 2024 via *100 Climate Neutral Cities Mission’s Pilot Cities Call* under the umbrella of the Climate City Contract contract. The

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implementation of the PED area should be also supported financially by a mix of external funds and funds from the investment platform coordinated by the Climate Agency. This way, external funds can be received in form of a 'Partial grant and partial self-finance' where monetary assistance would come from European and potentially from national, and regional funds as well. As Fehérdűlő PED is a pilot project for the city, it needs to be successful. The project needs all external potential support, so later the project can serve as an example or showcase for post PED replication, where more local investment can be attracted by showing the return and the success of the pilot project.

The least feasible option would be to apply an energy community business model, because of two main reasons. First, there is a heavily restricting regulatory environment for establishing and running an energy community. Second, it is currently out of the energy companies' scope to manage a community's energy flow and cooperate on citizen-founded projects, although it may change in the future. Finally, RES installation especially solar or wind is very challenging due to the regulatory environment of the country, for example solar grid feed in is prohibited at the moment (for household-sized plants).

Conclusions

This process has enabled Budapest to gain valuable insights for designing a tendering procedure that incorporates the essential features required to achieve and implement a PED in their area. To highlight some of the knowledge and experience gained, we list the most relevant points:

- In this study, sixteen different technology scenarios are compared based on their usage functions. The study identifies scenarios 11 and 12 as achieving a Positive Energy District (PED), with scenario 12 ensuring autonomous energy supply. Therefore, it is difficult but not impossible to achieve a PED in Budapest.
- Potential improvements are suggested on both consumption and production sides, such as innovative waste heat utilization, solar heat gain utilization, shading strategies (see bioclimatic conditions can be considered for the design as in STEP 3.1a.), consumer behaviour influence, and adopting IoT systems. On the production side, suggestions include increasing geothermal probes, extensive use of solar panels on facades and rooftops, and creative solar panel placement.
- Limitations include lack of major waste heat sources nearby, unfavourable geological conditions, or land use constraints.
- There are also uncertain returns on investments due to changing energy policies and absence of a legal framework for a renewable energy community.
- For financing, an Energy Performance Contract (EPC) through an Energy Service Company (ESCo) is deemed most feasible, potentially aided by external and Climate Agency-coordinated funds.

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6. PED design in Copenhagen

In this section, the steps defined in section 3.2 are applied to the city of Copenhagen. Starting with (Section 6.1) the city context and identifying the strengths, weaknesses, opportunities and threats of Positive Energy Districts; followed by the prioritization of one of the preselected areas in proposal stage (Section 6.2) and finalising with a PED detailed design for the selected area in section 6.3.The output is a set of recommendations for stakeholders to deploy PEDs in that area.

6.1. STEP 1: City's environment for PED implementation

Context

Copenhagen is located at the eastern side of Denmark and is faces the Øresund, the strait of water that separates Denmark from Sweden, and which connects the North Sea with the Baltic Sea. The population of Copenhagen Municipality is more than 610,000 inhabitants (distributed over approximately 70 km^2, which means a **density of 8,714 people per km^2**) and is expected to **grow by 20%** within the next decade. It is a city with a large share of young citizens and has the lowest average age of the country, namely 35.9 years.

Copenhagen is situated in the **oceanic climate zone**. The warmest months are July and August, with a mean daily minimum temperature of 13ºC and maximum of 20ºC. The coldest months are both January and February, with a mean daily minimum temperature of -2ºC and maximum of 2ºC. The month with most precipitation is July, in which the mean total rainfall is 57 mm; while the least is February.

Copenhagen has also **carbon neutral district heating projects** such as a carbon capture project, 'District Heating of the Future in the Capital Region 2050', Renewable energy Lolland, etc.

Under the name EnergyLab Nordhavn, the area will be developed into a **full-scale laboratory for a smart energy solution** (electricity, district heating and cooling, electric transport). The aim of EnergyLab Nordhavn is to develop new innovative business models, new energy technologies, and intelligent operating solutions, such as integrated and flexible energy markets, coordinated operation of electricity and heating systems, energy storages, energy-efficient buildings – subject to local optimization and intelligent interactions with the infrastructure and energy markets – and demand technologies offering flexible switching among energy carriers.

Conditions to allow a Positive Energy Balance

There are **strict requirements** for the new buildings in primary energy terms (30 kWh/m^2/year and 1000/A), but it is voluntary to achieve the nZEB class.

All PVs installed after 2012 have been on an hourly or immediate **net-metering** scheme, where the household surplus of electricity of up to 6 kW from solar panels is sold at a fixed price (significantly lower than the electricity price), and for higher capacity than 6 kW, it is not allowed to earn money.

The **electricity used for self-consumption** is supported by an **exemption from electricity tax**. This gives an economic incentive for self-consumption in buildings, although as the self-consumption is netted instantaneously, quite often the net self-consumption ratio is low. As of 2019, the pre-grid connection application procedure for self-consumption through instant settlement has been removed. Instead, the self-consumer can connect the renewable

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installation to the grid and then afterwards notify the local distribution system operator. The **new simplified rules minimize** the administration and avoid long processing times. Denmark is in the preparation for the national implementation of article 21 and 22 regarding an **enabling framework** for renewable self-consumption and renewable energy communities.

Collective **self-consumption** is allowed on building scale. All consumers as well as the generation plant have to be linked by a private grid and thereby have to be behind a common utility meter covering all consumers who will use the power produced.

Citizen energy communities are possible and there is a law and a book prepared to create them and on how to connect to the DH for heating supply. The DHN is not quite ready for citizens that produce their own energy (i.e. allow prosumers to be part of the network), this is something to be handle. So far citizen communities should focus on electricity side, but in terms of heating they are not ready to compete with DH prices. Supermarkets share their surplus heat to the DH system. Instead of producing more energy, it may have more sense to use better energy already being produced.

The legislated maximum injection concentration for **hydrogen** is not defined. Instead, any injection of hydrogen in the natural gas network needs permission from the Danish Safety Technology Authority according to the Danish Gas Regulations. **Synthetic methane** is not currently able to be certified as green by the Danish gas TSO. Therefore, integration into the grid is difficult as there is a legal limbo for the gas to be considered green. This obviously has connections to the question of certifying green hydrogen. Furthermore, and partly connected to the certification issue as well, synthetic methane is not eligible for government support in the same way as it is the case for biogas. This is a major barrier, since integration is in itself not financially viable and without government support it is not feasible with a large-scale production even though the overall conditions are in place.

Regarding **district heating** regulation, houses new built since 1998 are compelled to connect to the DHN (or to a RES). Thus, 53% of the building stock in Copenhagen is connected to the DHN. The philosophy is that it is cheaper and more efficient to make sure the DH is green and dynamic than trying to persuade consumers to establish energy communities and produce their own heat. Tariff design supporting a **flexible consumption** and regulation of the network are missing although it has been studied.

Conditions to allow a Renewable Energy Production

Electricity production prices are regulated by law and include a ten-year fixed price agreement which is the same for all the **wind turbines** on the island. The agreement stipulates a guaranteed price for the first 12,000 full-load running hours and afterward a lower one until the ten-year period expired. Wind turbines will in Copenhagen only be established as city initiative and not local energy communities, since there is simply no space.

The overall focus is on making the **heating system more dynamic**, and adding smaller electric RE such as PV on roofs, as well as improving energy efficiency.

There is a **limitation of biomass** production (sustainable level of production), since there is an interest on facing out biomass, looking forward on how is obtained (enhancing that should be sustainable), and there is **no more wood use** because it was not good for public health. Consequently, stove and fireplaces need to be maintained once a year. **City gas** is becoming more and more green, but there is still the question on how urgent should biomass be faced out.

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There is also **limitation for energy certification** on 25 kWh/m^2/year for the primary energy performance calculation of a building (the value can be exceeded but only up to 25 kWh/m^2/year can be used to lower the building energy performance values).

You need to negotiate a tariff if you want to have **access to the DHN**, there is no routine for this kind of prosumer, and there is more experience on big consumers, but no so much with citizens. To be connected to the grid, there are rules that need to be followed. It is possible for a prosumer to negotiate the tariff, but probably one of the parts will not be happy with the price agreed, since it could be not economically feasible because of the competitive prices of the DH.

Conditions to allow a Efficient buildings/ Building stock demand

The existing **building stock** has mostly high demand (132 kWh/m^2). In fact, 18% of Copenhagen's building stock is still energy-labelled E, F or G, which equates to about 7,600 buildings. This old building stock (although pretty and nice buildings) has influence in the decarbonisation, which is an issue in terms of base consumption. Cooling is not spread-out yet, but it will probably increase in the next years, but heating it is.

The "**Building Class 2020**" (equivalent to **nZEB** level) is only voluntary. The Danish Building regulation from 2018 set a minimum energy performance, but the stricter one is the Building Class 2020.

To some extent, the Danish building-type manufacture tradition has been a barrier for planning the community as a whole, more than as a collection of individual building units. In fact, the tendency in the sector, related to **low-energy buildings**, is to provide solutions based upon individual energy supply systems, mainly heat pumps, and the building types are often not developed with a friendly interface to district energy systems.

A certain share of **social housing** is required in new areas. Copenhagen Municipality carries out city **renewal programs** continuously to lift the building standard including energy performance. As, for instance, pensioner you can ask for a tax-free support for your domestic hot water and heat bill if the bill is above a certain level.

Energy Leap partnership to engage large building owners in energy efficient management of buildings of energy efficient construction, Urban renewal **funds**, temporary government subsidy for energy renovation, subsidy for replacing oil furnaces.

Conditions to allow Affordability

With respect to the **heat tariffs for DHN**, they are based on a large proportion of fixed tariff which pays for the long-term investment in infrastructure for production, storage and distribution. The fixed share of the heating tariff could be made all or more as variable, thus encouraging consumers to consume less heat.

Conditions to allow Liveability

There are green areas available and local plans specify more details on it, such as the maximum distance from residence to a **green area**.

Related to the **distance to work**, it is of 12.7 km as average for Copenhagen residents working in Copenhagen. When planning new areas, such as Nordhavn, the local plan preceding the build, sets limits to the distance, for instance from residential buildings to metro station and supermarket.

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Since 34.7% of neighbourhoods (out of the 388 neighbourhoods) have one or more **supermarkets**, and there are 199 supermarkets in Copenhagen area; this opens the **waste heat** possibilities.

Conditions to allow PED implementation

Regarding planning, in May 2020 the Danish government backed by a wide majority in the parliament, adopted an agreement to **invest** in the **green retrofitting** of housing units in the social housing sector up to 2026.

As local plans, Copenhagen aims to become **climate neutral by 2025** (CHP 2025 Climate Plan, adopted in 2012), with actions such as “Energy Leap partnership”, urban renewal funds, PV Action Plan and the replacement of oil furnaces.

The **District Heating** in Copenhagen is mostly **carbon neutral**, and wind energy and biomass electric production exceeds city’s total consumption.

The current SECAP, to 2020, targeted the 20% of GHG emissions reduction by 2020 (from the baseline year 2005). This is also set in the Strategy of the Action Plan, although little more ambitious: “*The vision of the City of Copenhagen is to be the first carbon neutral capital in the world by 2025. In the short/medium term, we will reduce the CO_2 emissions by 20% between 2005 and 2015*”.

SWOT analysis results

Copenhagen inputs are summarized in a SWOT table to identify which internal factors help or harm the PED implementation, as well as which external factors (National, EU level, etc.) creates opportunities and threats to its context.

What can be conclude is:

- Copenhagen has a high city density, which allows to have a greater impact (more people per km2) and its population is expected to increase. The city has a youthful demographic, with an average age of 35.9 years
- New buildings have a mandatory certification and ambitious energy performance standards but Building Class 2020 (nZEB level) is voluntary.
- There is a favourable regulatory environment for decentralized energy generation and many district heating projects and renewable energy initiatives contribute to the city's sustainability goals.
- Initiatives like EnergyLab Nordhavn focus on smart energy solutions, integrating electricity, district heating, cooling, and electric transport.
- Older building stock contributes to higher energy demand, with around 18% of buildings in energy-labeled E, F, or G categories. Traditional building-type manufacturing has hindered holistic community planning, favoring individual energy supply systems.
- The main challenges in Renewable Energy Integration are: Fixed price agreements for wind turbine electricity production, regulated by law; Limited space for wind turbines in Copenhagen, driving city-led initiatives instead of local energy communities; Challenges in integrating green gases like hydrogen and synthetic methane into the grid due to certification and support issues. Also a challenge for DHN is the availability of space for District-heat pumps.
- Very committed city with carbon-neutrality goals for 2025.

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Therefore, PED implementation has the potential to leverage its strengths, and capitalize on opportunities. The main barriers are insurance, Stakeholder mobilization, trust and technical quality.

	HELPFUL	HARMFUL
INTERNAL FACTORS (City context)	STRENGHTS	WEAKNESSES
	High city density	Missing a tariff design supporting a flexible consumption of the DHN
	EnergyLab Nordhavn: full-scale laboratory for a smart energy solution (electricity, DH&C, electric transport)	Rules to be followed to connect to the grid as a prosumer
	Participation in some carbon neutral district heating projects	Prosumer tariff can be negotiated but probably cannot compete with DH prices
	New houses since 1998 are compelled to connect to the DHN	Old building stock (with high demand and labels of E, F and G)
	53% of the building stock in Copenhagen is connected to the DHN	
	DHN is almost carbon neutral, thus it is good that buildings are connected to it	
	Electricity production prices are regulated by law with agreed ten-year fixed price for all wind turbines	
	Limitation of biomass production (for sustainable level of production with focus on facing out biomass)	
	City gas is becoming more and more green	
	Share of social housing required for new areas	
	Municipality carries out renewal programs to improve building energy performance	
	Copenhagen aims to become climate neutral by 2025 (first capital in the world)	
EX	OPPORTUNITIES	THREATS

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	PVs after 2012 have an hourly or immediate net-metering scheme, with surplus of electricity at a fixed price	Fixed price for net-metering the PVs is only up to 6 kW, and significantly lower than the electricity price
	Electricity for self-consumption has an exemption from electricity tax (incentive)	Legislation on maximum hydrogen injection concentration is not defined
	The self-consumer can connect the renewable installation to the grid (and then notify the operator)	*Building Class 2020* (equivalent to nZEB) is voluntary
	Denmark is preparing a framework for renewable self-consumption and renewable energy communities	Barrier in the Danish building-type manufacture (planning the community as a whole) because the tendency in the sector for low-energy buildings, which is to provide solutions based on individual energy supply systems
	Collective self-consumption is allowed at building scale	
	Strict requirements for new buildings in primary energy terms	
	Danish government agreement to invest in the green retrofitting of housing units in the social sector	

Table 20. Copenhagen SWOT analysis results

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6.2. STEP 2: Selection of suitable area to design a PED

As said in section 3, from the preselected districts in proposal stage, a prioritization exercise is performed.

Copenhagen identified two potential districts for the implementation of their PED:

- Potential district #1: Levantkaj
- Potential district #2: Kulturhus

Both were selected as they are part of a development area of the city.

Figure 47: Copenhagen p re-selected PED areas

Figure 48 Plan of the development of the areas

The process of the methodology explained in *STEP 2: Selection of suitable area to design a PED* is followed to prioritize one of the two for performing the next steps (towards a PED detailed design).

STEP 2.1

In this step the desired objectives or impacts to be achieved by the PED implementation are identified. Overall, the impacts that CPH wants to achieve by PED implementation is: Carbon neutral by 2025 of fossil free by 2050. This is achieved through a mix of improved energy efficiency and renewable energy and integration/flexibility of energy systems and usage. Although we are interested in good air quality, the local air quality is not a driving force for the PED nor climate plan. Our air pollution is primarily related to transport vehicles. Also, reducing energy bills is not a driving force. Since the first oil crisis back in the 1970’s it has been the ambition of Denmark and thus also Copenhagen to create a cost-effective, robust (in terms of

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security of supply and limiting costs) energy supply system. Introducing district heating and a production capacity able to exploit many different types of energy resources including local resources in combination with a persistent focus on energy efficiency (in end-use, distribution/transmission, and production) are some of the measures that were taken to achieve a cost-effective, robust energy system. First shifting from oil to coal and then from coal to renewable energy resources (including biomass) and waste. One of the qualities of the Danish approach is a relatively holistic focus on the entire system and all consumers.

The district heat supplied to Copenhagen today is already to a large extent relying on renewable energy and the electricity production is also increasingly based on renewable resources – the expanded transmission network linking Denmark to its surrounding neighbours and the European power market helps making Europe's power production greener and at the same time more robust, than would otherwise have been possible if each country was disconnected. So, Copenhagen's (and Denmark's) focus when it comes to PED is to achieve greater alignment between fluctuations in energy supply with the demand for energy over the 24 hours of the day, each day for the week, each season of the year. This integration and development of associated services is critical to making further progress int eh green transition. And, energy efficiency is still as important as ever – today in order to enable larger amounts of local renewable energy supply to be exploited.

The impacts are identified and the pairwise comparison is performed, which results in:

		A	B	C	D	E	F	G	H
RER (Renewable Energy Ratio)	A	**1.00**	5.00	5.00	5.00	0.20	0.20	5.00	5.00
Improve air quality	B	0.20	**1.00**	0.20	0.20	0.20	0.20	0.20	0.20
Reduce bills	C	0.20	5.00	**1.00**	5.00	0.20	0.20	5.00	0.20
Achieve zero energy imports	D	0.20	5.00	0.20	**1.00**	0.20	0.20	0.20	0.20
Positive Energy Balance	E	5.00	5.00	5.00	5.00	**1.00**	5.00	5.00	5.00
Efficient buildings	F	5.00	5.00	5.00	5.00	0.20	**1.00**	5.00	5.00
Affordable	G	0.20	5.00	0.20	5.00	0.20	0.20	**1.00**	5.00
Liveable	H	0.20	5.00	5.00	5.00	0.20	0.20	0.20	**1.00**
	ADDING VALUE	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6

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Then, the impacts are compared with the city objectives, which results in:

FINAL WEIGHT (considering CITY PRIORITIES)	Ranking	
13%	3	RER (Renewable Energy Ratio) factor
4%	6	Improve air quality
11%	5	Reduce bills
2%	8	Achieve zero energy imports
38%	1	Positive Energy Balance
12%	4	Efficient buildings / Building stock demand
3%	7	Affordable
16%	2	Liveable

STEP 2.2

Using the City context template, city level details about the renewable energy source (RES) potential are asked in step 1.1 (such as maps, GIS data, etc.). This data potential at city level is used to analyse the RES potential at district level and compare the two areas. For Copenhagen, as there was not sufficient data at city nor district level, a detailed analysis has been performed searching in the different open data platforms (sEEnergies, PVgis, Wind Atlas, geoDH map, etc.). A summary of the results is presented in the following table:

A summary of the results is presented in the following table:

	PED 1	PED 2
High solar energy potential generation in the area (kWh/kW peak – PVgis)	*972.55 kWh/kWp*	
High wind energy potential generation (W/m2 at 10 meters height – Wind Atlas)	*228 W/m2 (5.71 m/s) at a height of 10 m; 452 W/m2 in the sea with a velocity of 7.5 m/s a height of 50 m*	
Geothermal energy potential generation	*YES*	*YES*
There is a river/sea close from which could be possible to harvest energy	*YES*	*YES*
There is an industry/ice rink/waste water plant, etc. from which could be possible to harvest energy (thermal/electric)	*YES*	*NO*
There is a forest from which could be possible to harvest forest waste	*NO*	*NO*
There is gas grids access	*NO*	*NO*
There is a refuelling station near to the district	Yes	*Yes*
There is a centralized heating generation	*No*	*No*
There is RES production	*No*	*No*
Buildings already have ventilation or an air handling unit	*No*	*No*
Buildings already have heat pumps or splits	*No*	*No*
District heating connection	*Yes*	*No*
Supply Tº	*N/A*	-
Number of buildings connected	*1*	-

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substations available on the buildings	*N/A*	-
district network provides cooling	*No*	-
There is an electric substation nearby	*Yes*	*Yes*
There is an existing district heating or cooling network nearby	*Yes*	*Yes*
There is Virtual Power Plant in the district	*Yes*	*Yes*
There is an Energy Community in the district	*No*	*No*
There is a waste management (at level district) or waste water plant nearby	*No*	*No*
There are energy intensive industries in the district	*No*	*No*

Both areas are close to each other. PED 2 is inside a business area. The first one is close to technical facilities and recreation/leisure existing areas, that could potentially interact with the PED 1. Lake and sea are nearby of both areas. All area has district heating supply, and is not far away from an existing wind power plant.

Figure 49: Areas in the city of Copenhagen (https://kort.plandata.dk/spatialmap?). The points indicated in the map are the PED areas

No industry points close to the areas have been identified according sEEnergies Open Data platform. However, the city thinks some waste heat from tertiary buildings like supermarkets could be harvested. Nevertheless, LYNETTEN waste water plant is close to the districts, but there are other plans to exploit it.

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Figure 50: Potential waste heat source: Waste water plants (sEEnergies Open Data Platform)[22]. The points indicated in the map are the PED areas

According to https://dybgeotermi.geus.dk/geologiske-data/ it seems below 800 m there is possibility to find 50-60ºC underground (Gassum Fm - see image. It seems that a borehole of at least 2km depth is needed), with a geothermal resource > 15 GJ/m^2. At a depth of more than 3 km, 80-90ºC can be found with the same resource (>15 GJ/m^2).

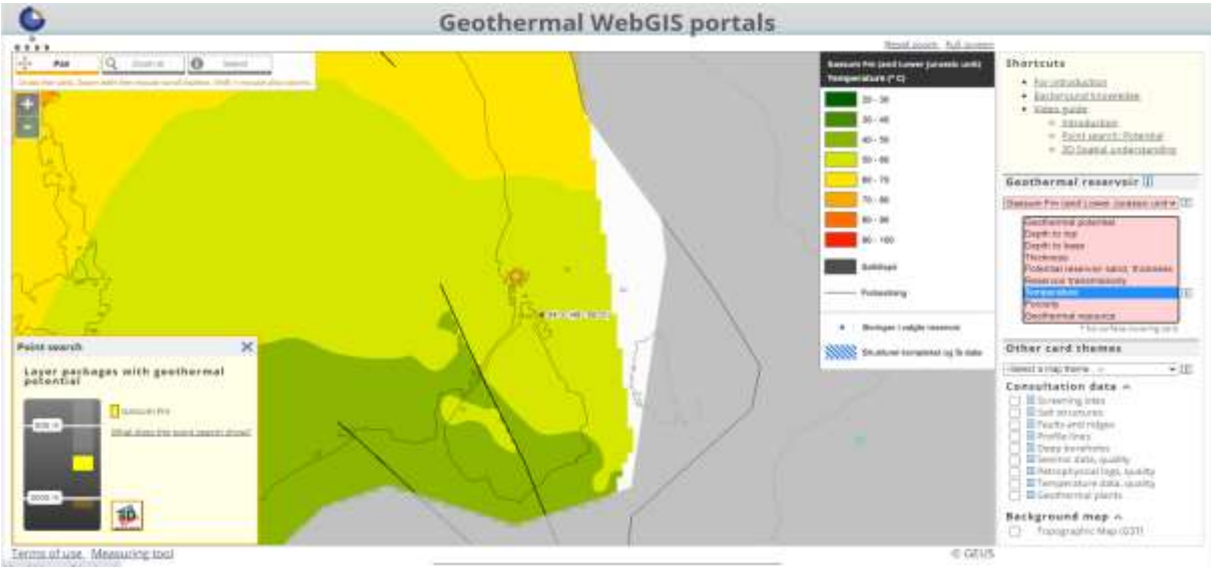

Figure 51: Geothermal temperature and layers at around 1 km depth (https://dybgeotermi.geus.dk/geologiske-data/)

22s-eenergies-open-data-euf.hub.arcgis.com/datasets/2357e5fcfb744d2f8f842cd7171a90a0_0/explore?location=48.135375%2C17.102720%2C11.88

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Figure 52: Geothermal resource (https://dybgeotermi.geus.dk/geologiske-data/)

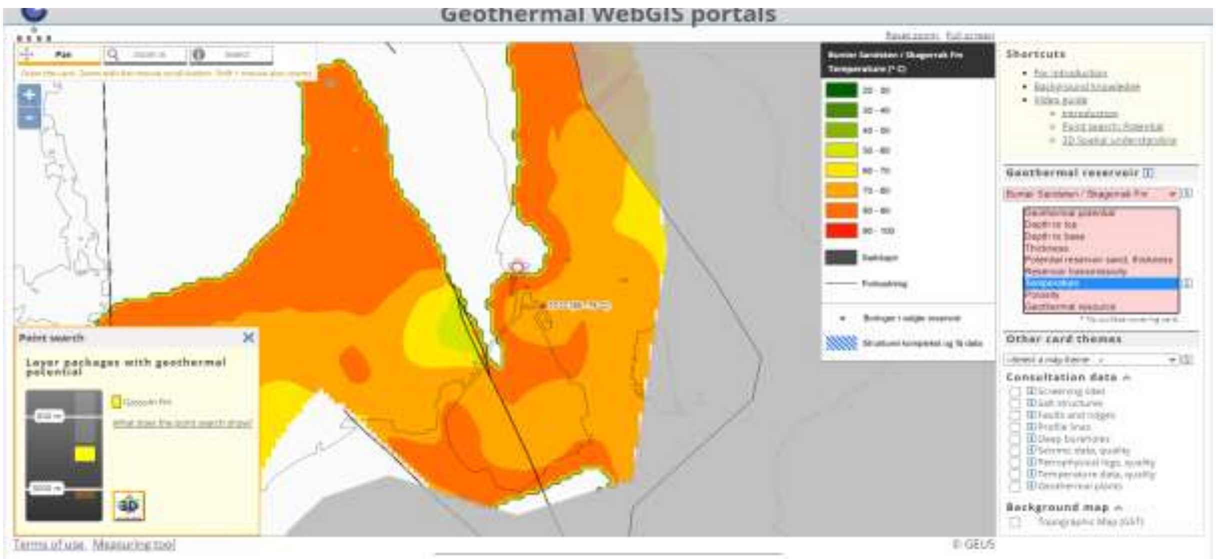

Figure 53: Geothermal temperature and layers > 3km (https://dybgeotermi.geus.dk/geologiske-data/)

Analysis at district level (PED areas):

Using PVgis the PV potential is obtained for the optimal tilt and azimut for a location in the middle of the PED areas. Both areas have a potential of 972.55 kWh/year/kWpeak installed is obtained, with a tilt of 41º and azimut of -1.

In Wind Atlas, the wind potential is obtained for a location in the middle of the PED areas, and at a height of 10 meters (to allow mini wind turbines) and 50 meters (in sea). A density of 228 W/m2 (5.71 m/s) is found in both areas at a height of 10 m, and a density of 450 W/m2 in the sea with a velocity of 7.5 m/s a height of 50 m.

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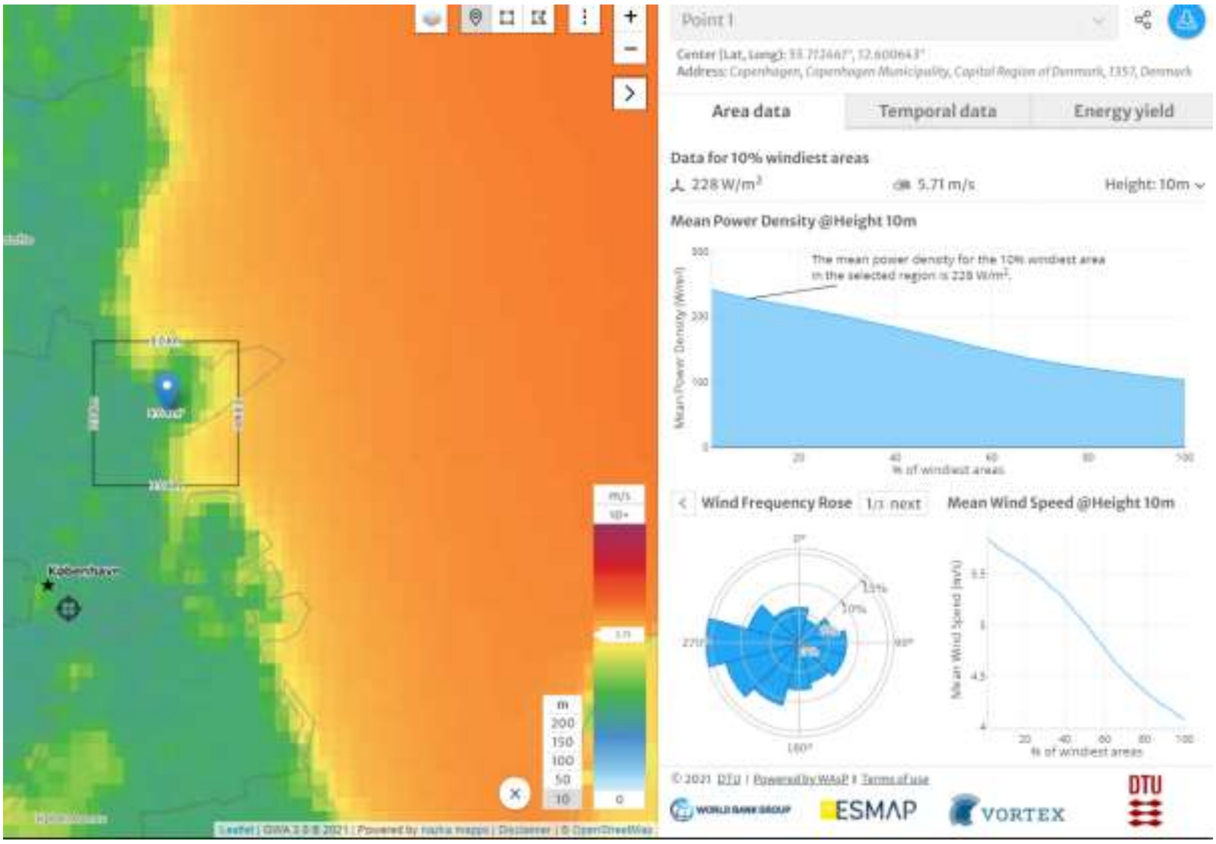

Figure 54: Wind potential at height 10 m

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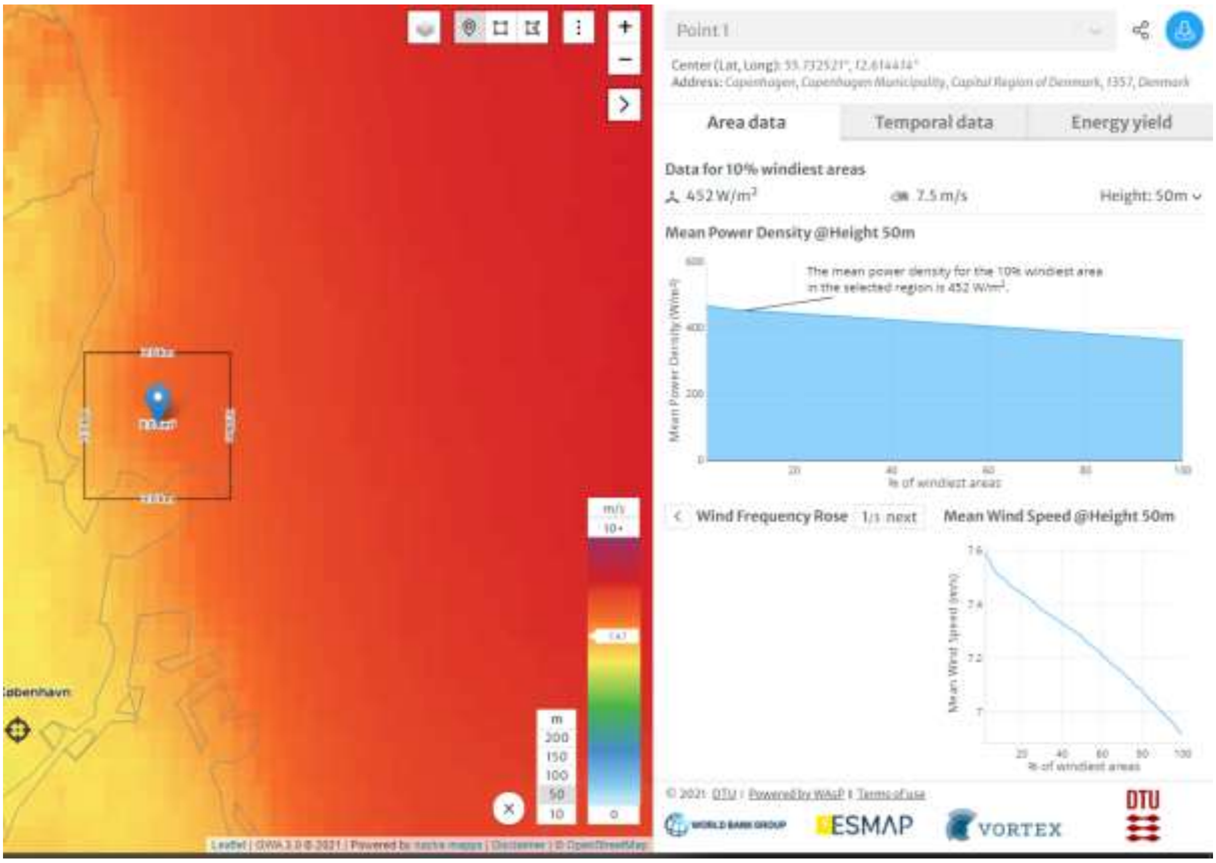

Figure 55: Wind potential at a height of 50 m in the sea

Lastly according to ChargeMap, there are two charging points (accelerated ones with a power of 16-30 kW).

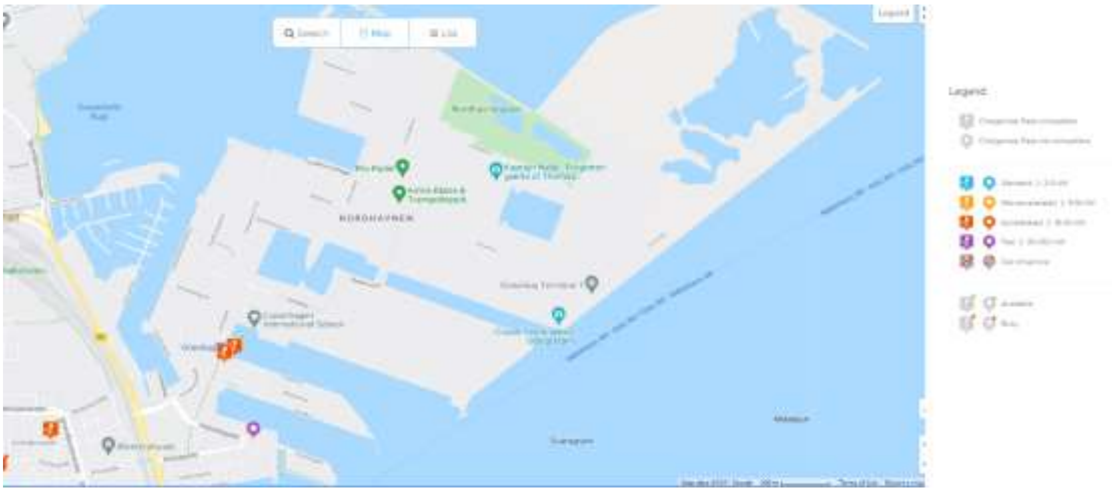

Figure 56: Charging points in PED areas

All of these characteristics, as well as spatial, social and economic characteristics are weighted using the resulting scores from STEP 2.1 in next step.

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STEP 2.3

Both areas were pretty similar and close to each other (and therefore, with similar characteristics). Considering spatial, technological, social and economic factors, a composite indicator that ease the PED area prioritization is obtained for each of the areas. The process is validated by the city. PED 1 resulted in higher composite indicator than PED 2. This is due to the fact that, PED 1 has, is a new development area preferred by the municipality. Summary of the results are shown in Figure 57.

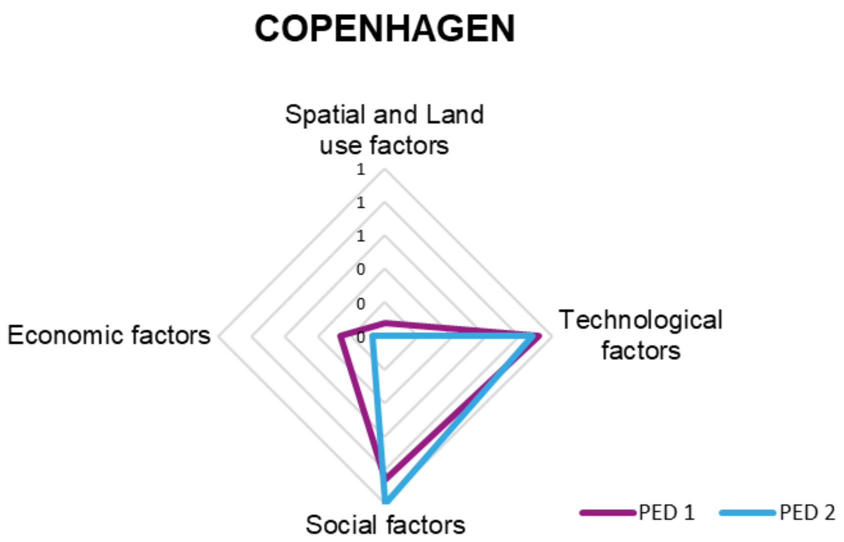

Figure 57: Final selection of PED and summary of scores, and final weights- Copenhagen

For the PED area also, Copenhagen identified some potential scenarios that could be performed, evaluating as well the co-benefits that could be obtained for each solution.

IMPACTS / CO-BENEFITS:		SCENARIO 1						
		Technology 1	Technology 2	Technology 3	Technology 4	Technology 5	Technology 6	non-technical
		Electricity storage [contributes to 3. Energy flexibility]	Electromobility hub [contributes to 4. Electric mobility]	Photo voltaic panels on roofs [contributes to 2. Renewable sources]	Large heat pumps for DH(/DC) [contributes to 2. Renewable sources]	Flexumers (smart building heat management system) [contributes to 1. Energy Efficiency and 3. Energy flexibity]	Smart building electricity/energy management system) [contributes to 1. Energy Efficiency and 3. Energy flexibity]	Energy community [contributes to 1+2+3+4]
Climate resilience	Climate adaptation	none	none	none	none	Low	Low	none
	Climate mitigation	High	High	High	High	High	High	Medium
Local economy, entrepreneurship and innovation	Local economy enhancement	none	none	none	none	none	none	Low
	Financial savings for citizens	none	Low	none	none	Low	Low	Low
	Increase employment rate and jobs	none	none	none	none	none	none	none
	Decrease future maintenance costs	none	none	none	none	none	none	none
Social inclusion and education	Social cohesion (gender, minority groups)	none	none	none	none	none	none	none
	Enhance citizen participation, connectivity and community	none	Medium	none	none	none	none	Medium
	Improve access to information, Social capacity building	none	none	none	none	none	none	Medium
	Raise awareness/ behavioural change	Medium	High	Medium	Medium	High	High	High
Health and well-being	Improve air quality	none	Medium	none	none	none	none	none
	Reduce noise pollution	none	none	none	none	none	none	none
	Reduce hot stops/ urban islands in the city	none	none	none	none	none	none	none
	Enhance attractiveness of the city	none	Low	none	none	none	none	none
	Promote healthier and more attractive lifestyles	none	Low	none	none	none	none	none
Biodiversity	Reduce ecological footprint	none	none	none	none	none	none	none
	Greater biodiversity	none	none	none	none	none	none	none
Resource management and efficiency *(circular economy)*	Waste efficiency	none	none	none	none	none	none	none
	Water efficiency	none	none	none	none	none	none	none
	Food efficiency	none	none	none	none	none	none	none
	Sustainable land use	none	none	none	none	none	none	none

Figure 58 Overview of co-benefits for scenario 1 Copenhagen.

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6.3. STEP 3: Detailed design of PED

STEP 3.0: Bioclimatic design

The main climatic variables (temperature, humidity, wind, rain, etc..) have been collected and analysed in order to support PED design in new development areas (with the aid of the program Climate Consultant). The principal climate data of each season (Winter, Spring, Summer, and Autumn) has been gathered with the aim of providing the necessary information to implement heating and cooling strategies specific to each season according the comfort standards previously detailed in STEP 3.0: Climatic conditions evaluation (Bratislava).

Local analyses of the current climatic conditions

GENERAL STRATEGIES FOR PASSIVE URBAN DESIGN

JANUARY - MARCH

1.ENERGY NEEDS:

Temperature: The minimum temperatures recorded reach temperatures below zero degrees, and the mean temperature do not even reach 5ºC. Therefore, there is an essential need for warmth during the whole day in January, February and March. (Figure 153: Dry bulb diagram) Since there is not much sun exposed time, especially in January, there is no need for shading during this period of the year. (Figure 154: Diurnal average diagram)

Wind: In the course of the first trimester of the year, wind direction varies through the months, with an average speed of 5,33 m/s. (Figure 158: Wind wheel_JAN-MAR)

2.SOLAR PASSIVE GAINS

The sunlight radiation should be optimized to generate solar gains in the buildings. The radiation is under 200Wh/sq.m even in the south façade, where there is sunlight during the longest time. Apart from the south façade, there is sunlit in the east façade from sunrise until 12:00 hours, and there is sunlit in the west façade from 12:00 hours until the sunset.

3.STRATEGIES

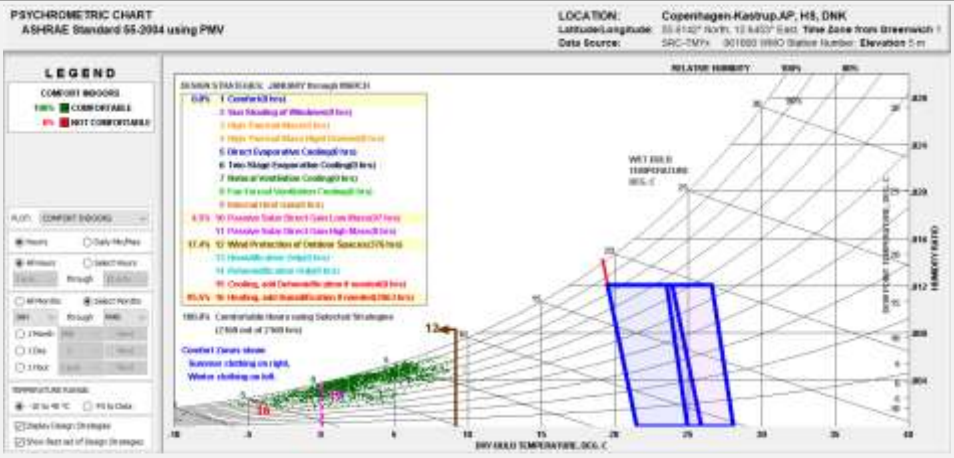

Figure 59: Psychometric chart without any strategy JAN-MAR

It is necessary to take advantage of the sunlight hours from January to March, when the minimum temperatures are under zero degrees. Especially, since the high wind speed decrease the thermal sensation.

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Therefore, the main façade of the buildings should be facing south with large windows on it, even if windows can be unshaded and facing in any direction, because any passive solar gain is a benefit, and there is little danger of overheating. In addition, it would be essential to incorporate thermal inertia enclosures, to allow accumulating energy during the winter. This is the windiest period of the year, although there is a general high-speed wind during the whole year. Therefore; it could be beneficial to avoid urban cayon like form in the urban landscape, which enhances the appearance of the venturi effect, increasing the speed of the wind in the centre, and creates high discomfort in some areas during winter, favouring thermal losses. Other strategies are vestibule lockers, which can be used as air locks to reduce penetration and preventing loss temperature. In the benefit of archiving 100% of the time to be comfortable, the design strategies implemented should focus on gaining passive solar direct gain low mass, wind protection of outdoor spaces and, as an especially important measure, to provide heating and humidification if needed. Some strategies to archive it are: • Facing most of the glass area to the south, in favour of maximize sun exposure. • Incorporating exterior structures or dense planting to protect the buildings from wind, since it can reach an average speed of 8 m/s • Using better glass in the windows (double or triple pane). • Implementing a more efficient heating system.
APRIL – JUNE
1.ENERGY NEEDS:
Temperature: The minimum temperatures recorded are mostly above zero degrees during these months, only in April the minumum temperatures drop below 0ºC. After that, temperatures rise, reaching over 25 degrees in June. (Figure 153: Dry bulb diagram) Even with the increase on the temperature, there is no need for shading. (Figure 154: Diurnal average diagram)
Wind: In the course of the second trimester of the year, wind direction is predominantly from the north-west in April and south-east in May and June, with an average speed of 4,33m/s. (Figure 159: Wind wheel_APR-JUN)
2.SOLAR PASSIVE GAINS
As the temperatures rise, solar gains are less important, although there is still relevant to keep some heat gain to counterbalance the temperatures drop during the night. There is sunlit in the south façade for large periods of time, although the sunlit barely reach the north one. Also, there is sunlit in the east façade from sunrise until 12:00 hours, and there is sunlit in the west façade from 12:00 hours until the sunset.
3.STRATEGIES

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

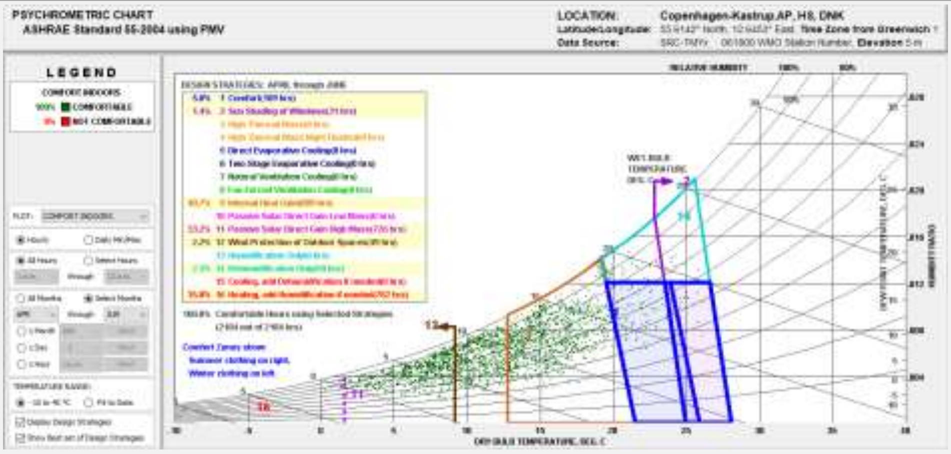

Figure 60: Psychometric chart without any strategy APR-JUN

Although it is still necessary to take advantage of the sunlight hours, minimum temperatures only decrease under zero degrees in April. During spring, the sunlight hours keep growing. As a result, east capitations are acceptable to provide comfort, but the south façade would be the best sunlit one. Windows facing north would barely receive sunlight during the morning, so the building would rather not have any windows in the north façade. In addition, it would be essential to incorporate thermal inertia enclosures, to allow accumulating energy.

In the benefit of archiving 100% of the time to be comfortable, the design strategies implemented should focus on sun shading of the windows, gaining internal heat, passive solar direct gain high mass, wind protection of outdoor spaces, dehumidification, and providing heating and humidification if needed.

Some strategies to archive it are:

- Using high mass interior surfaces (slab floors, high mass walls, stone fireplace...) to store passively.
- Sunny wind-protected outdoor spaces can extend living areas.
- Incorporating exterior structures or dense planting to protect the buildings from cold winds.
- Use compact building form with square-ish floorplan and multiple stories to minimize heat loss from building envelope.
- Facing most of the glass area to the south, in favour of maximize sun exposure.

JULY – SEPTEMBER

1.ENERGY NEEDS:

Temperature: The average high temperatures recorded are above 25 degrees in July and August, but the mean temperature is always below 20 degrees, due to colder temperatures in the night. (Figure 154: Diurnal average diagram)
During summer, it may be beneficial to allow some shading over the openings from 15:00 to 18:00 during July and August. (Figure 154: Diurnal average diagram)

Wind: In the course of the third trimester of the year, wind direction is predominantly from the north-west, with an average speed of 4,67m/s. (Figure 159: Wind wheel_APR-JUN)

2.SOLAR PASSIVE GAINS

There is sunlit in the south façade almost the whole day, although the sunlit barely reach the north one. There is sunlit in the east façade from sunrise until 12:00 hours, and there is sunlit in the west façade from 12:00 hours until the sunset.

3.STRATEGIES

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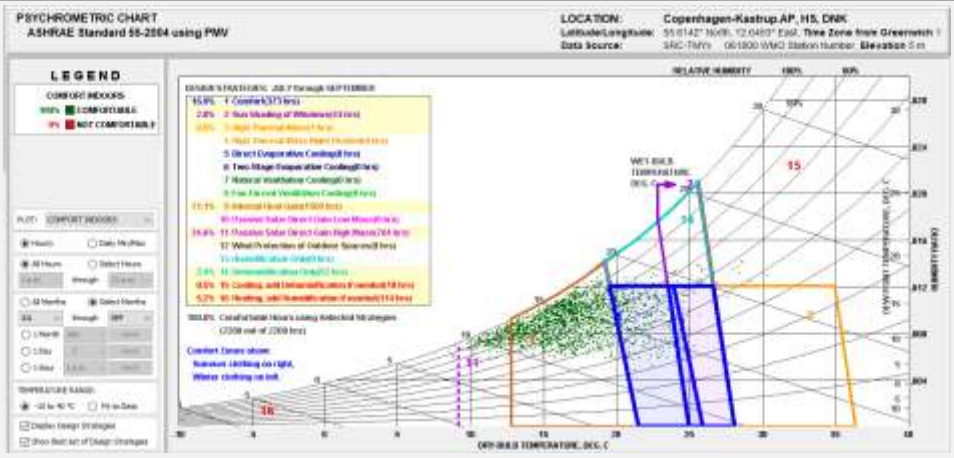

Figure 61: Psychometric chart without any strategy JUL-SEP

During summer, it would barely be necessary shading in the openings, allowing to optimize the passive solar gain. In daytime, the sun directly impacts on the south, east and west façades of the buildings, even the north façade would receive some indirect sunlight in the mornings.
Buildings should also be designed with floorplans that allows cross ventilation and openings to mild breezes, rather than exposing too much of the interior to the main wind.

In the benefit of archiving 100% of the time to be comfortable, the design strategies implemented should focus on sun shading of the windows, high thermal mass, gaining internal heat, passive solar direct gain high mass, dehumidification, and providing heating or cooling and humidification if needed.

Some strategies to archive it are:

- Using high mass interior surface materials (tile, slate, stone, brick or adobe).
- Sunny wind-protected outdoor spaces can extend living areas.
- Incorporating exterior structures or dense planting to protect the buildings from cold winds.
- Designing windows location to prevail breezes, incorporate shading elements and generate natural ventilation.

OCTOBER – DECEMBER

1.ENERGY NEEDS

Temperature: The minimum temperatures recorded reach below zero degrees, and the average temperature is never comfortable, especially in December when the maximum is under 10ºC. Therefore, there is an important need for warmth during this period. (Figure 154: Diurnal average diagram)
As the sunlight hours and the temperatures and radiation decrease so much, it would not be necessary to shade at all during autumn. (Figure 154: Diurnal average diagram)

Wind: In the course of the last trimester of the year, wind direction is predominantly from the south-west, with an average speed of 5m/s. (Figure 145: Wind wheel_OCT-DEC)

2.SOLAR PASSIVE GAINS

There is not much sunlight, so it should be optimized. In the south façade before and after mid-day, and there is no sunlit in the north one hardly ever. There is sunlit in the east façade from sunrise until 12:00 hours, and there is sunlit in the west façade from 12:00 hours until the sunset

3.STRATEGIES

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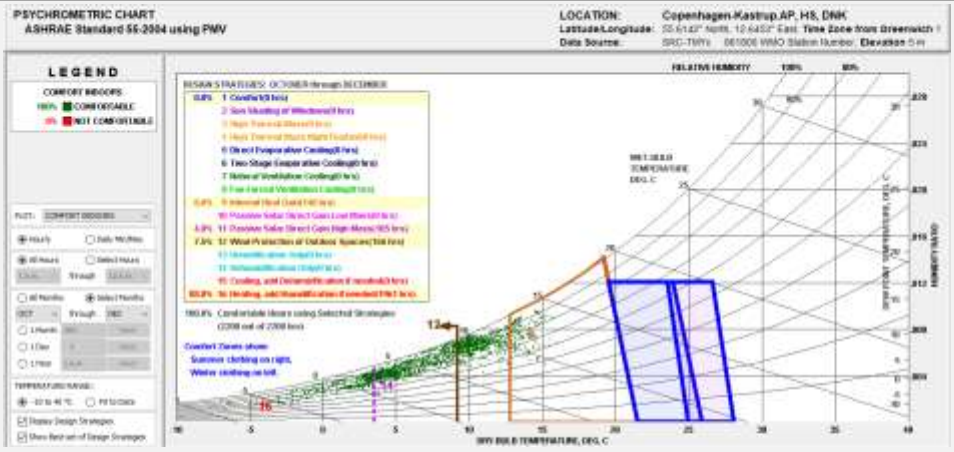

Figure 62: Psychometric chart without any strategy OCT-DEC

It is necessary to take advantage of the sunlight hours since the huge decrease in sunlight hours. Therefore, the main façade of the buildings should be facing south with large windows on it, which would provide a better optimization of the sunlight. There could also be windows in the east and west façades to provide acceptable capitations, although they would be less effective.

In order to optimize the climate behaviour of the buildings, they should not have overly large floor areas because doing so would waste heating energy. It would be easier to heat living spaces if buildings had compact forms, roughly square floorplans, and multiple stories to reduce heat loss through the building envelope. It would be especially efficient, those with a cramped floorplan, a central heat source, windows facing south, and a roof pitched for wind protection. In addition, it would be essential to incorporate thermal inertia enclosures, to allow accumulating energy during autumn.

In the benefit of archiving 100% of the time to be comfortable, the design strategies implemented should focus on gaining internal heat, passive solar direct gain high mass, wind protection of outdoor SPACES and, as an especially important measure, to provide heating and humidification if needed.

Some strategies to archive it are:

- Facing most of the glass area to the south, in favour of maximize winter sun exposure.
- Incorporating small well-insulated skylights reduce daytime lighting energy and cooling loads.
- Adding more insulation in the façades and roof, in order to avoid thermal bridges.
- Using better glass in the windows (double or triple pane).

STEP 3b: Detailed design of PED

The objective of Task 6.1 is for each Fellow City to develop guidelines or to launch a tender procedure for a PED in an area of their city with the aim to design a positive energy district.

Copenhagen's chosen approach to this task is to embed the Task 6.1 work in the 'Energy Strategy 2035' (-2050) and 'Copenhagen Climate Plan 2035' currently under preparation (2023-2025). These will replace the current Climate Strategy and Plan 2025. The 'Energy Strategy 2035' is expected politically adopted late 2024.

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Approach to PED design

Climate positivity is one of the 3 ambitions that will guide the climate effort agreed for Copenhagen Climate Plan 2035. The exact definition of what is meant by "climate positivity" has not yet been politically decided by the City Council – it awaits the results of a number of task groups. A decision on definition is expected in second half of 2023.

A two-pronged approach to PED is applied in Copenhagen:

- A top-down strategic overview of the role of the municipality in:
    - Finding space and locations for renewable energy – heat pumps and photovoltaics;
    - Ensuring a timely and strategic transition to lower supply temperature district heating;
    - Preparing public and private buildings for flexibility and lower heat temperatures (which requires energy efficiency improvements);
    - Keeping an eye on the strain that new electricity end-uses such as electric vehicles, batteries, and local electricity production place on the electricity distribution network and demand for new transformer stations.
- Case-by-case trials and experience gathering where we have an opportunity to implement elements as part of other activities, such as:
    - City rejuvenation projects (buildings and districts);
    - Partners in the Energy Leap partnership (consumption benchmarks for building owners and building administrators);
    - Buildings and vehicles owned by the municipality itself;
    - Research, living lab, and other test projects (such as EnergyLab Nordhavn), often in collaboration with solution providers/developers and research institutions.

The reasons for the two-pronged approach are that stand-alone PEDs in Copenhagen risk:

1. undermining the economy our common, well-functioning district heating (and electricity) system if the city context surrounding the PED is not considered;
2. creating lost opportunities since a society holistic perspective is not applied; and
3. having an unwanted social bias benefitting the well-to-do's.

We distinguish between new districts and existing districts since these offer different opportunities. Existing districts are subject to different limitations and possibilities.

Instead of making a detailed design of a specific PED case, we therefore in "PED design stage 3" focus on how Copenhagen City can embed the idea of PED in the overarching strategies guiding the longer-term energy transition strategy of the city. This is also expected to contribute to replication of PED aspects beyond the ATELIER project period. A strategic and holistic approach can help prepare buildings and building owners for change, prepare electricity and

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district heating networks, find space for local renewable energy production, integrate climate aspects in city rejuvenation projects, etc. – thus lending greater overall impact.

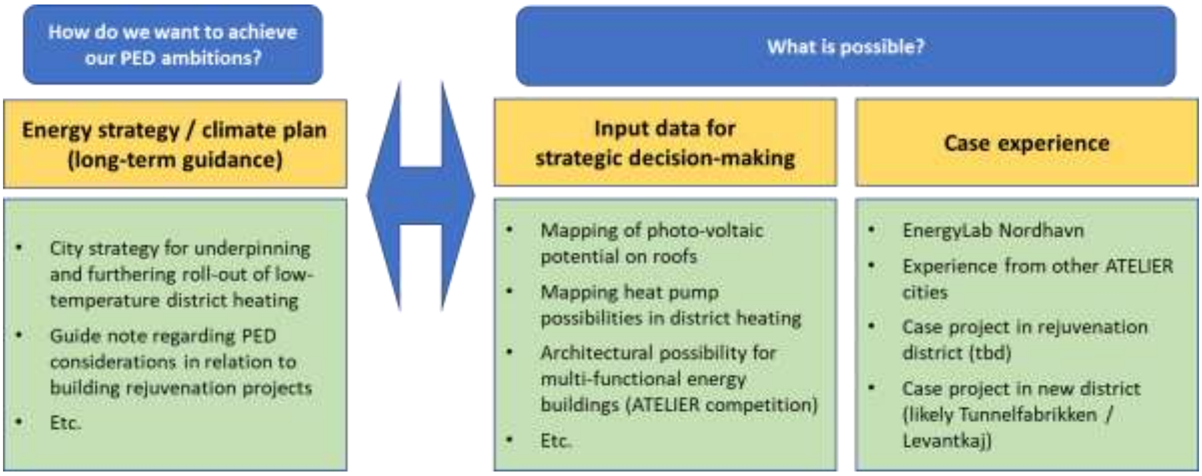

Figure 63: Integrating PED aspects in the overarching city strategies and guides (rather than detailed PED project design).

The key challenge – Finding space for the green transition

A key challenge for Copenhagen, as for many other large cities, is to find the **physical space** for all the required city activities and qualities, including those of the green energy transition and climate sustainability. Copenhagen therefore explores what the needs are and how best to combine it with other strategic plans and activities.

Specifically, Copenhagen has as part of WP6 so far carried out the following:

- An analysis of potential sites for large scale heat pumps and how to reserve these areas (addressing the technically suited places from a DH system perspective as well as the legal maneuver room regarding ownership and handling of the investment risk) through a series of discussions with relevant departments of the city administration and the district heating company regarding intermediary ownership of area, permitting investment risk, etc.
- An action plan for photovoltaic systems on roofs including mapping of building integrated photovoltaic potential and launch of support scheme for siting assessment:
    - Data is publicly accessible via a GIS-based map and improvements are being made and discussed);
    - Municipal photovoltaic advice support scheme for siting assessment (Climate Task Force within City Rejuvenation);
    - Discussions on legal possibilities for municipal ownership.
- A student competition “Imaginative use of city space – Boost the green energy transition with inspired multi-functional technical buildings”, launched February 2023 and completed July 2023.

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The competition is explained in more detail in the following section. For more detail, please see the ATELIER newsletter from June 2023 which includes a presentation of the three winning concepts as well as an interview with the students.

ATELIER competition "Imaginative use of city space"

In early spring 2023, ATELIER Fellow Cities Bratislava and Copenhagen successfully organised an ATELIER student competition 2023, challenging young students of architecture, urban design, and similar disciplines to come up with an innovative concept for multi-functional technical buildings. Among the participants, three winning teams have been awarded.

The concepts developed by the competition participants are to be combined to form a catalogue that can inspire and guide the design of energy positive districts in any city. Therefore, the results are being shared with the EU smart city community.

The main motives for launching the ATELIER student competition were three-fold – 1) A need for multi-functional technical buildings, 2) a wish to learn from other countries and professions, and 3) to help foster a new generation of architects/citizens that understands the demands of the energy transition from a city planning perspective.

Space is a limited resource in our cities. Copenhagen is as mentioned earlier currently preparing our next climate strategy and it is clear, that more local energy production is needed. A few districts reaching energy positivity is not enough to fulfil Copenhagen's climate ambitions. It is necessary to find a way to make replication easier and to engage the city population in the endeavour. Space is a very limited resource in our cities, so we must build smart.

Bratislava and Copenhagen were therefore looking to gather inspirational ideas for combining technical buildings with other city functions and compile these into a catalogue that can inspire and guide the design of energy positive districts in any city. Ensuring a high aesthetic quality of the build and its surroundings, could even make the buildings proud landmarks – signalling district identity instead of simply trying to hide or camouflage the technical buildings.

The choice fell on an international competition since each nation has its unique way of living and using city space. The hope was that this could perhaps inspire a new city culture and infrastructure that is more sustainable. Mutual exchange of ideas, expertise and lessons learned is key to a successful energy transition. That is also why Copenhagen engages in projects such as ATELIER.

And finally, Bratislava and Copenhagen wish to encourage students and young professional to work towards sustainability be providing them real-life challenges to practice their skills. Students have the added quality that they are freer to challenge existing beliefs more radically than a professional consultant.

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Figure 64: Timeline for the ATELIER competition.

The biggest challenge in organising the competition was to align the timing with school timelines, especially when you are seeking contestant from several schools and across borders.

The recommendation from ore experienced people within architecture was that architect students are used to participating in competition that require them to use their spare time outside the study.

Looking back, a lesson learned could be that integrating the competition in the school curriculum might be a better suited approach – and perhaps even have a bigger impact on the student learning.

The formulated competition criteria reflect Bratislava's and Copenhagen's wish to think out of the box and at the same time be realistic about what can be achieved. Bratislava and Copenhagen were looking for a concept with a clear identity that can be applied in many different locations in our own city but also other cities. A concept with a clear architectural identity that can easily be modified depending on the location and budgets, and still retain its identity. Another quality that the winning concepts possess is that they encourage the public to engage in the energy transition and sustainability – by providing a glimpse into the heat pump technology or by expanding the idea of multi-functionality to making the build a hub for sustainability activities for the society. Another consideration was the use of resources in the build and to which extent the original concept Is likely to be diluted in the construction process a.o. due to economic realities.

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It is always inspiring to see what solutions young people, not yet set in their way of thinking and not bound by the experience and constraints that city planners operate under, can come up with. City planners not only have to find space for heat pump buildings but also to find space for electricity transformer stations and if they in any way can be made more architecturally attractive and even multifunctional, our cityscape would benefit greatly. It has been very inspiring to see the students' different takes on the presented problem.

Figure 65: First prize winning concept.

Originally the intention was to encourage teams composed of students from different types of studies – architecture, landscape, engineering, social studies etc. But the experiences from people, that were consulted, who had tried such an approach, were that it requires enormous efforts from the organisers, the schools, and the students, and still the risk is that no true integration in the solution creation takes place. Also, such an approach would shift focus from the idea of a catalogue of concepts that can be applied in many variations and locations and not just tailored to one specific site.

With regard to the lessons learned through the competition process, it became clear that the architect schools appear very interested in this type of competition and some expressed an interest in integrating it into their semester work. Doing so would give the students better time to reflect and do the necessary work and could be combined with thematic guest lectures relating to the transition challenge that the cities are facing. So, provided that the competition can be planned well in advance, it would be beneficial for all parties – schools, students, and the city – to integrate a next competition in a semester curriculum.

From an architectural student perspective, the opportunity to work on a real-life case is always welcome. Also, being awarded the opportunity to meet professional architects such as student access to the UIA 2023 is a valued prize. Perhaps more so than cash prizes which the organisers were told are often applied with the field of architecture. Awards in the form of cash prizes are, however, difficult for a municipality to apply – a private sponsor is needed – but the

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city has to be seen as neutral in the public eye and can therefore not allow a sponsor to use a competition to promote the sponsor unduly.

Another lesson learned is that it is not a simple task to really hone out what the competition task should be. Bratislava and Copenhagen drew on the expertise of architects, technology experts, city planners, educators, and competition organisers to arrive at a suitably focused and manageable competition task and format. However, the work of clearly describing the task helps us as city planners to get a much clearer idea of what it is we want to achieve in our city.

STEP 3.4: Financing options

From the options presented in Table 14 and considering Copenhagen city as a whole, it seems the financing options *2) "Energy community business model"* and *3) "Investment platform"* both sounds relevant to Copenhagen although maybe in a slightly altered form.

First of all, access to finance is not the main barrier for RE investments in Copenhagen. Instead, the main barriers are the mobilisation of interests, organisation of the project, trust in the technical quality and ability, and insurance (what if something goes wrong technically and who will fix the problem). Therefore, perhaps a solution offered by a large existing entity that can be trusted to make good on the agreed deliveries (because their public reputation is at stake, or because they are technically/financially strong) might create the most interest among the community members. This entity does not have to do it alone – it can be together with other stakeholders including the community members. And the municipality may have a role in facilitating the contact and dialogue or offer a third-party appraisal.

There will most likely be some individual citizens or building associations that will be strong enough to mobilise their own project with or without outside financing, but they will most likely constitute a minority of the population.

As Copenhagen have not yet made a final decision regarding the choice of case PED area, it is not possible to describe the applied financing model. If we select a case in existing buildings subject to the city rejuvenation scheme, then at least part of the financing will be municipal.

The least relevant option is the option *1) "EPC"* due to the fact that it is linked to the achieved bill savings.

With regards to the area of the EnergyLab Nordhavn (which affects the area proposed in STEP 1 and 2). The EnergyLab Nordhavn project took place before the ATELIER project really kicked off. In ATELIER, Copenhagen have worked to try to make this Innovation Forum for the Nordhavn district more permanent through the creation of an association. The financing type that was used for the first phase falls in to category 4 of Table 14 ("European, National, Regional funds").

The EnergyLab Nordhavn (2015-2019, EUDP Journal number 64014-0555) was financed partly by EUDP funds (60%) and partly the business partners of the project consortium (40%). The lead partner was the Electric Power & Energy departments at DTU Electrical Engineering (a research institute). The project partners were city representatives, district heating company, electricity network company, product developers and, engineering consultants. After the EUDP project period, some of the EnergyLab Nordhavn partners chose to form an association as a platform for discussing, creating, and demonstrating new innovative solutions.

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Ordinary citizens and other stakeholders located in the North Harbour were invited to join and the membership fee depends on the type and size of the member. The membership fee is a token fee that covers the cost of a minimal secretariat. Several fees (greater for large businesses and smaller ones for private individuals) were defined to join the association. This second phase of the Innovation Forum does not fall in to any of the categories listed in Table 14. More information can be found in D3.8, which also lists the current members and way of operation.

Conclusions

Thanks to this process Copenhagen was able to gather some insights for designing a tendering procedure that considers the necessary features to achieve and implement a PED in their area. For instance:

- There is a need for an alignment on energy supply fluctuations (from RES) and demand patterns. PED could help on providing some insights about it.
- Space constraints in urban environments drive the need for innovative building design, especially for technical structures like heat pump buildings. Integrating technical buildings with other city functions and ensuring aesthetic quality can contribute to the cityscape and sustainability, as well as PED goals.
- Engaging students in real-life sustainability challenges fosters creative solutions that challenge conventional thinking. Integrating competitions into architecture curricula can provide more time for reflection and yield impactful results.
- Financing options for renewable energy projects must consider local barriers beyond access to funds, including mobilizing interests, trust, and project organization. Different PED areas may require varying financing models; choices should align with the specific context.
- Leveraging trusted entities and collaborative stakeholder involvement can facilitate financing and community engagement.

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7. PED design in Krakow

In this section, the steps defined in section 3.2 are applied to the city of Krakow. Starting with (Section 7.1) the city context and identifying the strengths, weaknesses, opportunities and threats of Positive Energy Districts; followed by the prioritization of one of the preselected areas in proposal stage (Section 7.2) and finalising with a PED detailed design for the selected are in section 7.3. The output is a set of recommendations for stakeholders to deploy PEDs in that area.

7.1. STEP 1: City's environment for PED implementation

Context

Kraków is located in southern Poland on the Vistula River. It is the second largest city in Poland with a population of 780,000 inhabitants, surface area of 327 km^2 and a **density of 2,385 people per km^2**. The city is the administrative and economic centre of Małopolska Region.

Kraków is a dynamic and vibrant city, with 23 universities and 37 research and development institutes, over 11,000 scientists and academics, and 150,000 students. Kraków is one of Poland's most **important economic centres**, due to its great location for international business, among other things.

In terms of climate, Kraków has a **moderately continental climate**, with a mean annual temperature of around 8.2 ºC. Winters are cold and temperatures are often below freezing, and mild or pleasantly warm summers. The average temperature of the coldest month (January) is of -1.9 ºC; and 19 ºC in the warmest month (July). Precipitation amounts to 670 mm per year, ranging from 35 mm in the driest month (February) to 90 mm in the wettest (June). On average, there are only around 1,400 sunshine hours per year.

There are **previous experiences at national level**, related to innovative, smart energy solutions. Żywiecka Energia Przyszłości is an **energy cluster** that includes cooperation with the Tauron Dystrybucja DSO and envisages carrying out distribution activities within a network of less than 110kW. Also, Spółdzielnia Nasza Energia is a **cooperative** for the generation of renewable heat and electricity (heat and electricity producing biogas installations). Finally, **Słupsk pilot project** wants to eliminate **energy poverty** and become one of the cleanest cities in terms of air quality standards in Poland. It includes vulnerable consumers, the increase energy efficiency by refurbishing houses and replacing old, coal-burning stoves with RES heating; as well as investments in public transport and to facilitate PV installations.

Conditions to allow a Positive Energy Balance

In Polish law, more and more detailed **regulations regarding buildings** are gradually being introduced. Updated in 2017, the regulation for the technical conditions, that buildings must meet, introduced an obligation for new public buildings to meet the **zero-emission standard** from 2019. The next obligatory step, based on another technical conditions update in 2021, was that all public buildings have to meet the zero-emission standard from 2026 and new commercial buildings have to be the same from 2028.

In Poland, the owner of a **photovoltaic micro-installation** with a capacity of up to 50 kWp can become a **prosumer** (understood as both a producer and a consumer of energy). Currently, there are two billing systems for electricity from PV.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

Until March 31, 2022, **net-metering** was the only, main system on the market. In this settlement system (discount system), it was necessary to sign a comprehensive contract for the provision of electricity distribution and sale services under one comprehensive contract. The discount system was also possible in the case of local government units, housing communities, religious associations.

The **discount system** is a method of cashless settlement of electricity consumed by a prosumer and produced in a micro-installation. The discount is settled annually. On the other hand, the electricity bills themselves can be settled as before the installation of the PV installation, i.e. on a monthly, bi-monthly or semi-annual basis. It depends on the provisions in the comprehensive contract with the energy supplier. After one year, the energy seller is obliged to make a settlement of the energy fed into the grid and consumed. However, for installations with a capacity of up to 10 kWp per 1 kWh supplied to the grid, the prosumer may receive 0.8 kWh above this value, the coefficient of 0.7 applies.

From April 1, 2022, there is a new mandatory system, called: **net-billing**, for new owners of PV. This system assumes that owners of PV installations sell surplus energy to the grid, at current prices and the income remains on the virtual account, and in the upcoming months, when the PV generation is not enough, they have to pay for the consumed energy in the same way as other consumers with the current prices, firstly from this virtual account.

The owners who use the net-metering system will be able to use it for the next 15 years.

According to the current regulations, connecting home installations up to 50 kW is mandatory for network operators. However, refusals for home photovoltaic installations below 50 kW are very rare. Most often this happens due to poorly selected inverters.

Recently, a lot of changes have been taking place at the national level in order to define the framework for the functioning of energy communities. Recently, the first **collective prosumer model** in Poland was launched for a multi-family building, where the energy generated by PV goes not only to common parts of the building, but also to the apartments of individual residents.

The Renewable Energy Sources Act defined the term of '**energy clusters**' as civic-law agreements with diverse parties including natural persons, legal persons, scientific units, research institutes and local-government units. The agreement concerns the balancing of demand and generation, distribution of or trade in energy from renewables or other sources, within a distribution network with voltage below 110 kV; only a few clusters working in Poland and no specific regulation about them.

There are no Polish regulations focusing directly on **hydrogen** production, although hydrogen strategy is under development.

Connecting to **District Heating** is not mandatory, but in Polish Energy Law there is a record: "*An entity with a legal title to use a facility that is not connected to the heating network or equipped with an individual heat source, located in an area where there are technical conditions for supplying heat from the heating or cooling system,* ***ensures energy-efficient*** *use of local fuel and energy resources by connection of the facility to the heating network, provided that there are technical and economic conditions for connecting to the heating network and supplying heat to this facility from the heating network*."

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Municipal companies in Kraków have development plans envisaging numerous activities for improvement of **energy efficiency**. MPEC has drafted document defining extension plans for district heating network and successive inclusion of new users. The main goals include development of the market for hot water supply, and of heat network in the historical part of the city, which are only possible thanks to the innovative technology of flexible pipes.

Conditions to allow Renewable Energy Production

The Energy Law specifies that an energy company generating electricity in a renewable energy source installation with a total capacity of the renewable energy source installation not exceeding 5 MW is exempt from the concession fee for the generation of energy in this installation.

In addition, generation from qualifying renewable sources benefits from a support system of green certificates. Micro-installations do not pay the connection fee if connecting to the distribution grid. Similarly, cogeneration facilities may benefit from purple certificates (which are certificates of origin reflecting the fuel used)

Burning solid fuels is not allowed by the City of Kraków since 2019. The Program of Reduction of surface Emission in Krakow includes production with **biomass** unless the appropriate filters are used (more expensive investments). Furthermore, it does not ban gas and/or light oil boilers (that do not emit PM).

In 2022 21 % of electric energy in the Polish Power System comes from RES, due to **strong dependence** of the economy on **coal**, economic circumstances and the national energy policy. In 2022 there are 10 090 RES micro-installations (79,292 kWp) connected to the **distribution grid** in the city. The **share of renewables in electric energy consumption** by municipal companies may be as high as 30% thanks to production from: landfill gas and biogas (2,347 MWh/year), sewage sludge biogas (12,093 MWh/year), waste incineration (55,298 MWh/year), turbine in drinking water pipe (2,650 MWh/year), photovoltaic modules (105 MWh/year).

Attempts are being made to **increase local generation of renewables**. The Municipal Heating Company (MPEC) expanded its offer and sell heat produced locally in areas without access to the district heating network. The photovoltaic (PV) market and exchange of heat sources to environmental-friendly ones is developing dynamically.

There is **dispersion of housing**, meaning that a great percentage of forest and nature protection areas limit the installation of solar and wind farms (Kraków does not have wind farms, landscape is protected). Land prices are high.

There are good conditions for the development of **biogas plants** using fermentation processes from organic waste at landfills, animal waste on farms and sewage sludge in sewage treatment plants. In addition, some of the municipal companies try to possess large undeveloped areas which could be used for building solar farms and consequently, the energy produced transferred to people suffering from energy poverty

Open discourse and education are necessary to transfer benefits of RES to society; however, they need to be considered together with other measures. In Kraków residents play active role in decision-making processes in the city. An example is the Krakow Civic Climate Panel held in 2020 related to climate actions. In addition, every year there is a so-called participatory budget, i.e. residents decide on which investment activities funds will be transferred, including the field of climate protection or RES development. The most recent example of cooperation

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between residents and city authorities is the Transport Discussion Panel. Residents decide about the future of transport in Krakow.

There is **political support for the Renewable** Energy Production: under the **Regional Operational Program 2014-2020**, the Kraków Municipality co-finances investments related to replacement of old heating boilers for installations that meet the current pollution emission standards; the **Development Strategy of the Małopolska Region 2011-2020** recommends the increasing of the utilisation and promotion of RES substantially; the most recent **National Energy and Climate Plan (NECP)** for the years 2021–2030 sets the following climate and energy goals for 2030 (7% reduction in greenhouse gas emissions in non-ETS sectors compared to 2005 levels, the share of coal in electricity production to be reduced to 56%–60%, and 21%–23% share of renewable energy sources in final gross energy consumption); and the plan for **prosumer financial support programs**, such as the 'My Current' program, with the goal to increase energy production from photovoltaic sources. This last program assumes co-financing of new 2-10 kW solar photovoltaic installations, and it is anticipated that 200,000 beneficiaries will benefit from the subsidy.

Conditions to allow Efficient buildings/ Building stock demand

Building stock is generally **old**, with many historical buildings (under monument protection) mainly in old town, which is partly the cause of the problem with thermal modernization. In Kraków there are over 122 000 buildings. 8% of them were built before the 1956, 63% from 1956-1990. This means that the building stock have a big influence in the decarbonisation of the city's energy system, with most of city's emissions coming from buildings; and part from mobility (industry not taken into consideration).

There are several **financial instruments and incentives** for existing buildings' renovation, mainly at national (Poland) level, such as the **Thermo-modernisation Fund**, funded through the state budget, with main objective to provide financial assistance for projects to improve the condition of existing housing; the **Green Investment Scheme** for the energy management in public building, supporting projects to improve the energy efficiency and reduce CO_2 emissions of public buildings; the **Operational Programme Infrastructure and Environment 2014-2020** from the European Regional Development Fund and the Cohesion Funds, for the promotion of energy efficiency, intelligent power management and the use of RES in public infrastructures; and **information campaigns** for promoting energy efficiency by the Ministry of the Climate and Environment among others. At the local level, it is also possible to obtain support for thermal modernization of buildings, e.g. detached houses.

Conditions to allow Affordability

With respect to the **energy prices**, the web page from Polish government[23] contains information on electricity market characteristics and on the Council of European Energy Regulators (CEER). It contains also information packages for liquid fuels, heat, gas and electricity. The Krakow Municipality also runs a website: www.krakow.pl, which contains the most important information for residents, including information related to energy market and climate crisis. In 2021, a dedicated webpage related to climate protection was created.

Conditions to allow Liveability

Generally, issues related to biologically active terrain are related to planning documents. Thus, in the provisions of local plans or in the decision on building conditions, the size of the biologically active area is always defined as a percentage in relation to the area that can be

[23] https://www.ure.gov.pl/en

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developed; but there are no such guidelines for the city as a whole. According to the Husqvarna Urban Green Space Index[24] (HUGSI), Kraków is on the list of the 10 **greenest cities in the world** (4th place).

Krakow is also focusing on the idea of a **"15-minute city"** for the city planning, to be built in a holistic way (or mixed-used districts).

In accordance with the **Transport Policy** in force for the City of Kraków 2016-2025, the rolling stock is being replaced with modern, accessible to people with mobility limitations and sustainable vehicles. It also includes building the infrastructure (e.g. the longest bicycle bridge in Poland), and have launched a reloading point for cargo bikes.

Kraków is also the first city in Poland where some of the bus lines are operated only by **electric buses**. The low-carbon units reduced CO_2 emissions by 2,500 tons annually. The tram fleet is being also modernised or exchanged, as modern units use 45% less energy. Residents' access to public transport is facilitated and traffic and parking is being limited. Electric cars in Krakow are exempt from parking feeds, while the monthly subscription for a hybrid car is 2.5 times lower than other internal combustion vehicles.

Conditions to allow PED implementation

Regarding the **planning** affecting the PED implementation, at national level there are several documents such as the National Energy and Climate Action Plan, the Polish Energy Policy till 2040, Act on courses of action in electro-mobility as well as a resolution defining energy standards in buildings. In regards of local planning, there are several of them defining the municipal energy strategy, such as PGN (**Low Carbon Economy Plan**) setting goals for CO_2 reduction by 2020 (and extended to 2040) and air quality improvement; the **ZPZC** defining strategic goals in energy performance, including measures for improving energy efficiency, and the **MPA**, the Municipal Climate Adaptation Plan. In addition, the city is creating new plans going beyond national goals through different actions in energy efficiency (i.e. improvement on the system for energy management in municipal buildings, thermal modernisation of municipal buildings, energy consulting, promotion of god practices and national and municipal subsidies), and in heating (i.e. retaining the significant role of the DHS, modernisation and extension, gradual transformation of the CHP plant and heating and cooling buildings with heat pumps in the area not covered by the DHS). Also, **SECAP** is under development. As for **Kraków experiences**, it can be highlighted the participation in Deep Demonstrations of Healthy, Clean Cities Climate KIC. As part of DD HCC, the Zero-Emissions Kraków Programme creates and tests new solutions, involving businesses, NGOs, educational institutions, and first and foremost – residents. This long-term programme provides many opportunities to acquire external financing for preparatory works and investments. Other good practices or experiences are the cooperation with academic centres to implement innovative solutions (in projects such as GeoPLASMA-C, to increase the use of shallow geothermal energy; RESHeat, for the automation of the tri-generation energy system, using at least 70% renewables; Cooperation of heat pumps with the heating network; Passive Energy Wastewater Treatment Plant; "Heat Map for Kraków").

[24] https://www.hugsi.green/

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SWOT analysis results

Krakow inputs are summarized in a SWOT table to identify which internal factors help or harm the PED implementation, as well as which external factors (National, EU level, etc.) creates opportunities and threats to its context.

What can be conclude is:

- Krakow still has an old building stock. Fortunately, companies in Kraków have development plans for improvement energy efficiency. Furthermore, new buildings have a mandatory certification and ambitious energy performance standards.
- There is a favourable regulatory and stakeholder environment (e.g. bank loans, RES micro-installations, etc.) and political and citizen support. Only some technologies (e.g. hydrogen) regulations need stronger efforts.
- There are still efforts to be made in decarbonising DHN.
- There are experiences and lessons learnt from national level, as well as funding available.

Krakow's PED implementation has a strong foundation due to its economic significance, political support, and growing renewable energy infrastructure. The city's focus on modernizing transport and achieving sustainable rankings also aligns with the PED goals. However, challenges lie in renovating historical buildings, expanding renewable energy sources, and navigating regulatory complexities. By leveraging its strengths, embracing opportunities such as financial incentives and national mandates, and addressing weaknesses and threats, Krakow can effectively move towards realizing Positive Energy Districts. Coordination among stakeholders, innovative regulatory adjustments, and community engagement will be essential for successful implementation.

	HELPFUL	HARMFUL
	STRENGHTS	WEAKNESSES
INTERNAL FACTORS (City context)	Important economic centre (for international business)	Biomass is not allowed in Kraków unless appropriate filters are used (more expensive investments)
	Companies in Kraków have development plans for improvement energy efficiency	Housing dispersion, which means that a great percentage of forest and nature protection areas limit the installation of solar and wind farms
	Burning solid fuels is not allowed by the City of Kraków	Old building stock, many historical buildings (under protection)
	Bank for Environmental Protection offers loans with subsidies for the purchase and installation of solar collectors for households and small enterprises	Buildings responsible for most of city's emissions (big influence of old building stock), mainly from heating

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	10090 RES micro-installations connected to the distribution grid in the city	
	Share of renewables in electric energy consumption in the city can reach 30%	
	Good conditions for the development of biogas plants using fermentation processes from organic waste.	
	Citizens want participate in transformation process	
	Political support for the renewable energy production (under different programs and strategies), with co-financing investments, promotion of RES, etc.	
	Kraków is on the list of the 10 greenest cities in the world (4th place), by the Husqvarna Urban Green Space Index (HUGSI)	
	Transport policy to replace rolling stock with modern, accessible and sustainable vehicles	
	First city in Poland where bus lines operated only by electric buses	
EXTERNAL FACTORS (National, EU level)	OPPORTUNITIES	THREATS
	Experiences at national level (Poland): energy cluster, cooperative for generation of renewable heat and electricity, and project for eliminate energy poverty.	It is not possible the peer-to-peer exchange of energy. Lack of clear organizational rules.
	Updated in 2017, the regulation for the technical conditions, that buildings must meet	No Polish regulations for hydrogen production yet
		Connecting to District Heating network is not mandatory
	Owner of a PV micro-installation (capacity up to 50 kWp) can become a prosumer	Only 21% of electric energy in the Polish Power system comes from RES
	Encouraging billing systems for prosumers	Strong dependency of the economy on coal
	No concession fees for projects not exceeding 5 MW	

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	Micro-installations do not pay the connection fee if connecting to the distribution grid	
	Financial instruments and incentives for existing buildings' renovation at national and local level	

Table 21. Krakow SWOT analysis results

7.2. STEP 2: Selection of suitable area to design a PED

In 2020, various areas in the Municipality of Krakow were considered, for which the probability of creating an Energy Positive District would be the greatest. Krakow identified the following three districts:

- PED area 1: "Nowa Huta Przyszłości" (planned buildings)
- PED area 2: Kluzeka/Pigonia Street (existing buildins)
- PED area 3: PED on the campus of Kraków University of Science (al. Jana Pawła II 37)

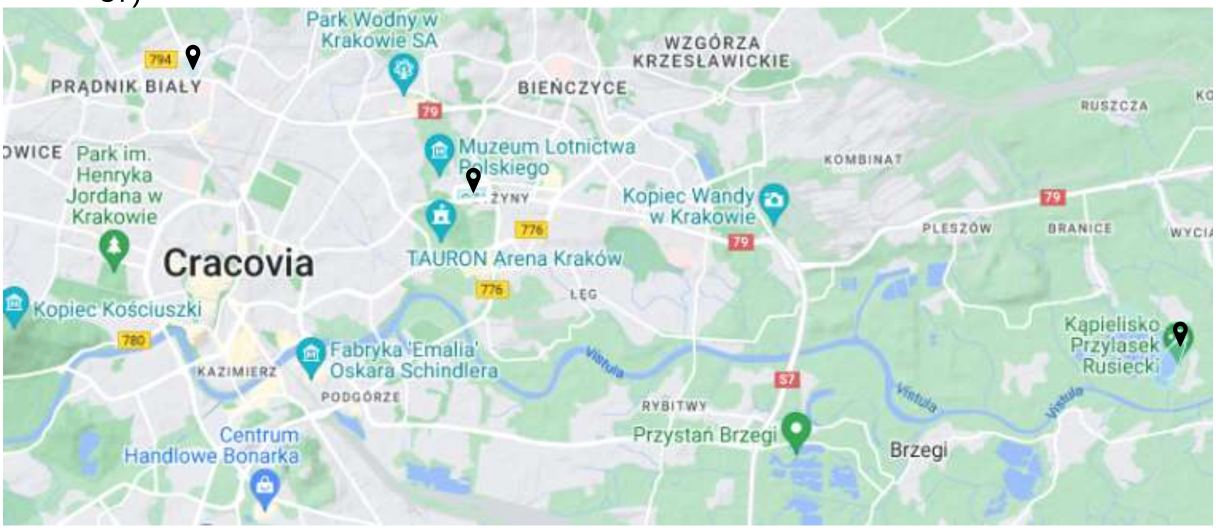

Figure 66 Krakow pre-selected PED areas

The process of the methodology explained in *STEP 2: Selection of suitable area to design a PED* is followed to prioritize one of the two for performing the next steps (towards a PED detailed design).

STEP 2.1

To start assessing the districts, first (STEP1.2) the desired objectives or impacts to be achieved by the PED implementation are identified. The impacts are identified and the pairwise comparison is performed, which results in:

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		A	B	C	D	E	F	G	H
RER (Renewable Energy Ratio)	A	1.00	0.20	5.00	5.00	0.20	0.20	5.00	0.20
Improve air quality	B	5.00	1.00	5.00	5.00	0.20	0.20	5.00	5.00
Reduce bills	C	0.20	0.20	1.00	5.00	0.20	0.20	5.00	5.00
Achieve zero energy imports	D	0.20	0.20	0.20	1.00	0.20	0.20	0.20	0.20
Positive Energy Balance	E	5.00	5.00	5.00	5.00	1.00	5.00	5.00	5.00
Efficient buildings	F	5.00	5.00	5.00	5.00	0.20	1.00	5.00	5.00
Affordable	G	0.20	0.20	0.20	5.00	0.20	0.20	1.00	5.00
Liveable	H	5.00	0.20	0.20	5.00	0.20	0.20	0.20	1.00
	ADDING VALUE	21.6	12	21.6	36	2.4	7.2	26.4	26.4

Then, the impacts are compared with the city objectives, which results in:

FINAL WEIGHT (considering CITY PRIORITIES)	Ranking	
9%	**5**	RER (Renewable Energy Ratio) factor
22%	**2**	Improve air quality
9%	**6**	Reduce bills
2%	**7**	Achieve zero energy imports
31%	**1**	Positive Energy Balance
15%	**3**	Efficient buildings / Building stock demand
2%	**8**	Affordable
12%	**4**	Liveable

STEP 2.2

Using the City context template, city level details about the renewable energy source (RES) potential are asked in step 1.1 (such as maps, GIS data, etc.). This data potential at city level is used to analyse the RES potential at district level and compare the two areas. PED area 2 was withdrawed from the Krakow team due to legal issues. For Kraków, as there was not sufficient data at city nor district level, a detailed analysis has been performed searching in the different open data platforms (sEEnergies, PVgis, Wind Atlas, geoDH map, etc.). A summary of the results is presented in the following table:

Results are presented in the following table:

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	PED 1	PED 3
High solar energy potential generation in the area (kWh/kW peak – PVgis)	*1046.04*	*1042.98*
High wind energy potential generation (W/m2 at 10 meters height – Wind Atlas)	*102*	*33*
Geothermal energy potential generation	*YES*	*YES*
There is a river/sea close from which could be possible to harvest energy	YES	*NO*
There is an industry/ice rink/waste water plant, etc. from which could be possible to harvest energy (thermal/electric)	*YES*	YES
There is a forest from which could be possible to harvest forest waste	*NO*	*NO*
There is Gas grids access	*YES*	*YES*
There is a refuelling station near to the district	*NO*	*NO*
There is a centralized heating generation	*Yes (planned)*	*Yes*
There is RES production	*Yes (planned)*	*#N/A*
Buildings already have ventilation or an air handling unit	*Yes (planned)*	*#N/A*
Buildings already have heat pumps or splits	*Yes (planned)*	*#N/A*
District heating connection	*No*	*Yes*
Supply Tº	*#N/A*	*Heating season: temperature of the heating medium 135C (supply) /65C (return) Summer season: temperature of the heating medium 70/30C*
Number of buildings connected	*#N/A*	*All in this district*
substations available on the buildings	*#N/A*	*#N/A*
district network provides cooling	*0*	*#N/A*
There is an electric substation nearby	*No*	-
There is an existing district heating or cooling network nearby	*No*	*Yes*
There is Virtual Power Plant in the district	*No*	*No*
There is an Energy Community in the district	*No*	*No*
There is a waste management (at level district) or waste water plant nearby	*Yes*	*No*
There are energy intensive industries in the district	*Yes*	nearby

In the following document, the details from the analysis are presented.

First, the data at city level is analysed:

District heating areas

Both areas identified do not have access to a nearby district heating network according to sEEnergies Open Data platform. But, the city has confirmed the PED area 3 has a district heating network. In fact, PED area 3 is already connected.

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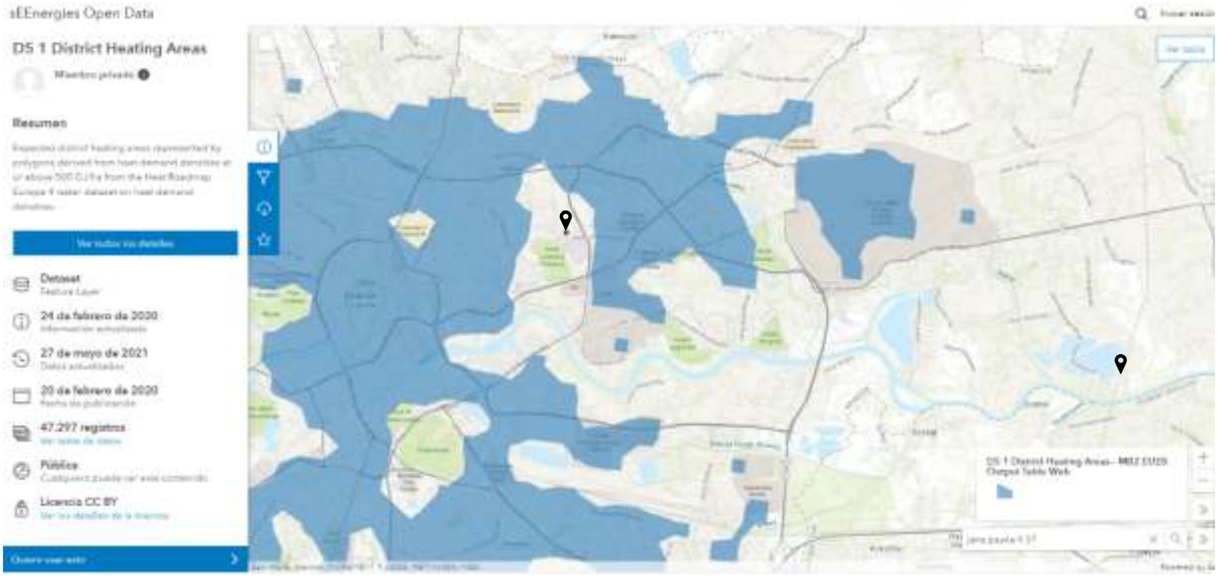

Figure 67: District heating areas in the city of Krakow (sEEnergies Open Data platform)[25]. The points indicated in the map are the PED areas

Potential waste heat sources (industry, waste water treatment plants, among others).

Industry area are relatively close to PED area #1. There are the largest industry waste producers (Arcelor Mittal. Budimex SA, ZŁOMEX S.A., MADROHUT SA, TAMEH S.A).

A few years ago, Arcellor Mittal provided heat to the network, and also TAMEH SA used to want to do the same, but at the moment, none of them do that. Currently, DH is not powered by private industrial facilities, heat sources for DH are CHP Plant in Kraków and Skawina and ZTPO (The Thermal Waste Treatment Plant). Another industry waste producer is Kraków CHP Plant (PGE Energia Ciepła is 2.7 km in a straight line from PED area #3)

[25]https://s-eenergies-open-data-euf.hub.arcgis.com/datasets/b62b8ad79f0e4ae38f032ad6aadb91a0_0/explore?location=48.133640%2C17.172547%2C12.87

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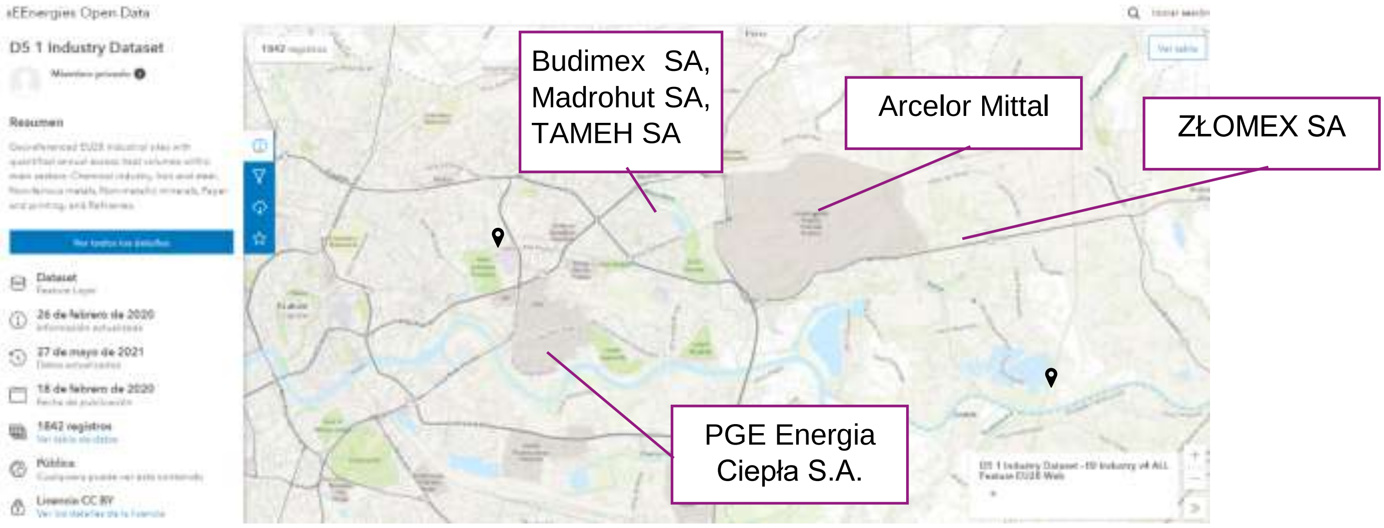

Figure 68: Potential waste heat sources (industry) (sEEnergies Open Data platform)[26]. The points indicated in the map are the PED areas

There are 2 waste water plants in Kraków – Kujawy and Energy Passive Sewage Treatment Plant in Płaszów. These facilities generated 12,093 MWh of energy from biogas in 20208, for their own purposes.

Figure 69: Potential waste heat source: Waste water plants (sEEnergies Open Data Platform)[27]. The points indicated in the map are the PED areas

Furthermore, according to the portal Geoplasma, Krakow PED areas are both suitable for: borehole heat exchangers, and groundwater heat pumps, but it might need additional information.

[26]https://s-eenergies-open-data-euf.hub.arcgis.com/datasets/a6a1e8e95514413a90bbb2e40515fdb2_0/explore?location=44.450426%2C17.567450%2C4.70

27s-eenergies-open-data-euf.hub.arcgis.com/datasets/2357e5fcfb744d2f8f842cd7171a90a0_0/explore?location=48.135375%2C17.102720%2C11.88

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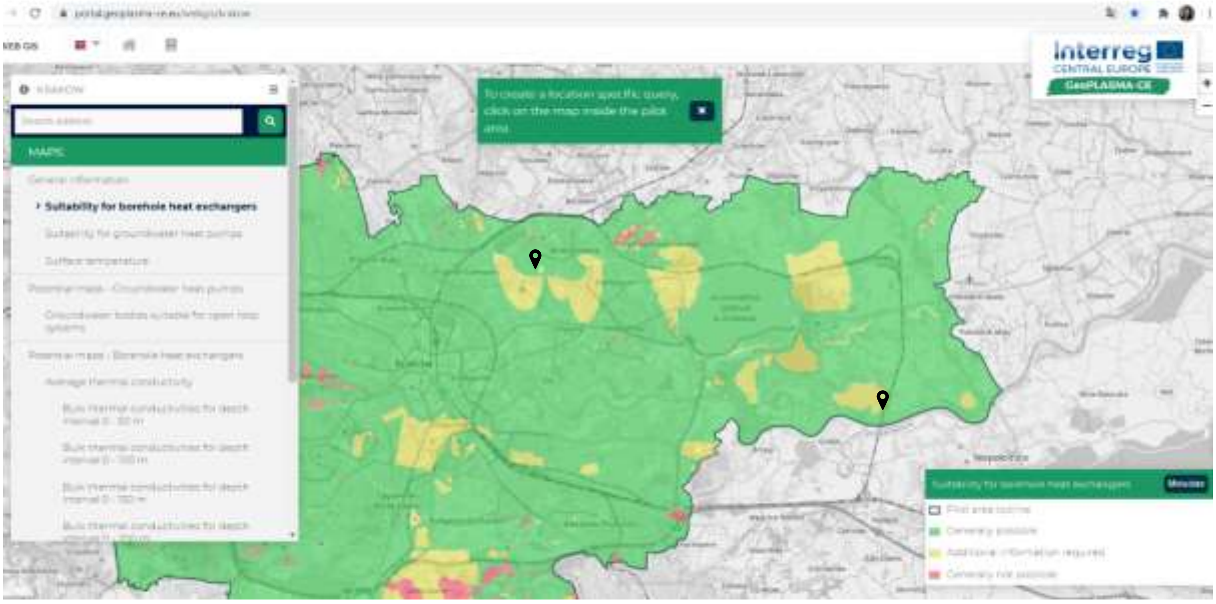

Figure 70: Suitability for borehole heat exchangers (https://portal.geoplasma-ce.eu/webgis/Krakow). The points indicated in the map are the PED areas

Using PVgis the PV potential is obtained for the optimal tilt and azimuth for a location in the middle of the PED areas. For PED area 1 a potential of 1046.04 kWh/year/kW peak installed is obtained, with a tilt of 35º and azimuth of 0. For PED area 3 a potential of 1042.98 kWh/year/kW peak installed is obtained, with a tilt of 35º and azimuth of 0.

In Wind Atlas, the wind potential is obtained for a location in the middle of the PED areas, and at a height of 10 meters (to allow mini wind turbines). For PED area 1, a potential of 102 W/m^2 is obtained for a height of 10 meters and a wind velocity of 3.58 m/s. For PED area 3 a potential of 33 W/m^2 is obtained for a height of 10 meters and a wind velocity of 2.48 m/s.

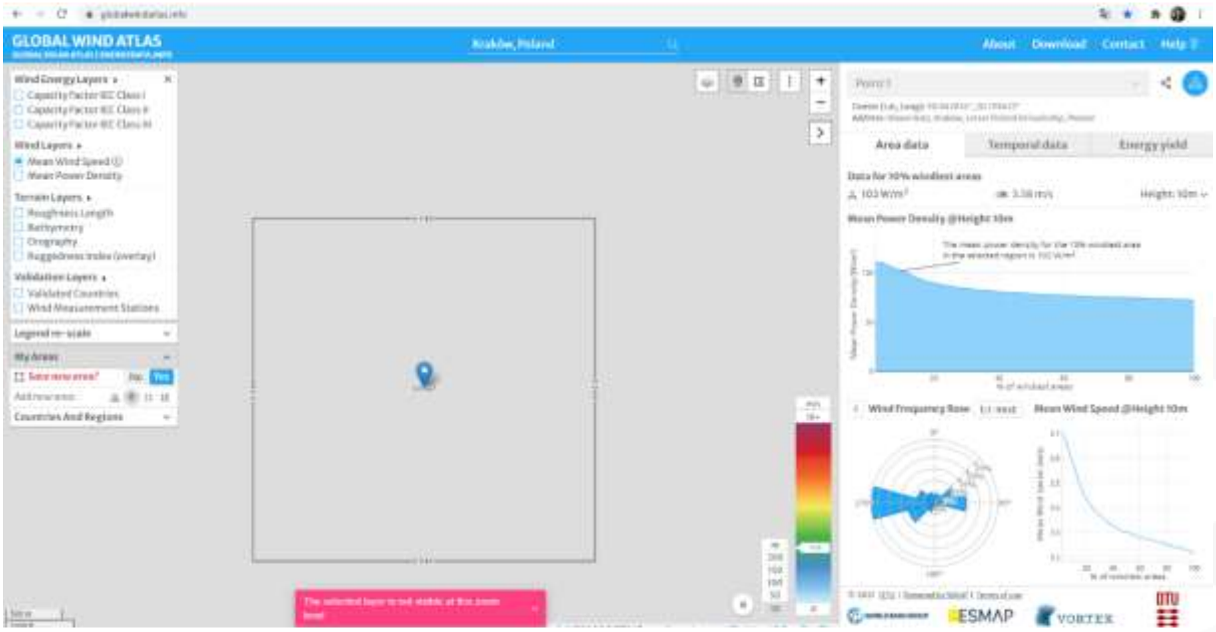

Figure 71: Wind potential in PED area 1

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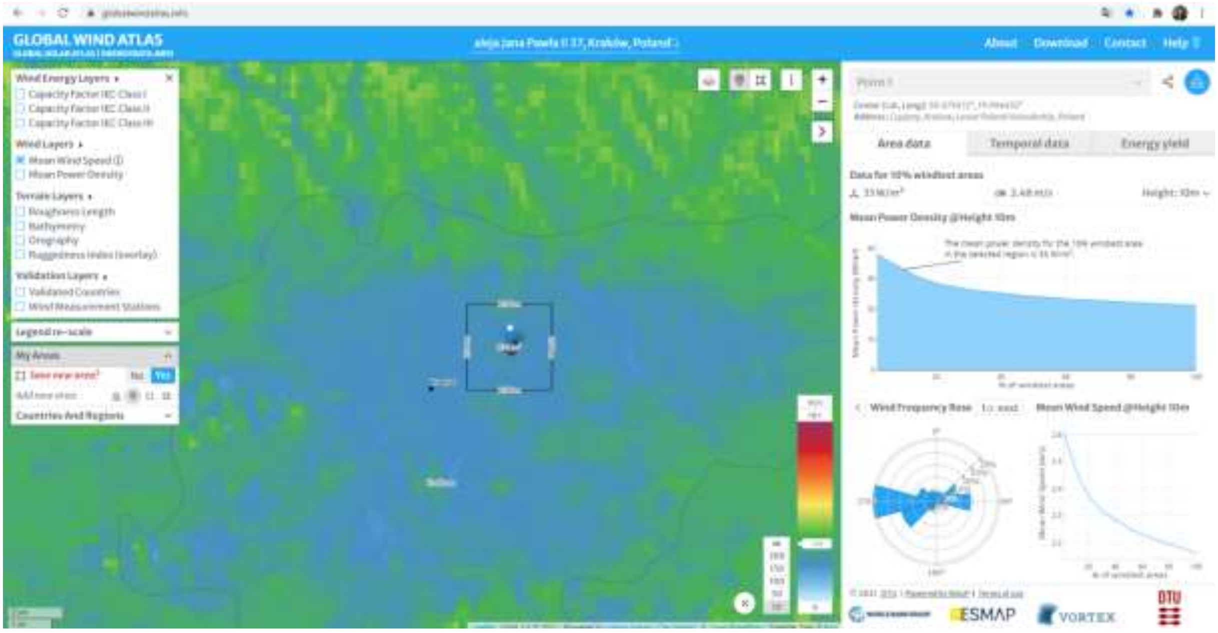

Figure 72: Wind potential in PED area 3

Lastly, according to ChargeMap, in PED area 3 there is 1 fast charging point (with a power greater than 30kW), and in PED area 1 none.

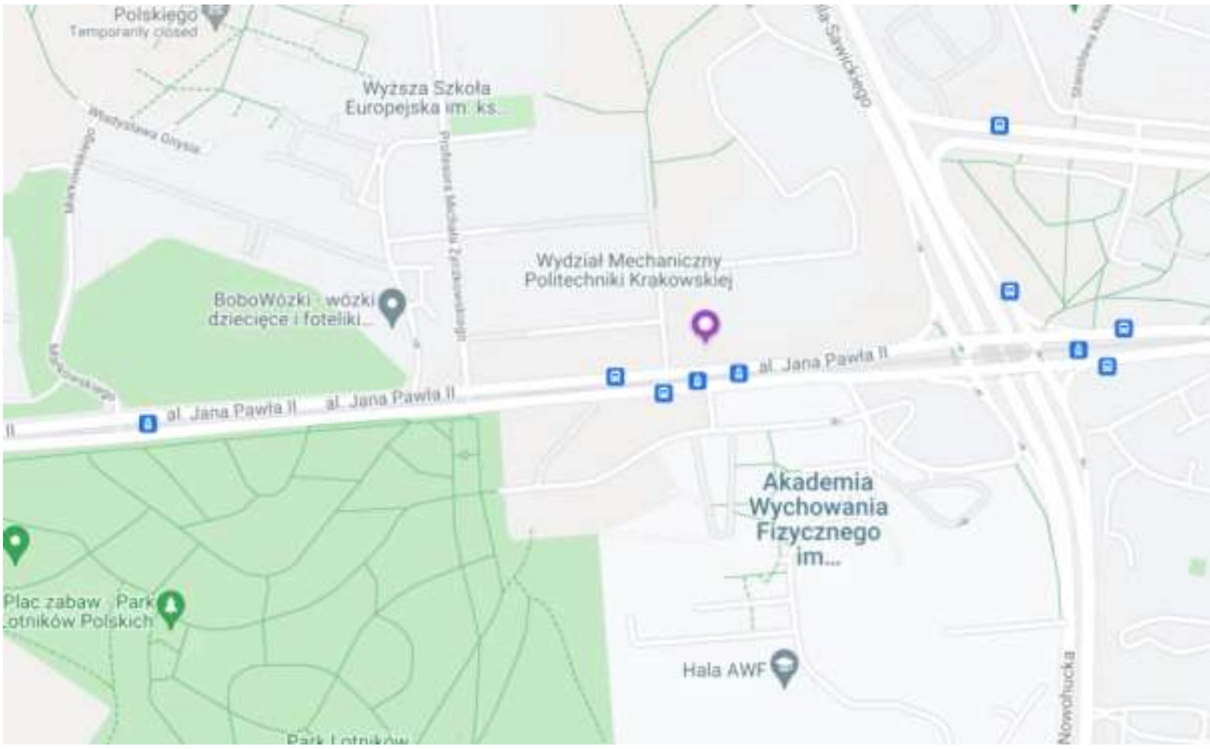

Figure 73: Charging points in PED area 3.

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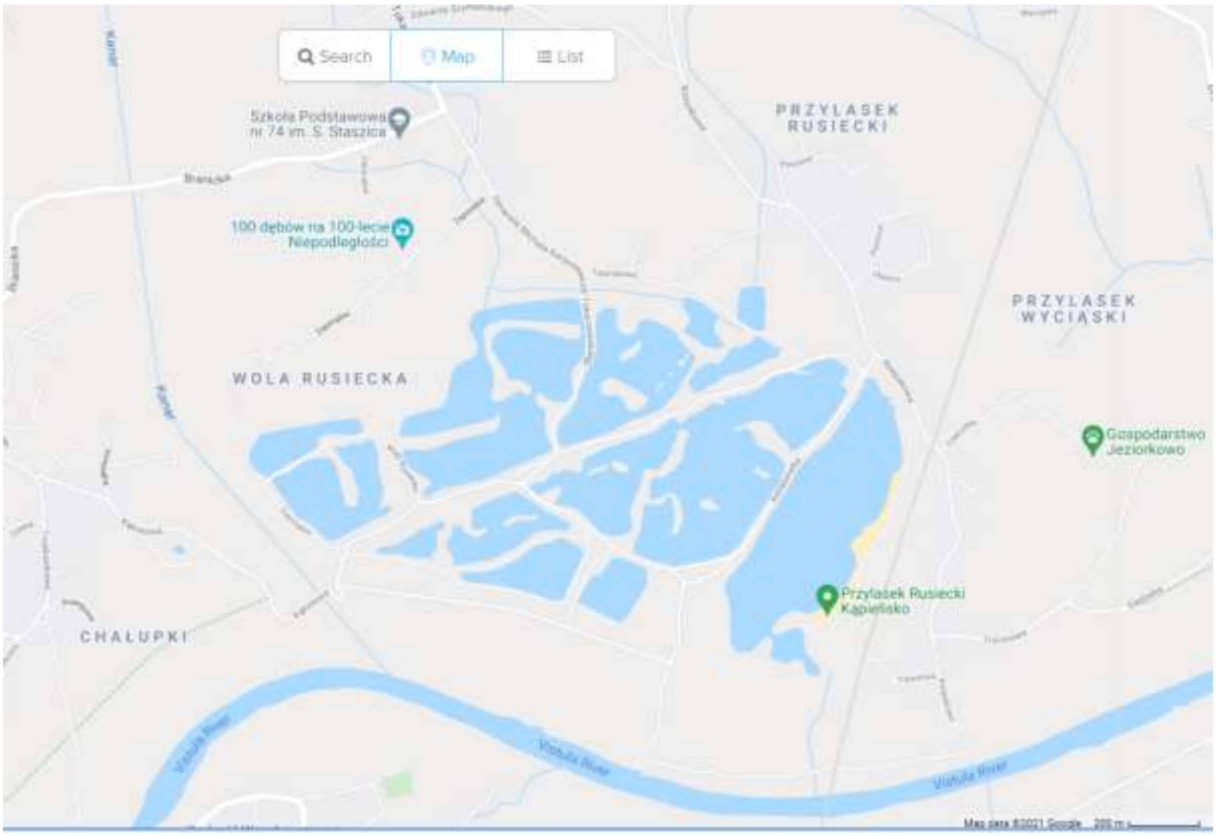

Figure 74: Charging points in PED area 1

All of these characteristics, as well as spatial, social and economic characteristics are weighted using the resulting scores from STEP 2.1 in next step.

STEP 2.3

Considering spatial, technological, social and economic factors, a composite indicator that ease the PED area prioritization is obtained for each of the areas. The process is validated by the city. PED area 1 obtained a final score of about to 0.97 whereas PED area 3 obtained a final score of 1. This is due to the fact that, the latter is a new development area preferred by the municipality. Summary of the results are shown in Figure 75.

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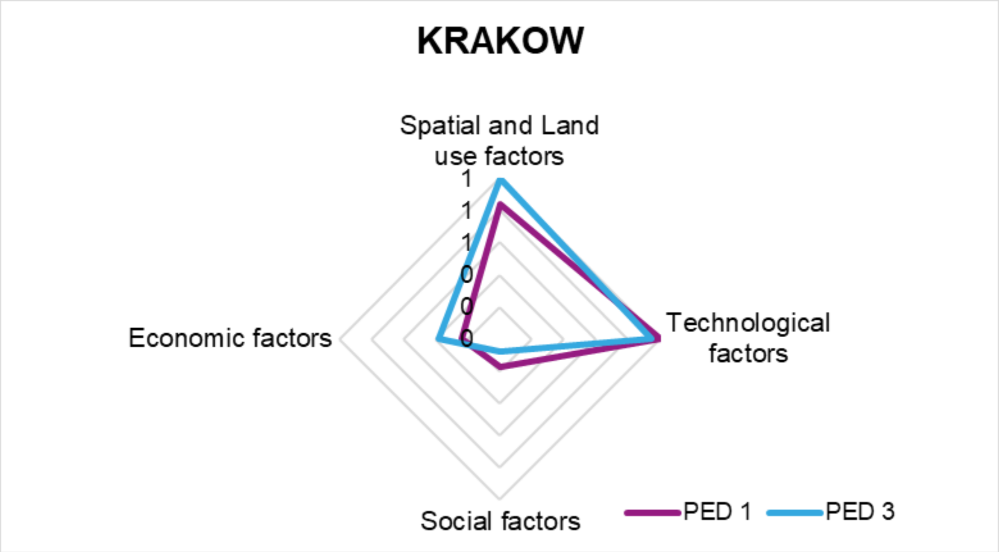

Figure 75: Final selection of PED and summary of scores, and final weights- Krakow

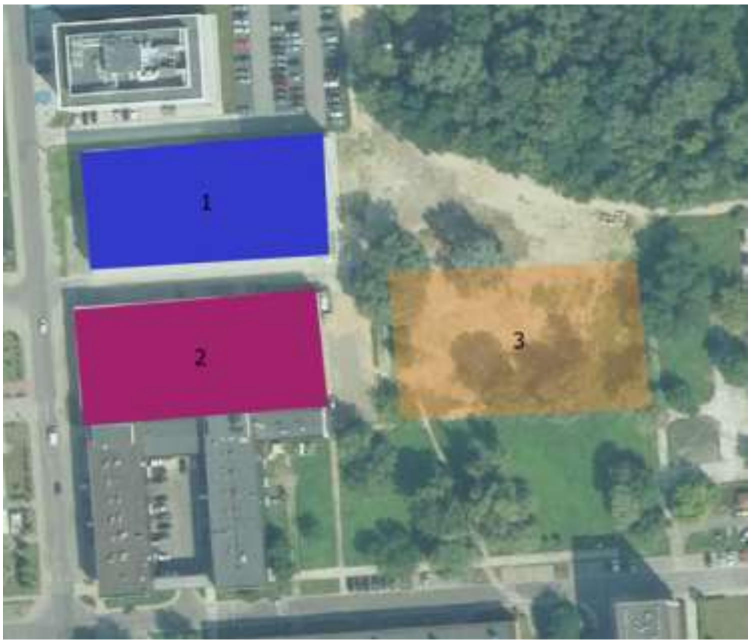

Figure 76 Selected PED: Building 1: Tennis Centre of Kraków University of Technology, Building 2: Spoty hall of Kraków University of Technology (with offices), Building 3: Center of Eco-Energy technologies (planned)

To sum up, initially, the area of "Nowa Huta Przyszłości" was considered, a new, undeveloped area on which design works were carried out. However, due to the distant horizon of the investment implementation and the conducted by Cartif analysis, this area was rejected. On the other hand, the Kluzeka/Pigonia area, inhabited mainly by the elderly, was an area where the potential for innovative, new energy solutions was not noticed. And also, by the other legal issues. Hence, finally, due to the greatest potential, both technological, organizational and scientific, the area of the campus of the Cracow University of Technology was selected.

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7.3. STEP 3: Detailed design of PED

STEP 3.1: Baseline calculation

A 3D model using CYPETHERM Eplus has been used to model the 3 buildings. Floor plans, envelope performance characteristics, schedules and bills have been used to create and calibrate the model.

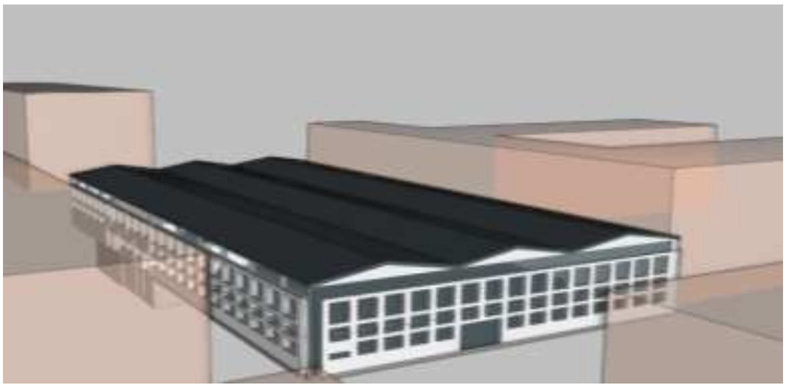

Figure 77 building 2 Krakow

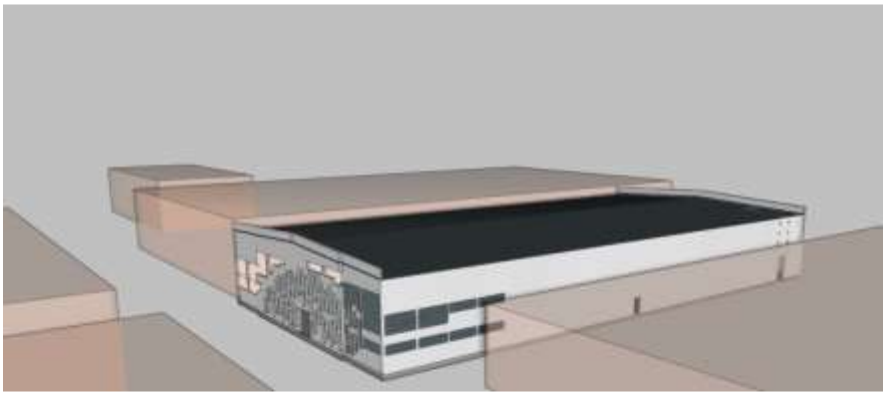

Figure 78 building 1 Krakow

Figure 79 shows an overview of the total electricity demand and total gas demand of building 1 plotted against the measured monthly data from the bills.

Figure 79 Calibration process Krakow – building 1

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The same process has been followed with building 2 and 3. As a result, the current situation (baseline) of the buildings is the following:

kWh/m^2	SH	SC*	DHW	ELECT.
Building 1	41.71	0.20	1.84	32.26
Building 2	39.79	-	-	49.55
Building 3	26.00	9.07	-	35.79

Figure 80 Summary of Baseline results

The results show a Good performance of the buildings, although they do not reach NZEB levels of 2021. Calculating the PED energy balance, results in:

Table 22 District balance

DHN delivered	0.41 GWh/year
GRID delivered	0.42 GWh/year
PEBnren=	1.59 GWh/year
PEBnren/m2	145.13 kWh/m^2[28]
Emissions	315.19 tons of CO2
Total costs	33,300.77 €
Total cost per month	2,775.06 €/month

[28] Maximum permissible values of primary energy for heating, ventilation and DHW (EP_{H+W} in kWh/(m^2·year)) in Poland (Kaczorek, Bekierski, & Budowlanej, 2020). The buildings were constructed between 2002 (B1) and 2016 (B2), and the value for education buildings is 164 kWh/m2 of primary energy for buildings constructed between 1999-2008 and 136.94 between 2014-2016.

Building category	$EP_{H+W\ max}$	
	Obligatory from 1 January 2017	Obligatory from 1 January 2021* (NZEB level)
Residential building: - single-family house - multi-family house	95 85	70 65
Hotels and dormitory	85	75
Non-residential building: - health care building - other	290 60	190 45
Industrial, heated storage and livestock buildings	90	70

* In case of buildings occupied and owned by public authorities, obligatory from 1st January 2019

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STEP 3.2: Selection of potential solutions> define scenarios

The city of Krakow selected several potential solutions to define the scenarios at district level. Evaluating as well the co-benefits that could be obtained for each solution.

IMPACTS / CO-BENEFITS:		SCENARIO 1						
		Technology 1	Technology 2	Technology 3	Technology 4	Technology 5	Technology 6	non-technical
		PV panels on buildings envelopes (roofs and facades)	Flat plate collector	Water-water heat pump	Underground thermal storage	Li-on electricity storage	E-charger	Energy Management Agent
Climate resilience	Climate adaptation	*Medium*	*Medium*	*Medium*	*Medium*	*Medium*	*Medium*	*none*
	Climate mitigation	*High*	*High*	*High*	*High*	*High*	*Medium*	*none*
Local economy, entrepreneurship and innovation	Local economy enhancement	*High*	*High*	*High*	*High*	*High*	*High*	*Low*
	Financial savings for citizens	*High*	*High*	*High*	*High*	*Low*	*Low*	*High*
	Increase employment rate and jobs	*Medium*	*Medium*	*Medium*	*Medium*	*Low*	*Low*	*Low*
	Decrease future maintenance costs	*High*	*Low*	*High*	*High*	*High*	*High*	*High*
Social inclusion and education	Social cohesion (gender, minority groups)	*none*	*none*	*none*	*none*	*none*	*none*	*none*
	Enhance citizen participation, connectivity and community	*none*	*none*	*none*	*none*	*none*	*none*	*none*
	Improve access to information, Social capacity building	*none*	*none*	*none*	*none*	*none*	*none*	*none*
	Raise awareness/ behavioural change	*Low*	*Low*	*none*	*none*	*none*	*Low*	*none*
Health and well-being	Improve air quality	*High*	*High*	*High*	*Medium*	*Low*	*High*	*Low*
	Reduce noise pollution	*none*	*none*	*Low*	*Low*	*none*	*High*	*none*
	Reduce hot stops/ urban islands in the city	*none*	*none*	*none*	*none*	*none*	*none*	*none*
	Enhance attractiveness of the city	*Low*	*none*	*none*	*none*	*none*	*High*	*none*
	Promote healthier and more attractive lifestyles	*Medium*	*Medium*	*none*	*Low*	*none*	*Medium*	*none*
Biodiversity	Reduce ecological footprint	*none*	*none*	*none*	*Low*	*none*	*none*	*none*
	Greater biodiversity	*none*	*none*	*none*	*none*	*none*	*none*	*none*
Resource management and efficiency *(circular economy)*	Waste efficiency	*none*	*none*	*none*	*none*	*none*	*none*	*none*
	Water efficiency	*none*	*none*	*none*	*none*	*none*	*none*	*none*
	Food efficiency	*none*	*none*	*none*	*none*	*none*	*none*	*none*
	Sustainable land use	*Medium*	*Medium*	*Low*	*Medium*	*Low*	*none*	*none*

Figure 81 Overview of co-benefits for scenario 1 (PV, solar thermal collectors, water-water heat pump, underground thermal storage, Li-on batteries, e-chargers and energy management agent).

The following scenarios evaluate the combination of PV on buildings envelopes (roofs and façades) and/or parking lots, solar thermal, air-water and water-water heat pump, underground thermal storage, Li-on batteries, demand management (heat recovery systems from DHW, activity sensors) and e-chargers. The possible creation of an energy community is also considered.

STEP 3.3: Scenarios evaluation and prioritization

The following scenarios were studied in detail:

1. PV on roofs, façades and parking canopies: Considering the PV potential of the buildings, it is assumed that building produce and self-consume their full PV potential. Exports are injected to the grid.
2. PV & HPs with and without storage: buildings are supplied at a lower temperature and heat pumps use a constant source (of around 15ºC[29]).
3. PV and greener DHN.

A scenario with only PV on roofs is assessed. The potential is the following:

Table 23 available surface

Building	Roof m²	m² façade (east)
1	1800	450
2	2887.5	228
3	4286.04	-

[29] Source can come from ground or water sink

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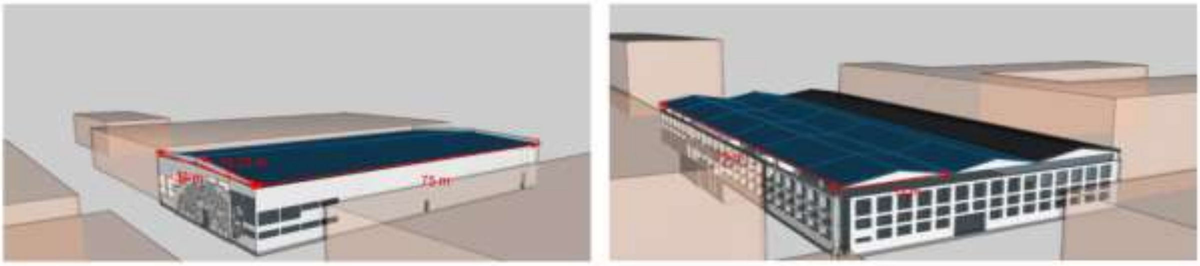

Figure 82 Possible PV installation in Krakow (building 2 on the left and building 1 on the right)

Even if using the total available Surface completely (which in principle is not the usual, as a space between rows needs to be placed for maintenance), the district cannot become a PED, therefore it is excluded from the list.

The results obtained are the following for the rest of the scenarios:

Baseline

1.59 GWh/yr (not PED)	2.8 k€/month	315.2 tons CO_2	0.42 GWh from GRID	0.41 GWh from district heating network

Variables	1. PV on roofs, façades and parking canopies (net metering with excess)	2. Collective PV & HPs (1.6 MWp: sharing excess)	3. Evs, PV & HPs (2.03 MWp: sharing excess)	4. PV and greener DHN
Economic savings	2.1 k€/month	3 k€/month	3 k€/month (+ car use)	1.5 k€/month
Environmental impact	-115 tons CO_2 reduction	-0.715 tons CO_2 reduction	-0.715 tons CO_2 reduction (+ car use)	-0.715 tons CO_2 reduction
Local production	1.14 GWh/yr production of PV	1.2 GWh/yr production of PV	1.5 GWh/yr production of PV	1.3 GWh/yr production of PV
Primary energy balance	-2 MWh/yr (PED)	-2 MWh/yr (PED)	-2 MWh/yr (PED)	-2 MWh/yr (PED)
Investment	0.4 M€, payback in ~14 years	0.54 M€, payback in ~ 15 years	0.63 M€, payback in ~ 17 years	0.4 M€, payback in ~21 years

* ONLY energy costs. Annual costs divided equally between the 12 months. ² PV does not fit in the district. ³ assuming DHN grid becomes greener
ALL cases have 80% subsidy. Last case does not include the investment of the new biomass boiler

The first scenario shows that PED cannot be achieved by only installing individual PV installations on roofs. If collective PV is installed, including also other areas (such as parking lots and a solar farm outside the district boundaries) is possible to achieve a PED (scenario 2). To be energy positive (accounting only electricity demand), an area of 12,000-16,000 m2 is needed. PV on roofs and façades (817 kWp) account up to 6536 m^2. Solar canopies in parking lots could be placed next to the new building 3. The space will not be enough an additional 2400-6400 m2 will be needed (from other buildings, parking lots, or off-site solar parks).

Collective HPs produce ~404.7 MWh/yr. of heat (at 45ºC for SH) which improves the PED scenario, but requires an upgrade of the emitters (radiators to fan coils or ground floor heating) and an adaptation of the DHN to be supplied with a temperature of 15ºC[30] or replace it with

[30] 15ºC have been assumed as source. Similar results could be obtained with GSHP, but costs could be higher. Cost of replacement of emitters is not included.

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another source, such as ground or water. The scenario leads to higher PV necessities and production.

Making greener the DHN (scenario 3) will allow to achieve similar scenario as scenario 1, but with much less PV, but requires to increase in at least 0.8 MW of biomass supply for the area.

Other options could be combining the above-mentioned solutions with: reduction of heat and electricity consumption of the buildings (through demand response, smarter buildings, adjust thermostats to lower temperatures in winter, behavioural change, etc.). Storage has not been considered yet due to the deadline to present the results. Further iterations of the scenarios could be made, once the feedback of the stakeholders is collected (on-going process). Final, detailed scenarios will be precise with the City at the next stage.

In conclusion, in terms of financial viability (investment and payback period), scenario 1, which involves solely installing a large amount of PV, is feasible for Krakow. However, it falls short in achieving a completely clean district, as the district heating network (DHN) remains un-decarbonized. On the other hand, both scenario 2 and scenario 4 yield similar, albeit cleaner results, but they come with higher payback periods. Scenario 4 needs an involvement of the DHN operator to invest themselves in the decarbonisation of the district heating.

STEP 3.4: Financing options

In the selected area of Positive Energy District in Kraków, which is located on the campus of the Kraków University of Technology, the most feasible option is to obtain funds from the European, National and Regional funds (European LIFE programme, National Recovery Plan, National & Regional fund for environmental protection and water management). The main investor on Kraków PED area is the University, so the probability to receive appropriate funds for the research unit is high, especially to develop innovative technologies related to energy efficiency and reduction of CO_2 emission. In this case, the partial funds are also possible, partly from the own resource of University, and partly from the grants.

The least feasible option could be to set up the investment platform, because this financing model, which simultaneously involve the financial sector, entrepreneurs, residents and the municipality in one investment project is not popular in Poland yet. It would be difficult to involve potential participants in the process.

Another option for financing the PED could be the loan in the commercial bank on preferential terms. The funds from the loan can be used for the purchase and installation of PV, energy storage, home charging stations and heat pumps.

Other energy efficiency subsidies could be used by companies to partially finance (or to improve the economic case) the PED:

Table 24 Energy efficiency subsidies in Krakow/Poland

Energy efficiency subsidies for companies		
Program	**Range of activities**	**Support level**
BGK ecological loan (FENG)	Modernization projects - e.g. renewable energy	Subsidy in the amount of 25% to 80% of the costs,

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	installation, thermo modernization.	depending on the type and location of the investment, as well as the type of investor.
Energia Plus	E.g. reducing the consumption of energy and primary raw materials, modernizing or replacing e.g. lighting; projects in the field of energy recovery	A loan on preferential or market terms – from PLN 0.5 to PLN 300 million, up to 85% of eligible costs, with the option to redeem up to 10% of the loan, but not more than PLN 1 million.
Thermo modernization bonus	Thermo modernization activities, implementation of a technical connection to a centralized heat source	Support in the form of a loan subsidy: 31% of the cost of the thermo modernization project, including the installation of RES, 26% of the project costs in other cases.
White certificate system	Projects aimed at improving energy efficiency, e.g. insulation of industrial installations, renovation and thermo modernization of buildings, energy recovery from industrial processes.	The amount of support depends on the amount of energy to be saved.
EOG Co-financing of projects implemented under the Financial Mechanism of the European Economic Area 2014-2021	thermal modernization, replacement of lighting, installation of RES installations	A loan on preferential or market terms
National Recovery Plan "Green energy and reducing energy intensity"	Improving the energy efficiency of the economy, increasing the use of RES	Support in the form of loans.
PHOENIX program	Improvement of energy efficiency, high-efficiency cogeneration, RES installations	Aid in the form of a grant, loan or partial loan forgiveness.
FENG program European Funds for a Modern Economy Priority III "Greening enterprises"	Increasing the use of renewable energy sources, reducing greenhouse gas emissions, energy modernization of buildings and production lines, purchase of energy-efficient equipment	Grant, financial instruments, capital instruments, guarantees and mixed support.

Conclusions

Thanks to this process Krakow was able to gather some insights for designing a tendering procedure that considers the necessary features to achieve and implement a PED in their area:

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Campus of Kraków University and also to duplicate the process in other areas in the city. For instance:

- There is a favourable context (regulatory, technical, economic) to deploy PEDs in Krakow. However, as PEDs sometimes require stakeholder cooperation, if Investment Platforms or similar schemes are not famous, might be a burden.
- There are EE programs as well as companies willing to deploy sustainable solutions.
- The decarbonisation of the DHN is a must to allow achieving an economically feasible PED (and also avoid oversizing technologies).
- Access to direct funds (from EU, national, etc.) or bank loans seem the most feasible options. Investment platforms are not popular.

The action of PED creation initially seemed impossible to implement in local conditions, which energy systems are strongly based on coal. However, the conducted analysis shows that with the use of appropriate technological investments and the introduction of organizational models, it is possible to create a PED in Krakow. The analyses confirm us that the important aspect of creating a PED is not only the production of electricity, but also storage, management and balancing the demand and supply.

Krakow believes that it is essential to involve academy sector in the processes related to climate actions. Integration with the Kraków University is another step-in combining sectors in order to carry out a just energy and carbon transformation of the city.

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8. PED design in Matosinhos

In this section, the steps defined in section 3.2 are applied to the city of Matosinhos. Starting with (Section 8.1) the city context and identifying the strengths, weaknesses, opportunities and threats of Positive Energy Districts; followed by the prioritization of one of the preselected areas in proposal stage (Section 8.2) and finalising with a PED detailed design for the selected are in section 8.3. The output is a set of recommendations for stakeholders to deploy PEDs in that area.

8.1. STEP 1: City's environment for PED implementation

Context

Matosinhos is located in the northern Porto district of Portugal, bordered in the south by the city of Porto. The city covers an area of approximately 62.42km^2 and is bathed by the Atlantic Ocean. It has a population of 175,478, which means a **density of 2,811 people per km^2**.

Matosinhos is a city where the presence of the sea (ocean) has an important role in its weather and economical activities. The privileged geographic conditions of Matosinhos, makes it the largest seaport in the North of Portugal.

The climate is **temperate oceanic**, with mild, rainy winters and pleasantly warm, sunny summers. The average annual temperature is 15 ºC, with an average temperature in the warmest month (August) of 25 ºC, and in the coldest month (January) of 13 ºC.

Conditions to allow a Positive Energy Balance

The **energy performance requirements** established for residential buildings are set in terms of the useful energy demand needs for heating and cooling. The total primary energy for heating, cooling and domestic hot water is also limited to a maximum value. There is a **minimum RES contribution** required for domestic hot water and space heating/cooling. Since 2009, **EPCs** became mandatory and need to be integrated in rental or sales contracts. Therefore, EPCs have become widely available to the public.

For **Renewable Energy Communities (RECs)** supplier license is not required for the energy sharing of electricity. The managing entity will need to coordinate the activities with the DSO and with the system operator(s) and take care of the implementation of the distribution between participants. For this purpose, corresponding supply contracts need to be established. The managing entity will also be billed for potential imbalances that the renewable energy community causes.

For the case of **Self-consumption Units (UPACs)**, they are supposed to meet individual consumption needs. Nevertheless, UPACs that are connected to the grid and have a capacity of up to 1 MW can feed their excess of electricity into the national grid and commercialise it on the electricity market. For their electricity excess they receive a remuneration tariff that is 10% lower than the market price.

Surplus energy from individual or collective **self-consumption** can be traded, including through aggregation and trade on a **peer-to-peer basis** in an organized or bilateral, both through a renewable power purchase contract; through a market participant against payment of a price agreed between the parties; and through a market facilitator, subject to an acquisition obligation with market remuneration.

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Framework for self-consumption of renewable energy on collective level and by **renewable communities** was introduced in 2019. Previously, self-consumption was limited to the individual level. The 2019 decree law adopts the major lines of the EU REDII in terms of membership, possible activities, etc. and the need to form a legal person. RECs are possible as far as they have an intelligent counting system and are installed at the same voltage level. Collective self-consumption schemes and RECs require registration and application on an online portal of the Portuguese Directorate General of Energy and Geology. For small Production Units (UPP) and Self-consumption Units (UPAC) with a capacity between 1.5 kW and 1 Mw or less than 1.5 kW but connected to the grid, to access to the remuneration regime and start operation, should ask for the support during the required prior registration on SERUP (Electronic Registration System).

The Portuguese government announced strong commitment to maximising the renewable capacity installed by developing large-scale projects for the **production of hydrogen**, which also benefit from certain infrastructure which already exists, notably pipelines. Moreover, there are several main initiatives that will see further development in the next couple of months, such as the setting up of a mechanism to support and encourage the production of green hydrogen; the regulation of hydrogen in the gas infrastructure; the setting of targets for hydrogen incorporation; the provision of financial support for hydrogen-based projects; and the incorporation of a collaborative lab (COLAB) for R&D for the hydrogen supply chain and new industries.

There is no **District Heating** regulation, but generally DHN are promoted. Nevertheless, cooling and heating demands are low due to favourable climate, and therefore, not so common to have centralized or district heating solutions.

Conditions to allow Renewable Energy Production

For the limits on **capacity installed**, it is for 1 MW in UPACs, but there are not clear limitations in RECs. Requirements are only for big power plants, from grating of a prior network capacity reserve title before the generator can apply for a production licence to build a power plant (and three procedures to reserve titles).

As for legal challenges on the installation of some technologies, it is mandatory to have intelligent metering of HVAC with electric power higher than 25 kW and/or boilers with thermal power higher than 100 kW. There is no specific spatial limitation for renewable energy communities defined. However, the terms of close neighbourhood relationship and proximity of the project are introduced and must be assessed, on a case-by-case basis, assuming the physical and geographical continuity of the project and the respective self-consumers or participants.

Conditions to allow Efficient buildings/ Building stock demand

Portuguese energy efficiency legislation focuses heavily on new buildings, both residential and non-residential. **nZEB** has been regulated in 2020, and public buildings are required to be nZEB from 2020 on, and **all new buildings** (including private buildings) are required from 2021 on. Existing residential buildings are only obliged to comply with these stricter requirements when they undergo renovations. The building component to be renovated must adhere to the minimum performance levels defined in the regulation.

For many decades Portugal was behind respect to energy performance regulations. In 1990 that the first **energy efficiency regulation** was introduced, with limited impact on building performance. With the transposition of the EPBD, a clearer focus was given, not only for

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technical **building systems and RES**, but also in the reinforcement of the **building envelope**. At the beginning of 2017 there were a total of 1.2 million **EPCs**, with 90% of them existing in the residential sector and 10% for non-residential sector.

As for **funding**, the Energy Efficiency Fund (FEE) is a **financial tool** that helps implement the National Energy Efficiency Action Plan (NEEAP), and among other forms of assistance, it allows for building owners to apply for funding in order to improve the energy performance and efficiency of the building (or building unit).

Conditions to allow PED implementation

In terms of **planning**, national plans aim to GHG emissions reduction by 2030, as well as to increase energy efficiency and RES use. Locally, **SEAP** (to 2020) is under revision to set more ambitious target of 40% GHG reduction by 2030 (SECAP).

There are no incentives to district projects at district/local level. But there are **feed-in tariffs** for certain installations.

SWOT analysis results

Matosinhos inputs are summarized in a SWOT table to identify which internal factors help or harm the PED implementation, as well as which external factors (National, EU level, etc.) creates opportunities and threats to its context.

What can be conclude is:

- New buildings have a mandatory certification and minimum RES contribution with the objective of reducing at least 50% of primary energy annual needs. As temperatures are mild, it is not common to have big energy systems for heating and cooling (sometimes only an air conditioner) in residential buildings.
- There is a favourable regulatory environment for Renewable energy communities. Self-consumption units (for individual purposes) are limited to 1MW, which is a limit higher than the neighbouring country of Spain limits for self-consumption (where is only 100kW per user). Surplus energy from individual or collective self-consumption can be traded, including through aggregation and trade on a peer-to-peer basis. If capacity is lower than that, remuneration regime can be performed as long as the installation is registered.
- There are strong political commitments with RES and hydrogen. District heating is not common. It is mandatory to have intelligent metering for certain installations.
- There are several financial incentives in place managed by Funso Ambiental allowing building owners to apply for funding to improve the energy performance and efficiency of their building.

Therefore, the Portuguese environment is very favourable for the implementation of PEDs. The national regulations and funds are seen as enablers and can provide big opportunities for the city of Matosinhos. Effective coordination of stakeholders is needed to realizing mix-used PED districts.

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	HELPFUL	HARMFUL
INTERNAL FACTORS	STRENGHTS	WEAKNESSES
	Low cooling and heating demand due to favourable climate conditions	Centralized or district heating solutions are not common (although they are promoted and not needed in many cases due to climate)
	Feed-in tariffs for certain installations at local level.	
EXTERNAL FACTORS (National, EU level)	OPPORTUNITIES	THREATS
	Minimum RES contribution of 50% in relation to annual primary energy needs.	Self-consumption Units connected to the grid to commercialise their electricity excess with a tariff 10% lower than the market price.
	Supplier license is not needed for sharing electricity in Renewable Energy Communities	It is mandatory to have smart metering of: - HVAC with electric power > 25 kW - Boilers with thermal power > 100 kW
	Self-consumption Units can connect to the national grid to feed and commercialise electricity excess	Many decades until 1990 that Portugal has been lacked of energy performance regulation.
	Surplus energy (from self-consumption) can be traded	
	Renewable communities' framework for self-consumption introduced in 2019	
	Portuguese government committed to develop large-scale projects for hydrogen production	
	It is mandatory that all new buildings (both public and private) are nZEB from 2021 on.	
	Fundo Ambiental allows building owners to apply for funding to improve the energy performance and efficiency of their building.	

Table 25. Matosinhos SWOT analysis results

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8.2. STEP 2: Selection of suitable area to design a PED

As said in section 3, from the preselected districts in proposal stage, a prioritization exercise is performed.

Matosinhos identified two potential districts for the implementation of their PED:

- Potential district #1: Custió residential area
- Potential district #2: Business hub

The former one is a residential area with 154 dwellings built in the year 2000. The current energy demand is being supplied by gas consumption with boilers and electricity demand fed by the grid. Houses do not have collective heating or cooling systems, and the energy performance is between C-D. The second area is a business hub, with offices (more than 110 companies, 5000 employees and 45 0000 m2). The demand is supplied with gas boilers and electricity fed by the grid. Furthermore, there is ventilation and single splits.

Figure 83: Matosinhos pre-selected PED areas

The process of the methodology explained in *STEP 2: Selection of suitable area to design a PED* is followed to prioritize one of the two for performing the next steps (towards a PED detailed design).

STEP 2.1

To start assessing the districts, first (STEP1.2) the desired objectives or impacts to be achieved by the PED implementation are identified. The impacts are identified and the pairwise comparison is performed, which results in:

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		A	B	C	D	E	F	G	H
RER (Renewable Energy Ratio)	A	**1.00**	5.00	1.00	1.00	0.20	0.20	1.00	0.20
Improve air quality	B	0.20	**1.00**	1.00	0.20	0.20	0.20	0.20	0.20
Reduce bills	C	1.00	1.00	**1.00**	5.00	0.20	0.20	1.00	0.20
Achieve zero energy imports	D	1.00	5.00	0.20	**1.00**	1.00	0.20	0.20	0.20
Positive Energy Balance	E	5.00	5.00	5.00	1.00	**1.00**	0.20	0.20	1.00
Efficient buildings	F	5.00	5.00	5.00	5.00	5.00	**1.00**	1.00	0.20
Affordable	G	1.00	5.00	1.00	5.00	5.00	1.00	**1.00**	0.20
Liveable	H	5.00	5.00	5.00	5.00	1.00	5.00	5.00	**1.00**
	ADDING VALUE	19.2	32	19.2	23.2	13.6	8	9.6	3.2

Then, the impacts are compared with the city objectives, which results in:

FINAL WEIGHT (considering CITY PRIORITIES)	Ranking	
5%	**6**	RER (Renewable Energy Ratio) factor
4%	**7**	Improve air quality
9%	**4**	Reduce bills
1%	**8**	Achieve zero energy imports
14%	**3**	Positive Energy Balance
15%	**2**	Efficient buildings / Building stock demand
7%	**5**	Affordable
46%	**1**	Liveable

STEP 2.2

Once the PED impacts ranking is defined, a data collection for PED area characterization starts.

Using the City context template, city level details about the renewable energy source (RES) potential are asked in step 1.1 (such as maps, GIS data, etc.). This data potential at city level is used to analyse the RES potential at district level and compare the two areas. For Matosinhos, as there was not sufficient data at city nor district level, a detailed analysis has been performed searching in the different open data platforms (sEEnergies, PVgis, Wind Atlas, geoDH map, etc.). A summary of the results is presented in the following table:

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	PED 1	PED 2	PED combined
High solar energy potential generation in the area (kWh/kW peak – PVgis)	*1500 kWh/kWp*		
High wind energy potential generation (W/m2 at 10 meters height – Wind Atlas)	*50 W/m2 a height of 10 m in the sea 490 W/m2 at 50 m*		
Geothermal energy potential generation	NO	NO	NO
There is a river/sea close from which could be possible to harvest energy	YES	YES	YES
There is an industry/ice rink/waste water plant, etc. from which could be possible to harvest energy (thermal/electric)	NO	YES	YES
There is a forest from which could be possible to harvest forest waste	NO	NO	NO
There is Gas grids access	YES	YES	YES
There is a refuelling station near to the district	NO	YES	YES
There is a centralized heating generation	NO	NO	NO
There is RES production	NO	NO	NO
Buildings already have ventilation or an air handling unit	NO	YES	YES
Buildings already have heat pumps or splits	NO	YES	YES
District heating connection	NO	NO	NO
Supply Tº	-	-	-
Number of buildings connected	-	-	-
Substations available on the buildings	-	-	-
district network provides cooling	NO	NO	NO
There is an electric substation nearby	NO	YES	YES
There is an existing district heating or cooling network nearby	NO	NO	NO
There is Virtual Power Plant in the district	NO	NO	NO
There is an Energy Community in the district	NO	NO	NO
There is a waste management (at level district) or waste water plant nearby	NO	NO	NO
There are energy intensive industries in the district	NO	YES	YES

Both areas do not have access to district heating or cooling networks. There are industry points close to PED 2 although it does not appear in sEEnergies platform. There is no geothermal potential in the area.

Using PVgis the PV potential is obtained for the optimal tilt and azimut for a location in the middle of the PED areas. Both areas have a potential of ~1500 kWh/year/kWpeak installed is obtained, with a tilt of 36º and azimut of 5.

In Wind Atlas, the wind potential is obtained for a location in the middle of the PED areas, and at a height of 10 meters (to allow mini wind turbines) and 50 meters (in sea). A density of ~50 W/m2 (2.94 m/s) is found in both areas at a height of 10 m, and a density of 490 W/m2 in the sea with a velocity of 7.1 m/s a height of 50 m.

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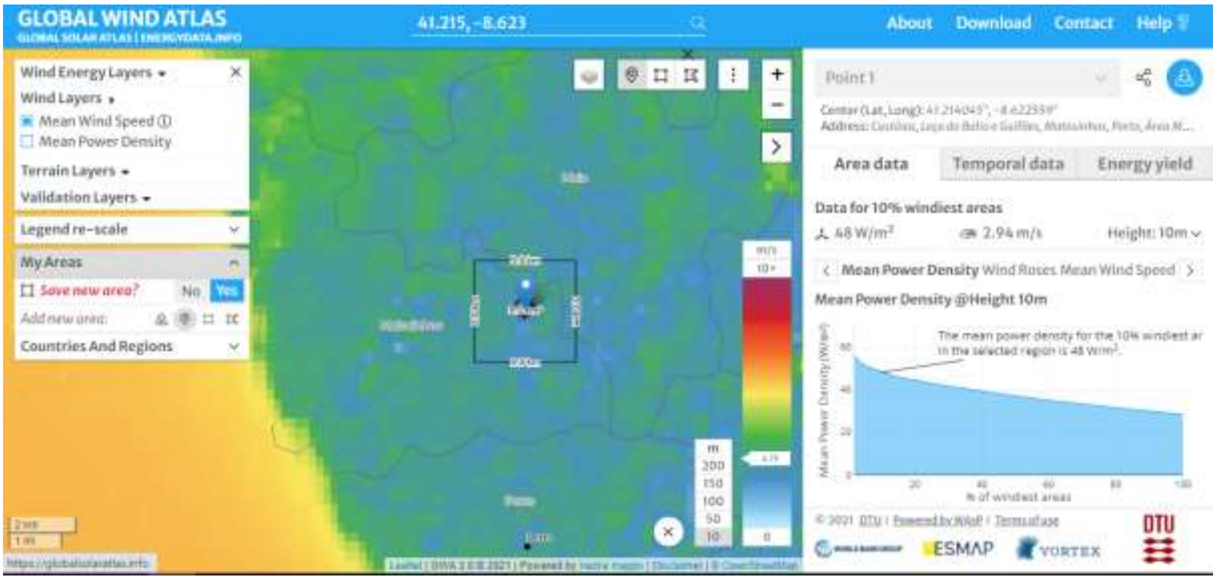

Figure 84: Wind potential at height 10 m

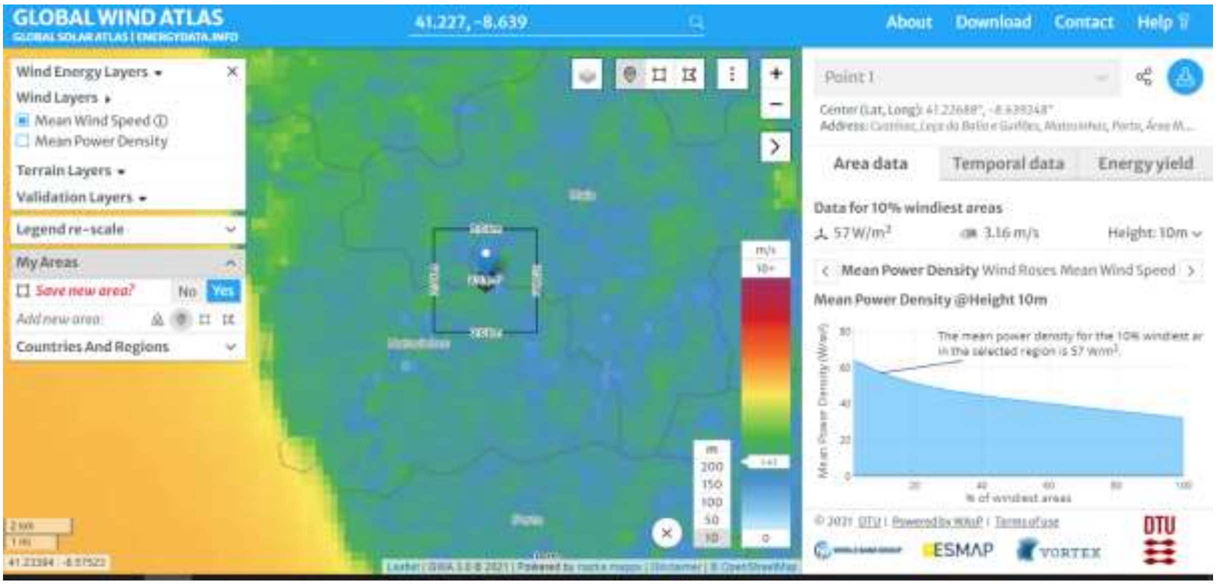

Figure 85: Wind potential at height 10 m

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

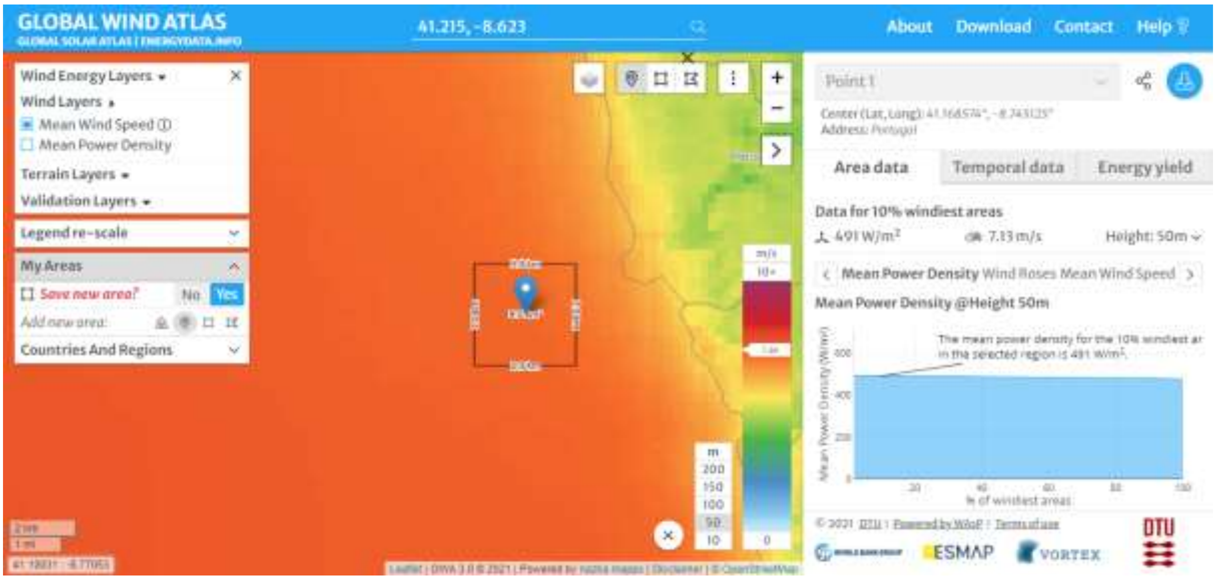

Figure 86: Wind potential at a height of 50 m in the sea

Lastly, according to ChargeMap, there is one charging point (fast one with a power of 30-500 kW) in the Business centre.

City wants to increase more charging points for e-vehicles. Use the river channel for e-bikes, e-scooters

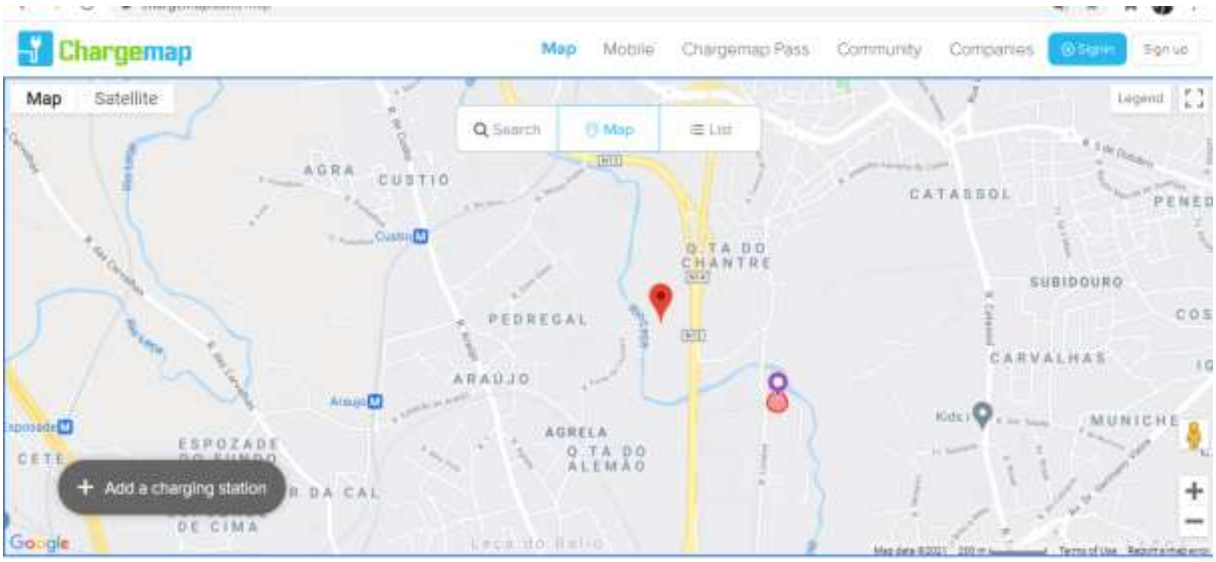

Figure 87: Charging points in PED areas

All of these characteristics, as well as spatial, social and economic characteristics are weighted using the resulting scores from STEP 2.1 in next step.

STEP 1.4

Considering spatial, technological, social and economic factors, a composite indicator that ease the PED area prioritization is obtained for each of the areas. The process is validated by the city. PED area 1 obtained a final score of 0.35, whereas PED area 2 obtained a final score of 0.54. Nevertheless, the city decides to have a PED that combines both areas (PED 3) which leads to a score of 0.64.

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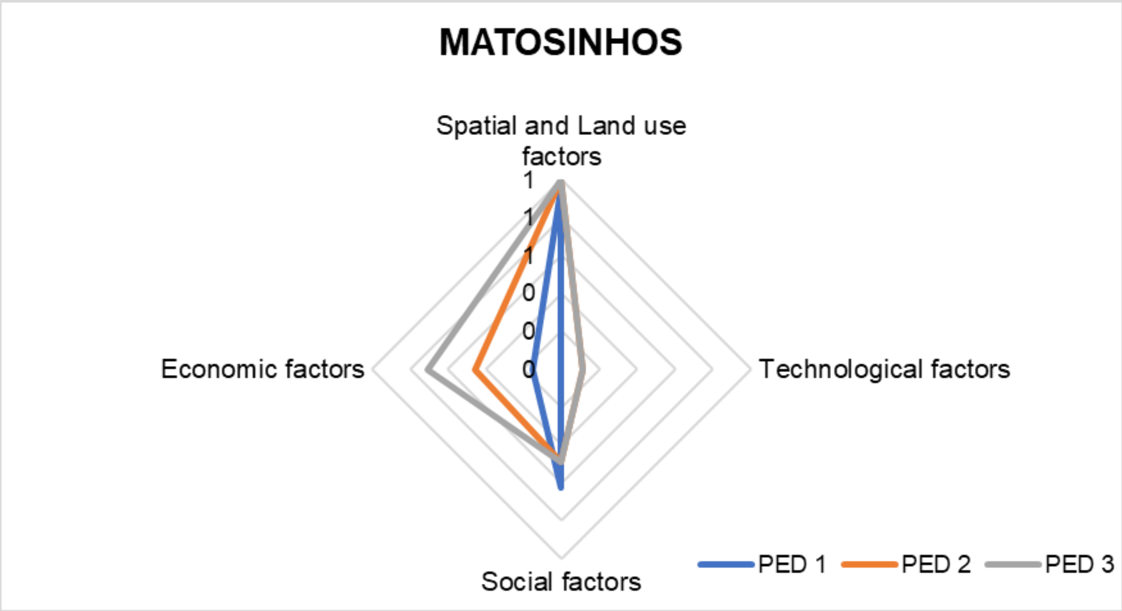

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8.3. STEP 3: Detailed design of PED

STEP 3.1: Baseline calculation

A 3D model using CYPETHERM have been used to model Lionesa and each Custió building. Floor plans, envelope performance characteristics, schedules and bills have been used to create and calibrate the models.

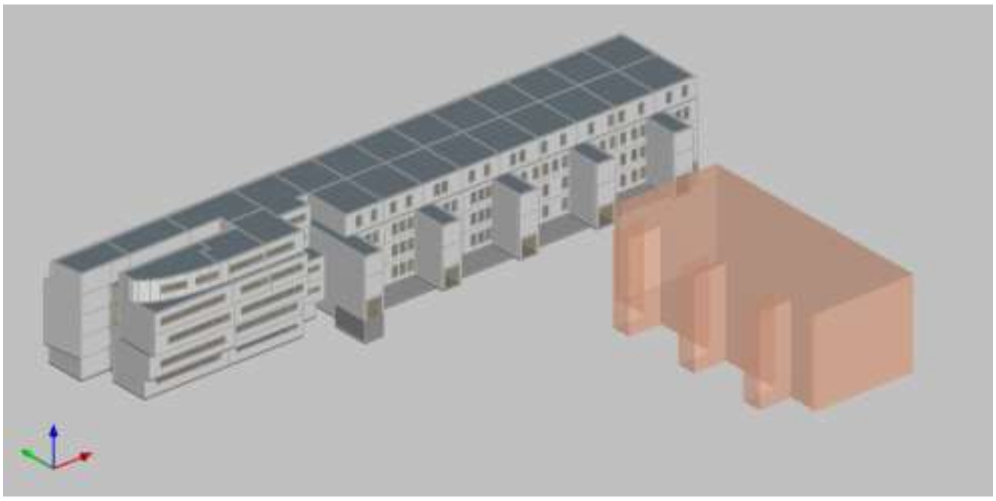

Figure 88 PED 1: Custió residential building 4

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 864374.

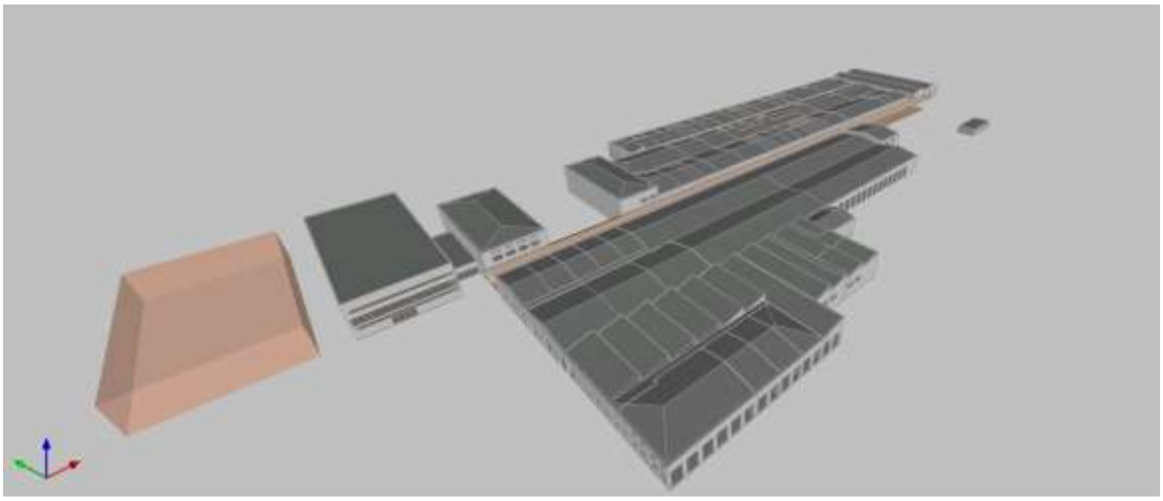

Figure 89 PED 2: Lionesa Business Hub

Figure 90 shows an overview of the electricity demand of the Lionesa business Hub plotted against the measured monthly bill data and disaggregated into electrical needs, and electrical consumption of space heating and cooling generation units.

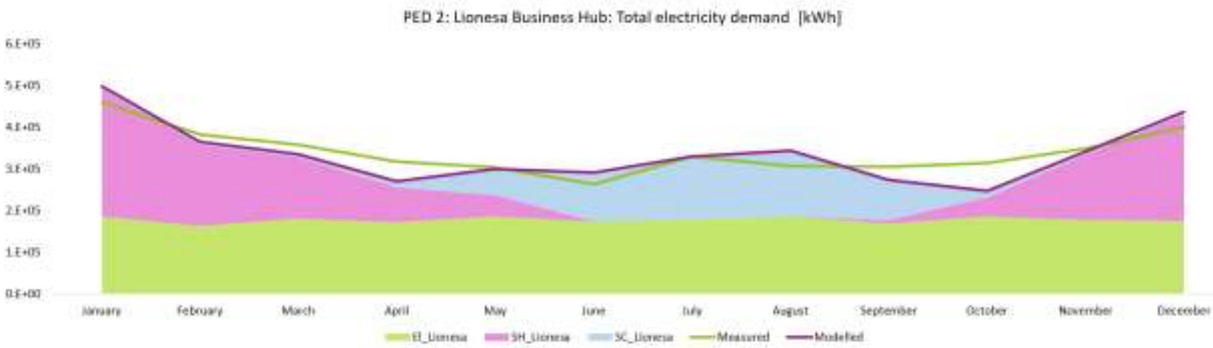

Figure 90 Calibration process Matosinhos

As a result, the current specific energy needs (baseline) of the buildings are the following:

kWh/m2	SH	SC	DHW	ELECT
Custió 1	4.09	0.00	25.47	6295.34
Custió 2	4.96	0.00	24.92	6421.94
Custió 3	4.63	0.00	31.37	6099.16
Custió 4	10.55	0.00	73.69	26442.50
Custió 5	2.78	0.07	0.07	11078.86
Custió 6	5.71	0.00	26.70	6472.69
PED 1 All Custió	**5.43**	**0.02**	**30.08**	**11.15**
PED 2 Lionesa	**80.29**	**58.21**	**0.00**	**75709.02**

Figure 91 Summary of Baseline results

Calculating the PED energy balance, results in:

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	GRID delivered [GWh]	Gas delivered [GWh]	PEBnren [GWh/year]	PEBnren [kWh/m2]	Emissions [tons of CO2]	Total costs [k€]	Monthly costs [€/month]
PED 1 All Custió	0.18	0.41	0.86	0.08	90.06	35.28	2940.22
PED 2 Llonesa	4.03	0.00	10.07	0.36	144.95	684.48	57040.28
Both	4.20	0.41	10.92	0.44	235.01	719.77	59980.50

Figure 92. District Balance

STEP 3.2: Selection of potential solutions> define scenarios

The city of Matosinhos selected several potential solutions to define the scenarios at district level. Evaluating as well the co-benefits that could be obtained for each solution.

IMPACTS / CO-BENEFITS:		SCENARIO 1					
		Technology 1	Technology 2	Technology 3	Technology 4	Technology 5	non-technical
		Thermal insulation/window renovation	Photovoltaics	Heat Pumps	Solar Thermal	Thermal Storage	energy community
Climate resilience	Climate adaptation	High	High	Medium	Medium	Medium	none
	Climate mitigation	High	High	Medium	Medium	Medium	none
Local economy, entrepreneurship and innovation	Local economy enhancement	Medium	Medium	Low	Medium	Medium	High
	Financial savings for citizens	High	High	High	High	High	High
	Increase employment rate and jobs	Medium	Low	Low	Low	Low	High
	Decrease future maintenance costs	Medium	Medium	Medium	Low	Low	High
Social inclusion and education	Social cohesion (gender, minority groups)	none	none	none	none	none	High
	Enhance citizen participation, connectivity and community	none	Medium	none	none	Low	High
	Improve access to information, Social capacity building	none	none	none	none	Low	High
	Raise awareness/ behavioural change	Medium	none	Low	Low	Medium	High
Health and well-being	Improve air quality	none	Medium	Low	Low	Low	High
	Reduce noise pollution	none	Medium	none	none	none	High
	Reduce hot stops/ urban islands in the city	none	none	none	none	none	none
	Enhance attractiveness of the city	High	Medium	none	Medium	Medium	none
	Promote healthier and more attractive lifestyles	none	none	none	none	none	Medium
Biodiversity	Reduce ecological footprint	none	none	Low	Low	none	none
	Greater biodiversity	none	none	none	none	none	none
Resource management and efficiency *(circular economy)*	Waste efficiency	none	none	none	none	none	none
	Water efficiency	none	none	Low	none	Low	none
	Food efficiency	none	none	none	none	none	none
	Sustainable land use	none	none	none	none	none	none

Figure 93 Overview of co-benefits for scenario 1 Matosinhos

The following scenarios evaluate the combination of deep renovation of the buildings and PV on buildings envelopes (on façades for PED 1 and over roofs for PED 2) and parking lots, solar thermal, air-water heat pumps for PED 1 with short-term thermal storage, e-chargers for PED 2 parking area and hydro off-site. The possible creation of an energy community is also considered.

STEP 3.3: Scenarios evaluation and prioritization

The following scenarios will be studied in detail over the reduced demand due to renovation works:

1. Only rooftop PV for PED 2 and BIPV (east façade) for PED1 + AWHPs for PED1 (no batteries, exports).
2. Rooftop PV, BIPV and PV installed on solar canopies for the selected parking areas + AWHPs for PED 1 (no batteries, exports). The total installed capacity is in Table 26.
3. Same as scenario 2 including Hydro off-site generation with a PaT (Pump as a Turbine) installed after a water treatment plant located nearby (Figure 97), with a total installed capacity of 9kW.
4. Same as scenario 3 including the expected demand and income from the installation of 6 eV charging points for electric cars, which an installed capacity of 22kW in the

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PED2 parking area, following the characteristics of the current installed points, identified on Figure 87.

PED Building's renovation:

The buildings' renovation has been estimated through a CYPETHERM model. The measures included window replacement for both PED areas, plus an improvement of PED 2 insulation properties adding *ETICS* (External Thermal Insulation Composite System) to the buildings envelope [10cm of XPS for roofs and 10cm of EPS for façades].

Figure 94 shows the overall results of the renovation; SH needs have been reduced while SC needs have increased (DHW and electrical needs remain the same). For both PED areas there are non-renewable primary energy savings (PEnren) of a 18.69%.

ETICS have not been applied to PED 1 due to small SH needs, this additional measure would reduce PEnren to a 19.34% but with a higher investment.

kWh/m2	Renovated SH	Renovated SC	% SH	% SC
PED 1 All Custió	2.92	0.03	46%	-106%
PED 2 Lionesa	75.71	76.26	6%	-31%
Both	78.63	76.30	8.27%	-31.02%

% reduction	GRID delivered	Gas delivered	PEnren	Emissions	Costs
PED 1 All Custió	16%	0%	8%	1%	13%
PED 2 Lionesa	20%	0%	20%	20%	20%
Both	19.43%	0.00%	18.69%	12.51%	19.29%

Figure 94 Summary of the Renovated results for Matosinhos

PV potential areas

In PED 1 area Custió there are no much available roof space (due to the presence of chimneys), instead BIPV "*Building Integrated PV*" over the east façade of Custió 4 will be studied alongside a nearby parking area.

Figure 95. PV potential area in PED1 for Matosinhos

For PED 2 area it includes the solar canopies over the parking area [yellow], and the rooftop PV as indicated in the Table 26.

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Figure 96. PV potential area in PED 2 for Matosinhos

Table 26 PV installed capacity in Matosinhos

Zone	Type	Orientation	Slope [deg]	Area [m2]	PV area [m2]	Installed capacity [kW]
PED 1	BIPV	East	90º	151.2	144.9	8.4
PED 1	Parking	South	0º	1440	1008	126
PED 2	Parking	South	0º	12115	8480.5	1060.1
PED 2	Rooftop	South	12º	7750	5425	678.1
PED 2	Rooftop	East	12º	5470	3829	478.6
PED 2	Rooftop	West	12º	5530	3871	483.9

Hydro potential

For estimating the hydro off-site potential, a research on available points with known water flow data has been performed; for this preliminary analysis the water treatment plant of Ermesinde has been selected for being close to the PED 2 area. This plant in 2016 registered a medium annual flow of 0.127 m^3/s, so based on the Global Hydro turbine calculator we can assume an installed capacity of 9 kW.

Figure 97. Hydro PaT capacity for Matosinhos

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The results obtained are the following for the four defined scenarios:

Baseline

10.9 GWh/yr (not PED) | 60 k€/month[a] | 235 tons CO_2 | 4.2 GWh from GRID | 0.41 GWh from GAS

Variables	1.Only rooftop PV + HPs + Renovation (no batt.)	2.PV[b] + HPs + Renovation (no batt.)	3. PV[b] + HPs + Hydro + Reno. (no batt)	3. PV[b] + HPs + Hydro + eV+ Reno. (no batt)
Economic savings	29.6 k€/month	58.0 k€/month	58.6 k€/month red. (eV services)[b]	59.8 k€/month red. (eV services)[b]
Environmental impact	-160.2 tons CO_2 reduction	-237.7 tons CO_2 reduction	-239.3 tons CO_2 reduction	-239.9 tons CO_2 reduction
Local production	2.18 GWh/yr production of PV	4.33 GWh/yr production of PV	4.38 GWh/yr prod. PV + Hydro	4.38 GWh/yr prod. PV+Hydro
Primary energy balance	5.19 MWh/yr (no PED)	-0.19 MWh/yr (PED)	-0.30 MWh/yr (PED)	-0.14 MWh/yr (PED)
Investment	7.01 M€, payback in ~19.7 years	8.85 M€, payback in ~ 12.7 years	8.85 M€, payback in ~ 12.6 years	8.89 M€, payback in ~ 12.4 years

As main conclusions, it can be seen that even though renovation works can be really expensive, are in fact a key instrument for achieving a PED. Onsite PV alone cannot achieve a PED either; there is a need for a greater area as a solar plant, in this case we had very large parking areas to increase PV installed capacity as we can see in the comparison between scenarios 1 and 2.

For the third scenario we can see that the impact of the Hydro turbine is small, due to its small installed capacity (9kW), other solutions could be studied to be also implemented.

In the last scenario we can appreciate that the impact of the eV charging stations has greater economic impact than in emissions or energy, is the scenario with greater investment and also the ones with greater savings and smaller payback thanks to the expected income.

Some considerations have been taken for this analysis

1. It is assumed that residential buildings receive 40% of national funds (Next generation) for building renovation works.
2. In this first analysis, solar thermal has not been included, there are obstacles (chimneys) on the PED 1 roof area, so the characterisation of the potential area will require a more detailed analysis.
3. Storage has not been considered yet due to the deadline to present the results. Further iterations of the scenarios could be made, once the feedback of the stakeholders is collected (on-going process).
4. Other options could be combining the above-mentioned solutions with: reduction of heat and electricity consumption of the buildings (through demand response, smarter buildings, adjust thermostats to lower temperatures in winter, behavioural change, etc.).

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STEP 3.4: Financing options

In the selected area for the Positive Energy District in Matosinhos, and following the instruments indicated in Table 14, the most feasible option would be through the use of European, National and Regional funds. It is admitted that the project could be partially financed by the grant and the remaining by municipal funds. Depending on the selected area, the main investor can be public (Municipality of Matosinhos) or private. In this context, it is worth mentioning that currently, there are several active incentives regarding energy efficiency in buildings and promotion of renewable energy projects (e.g. Fundo Ambiental).

There is some background allowing to move forward with the possibility of also using Energy Performance Contracts through ESCOs. This model is frequently used in the Portuguese context for implementing PV installations, in particular in the private sector. There are also some experiences regarding the use of Energy Community business model, namely through the use of cooperatives, but limited in terms of installations. The regulatory framework and policy context in Portugal can make the Investment Platform business model challenging to implement.

Conclusions

Thanks to this process Matosinhos was able to gather some insights for designing a tendering procedure that considers the necessary features to achieve and implement a PED in their area. For instance:

- There is a favourable environment at national level but also in the city to deploy PEDs, and a lot of political commitment
- The mild temperatures allow to have a baseline with lower energy needs than other cases. Nevertheless, the involvement of “virtual boundaries” are needed to become PED (by investing in a solar park).
- The energy community’s regulation seems promising and it will allow the deployment of the PED
- The involvement of a variety of stakeholders (residential, the municipal water mill, and the business hub) will allow to share the risks, investments and achieve a more ambitious PED concept.

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9. PED design in Riga

In this section, the steps defined in section 3.2 are applied to the city of Riga. Starting with (Section 9.1) the city context and identifying the strengths, weaknesses, opportunities and threats of Positive Energy Districts; followed by the prioritization of one of the preselected areas in proposal stage (Section 9.2) and finalising with a PED detailed design for the selected are in section 9.3. The output is a set of recommendations for stakeholders to deploy PEDs in that area.

9.1. STEP 1: City's environment for PED implementation

Context

Riga is the capital of Latvia and the largest city in the Baltic States with a population of 614,600 residents (2022). The city is expanded in 304 km^2. The population in Riga agglomeration reaches 1.2 million while the population of Latvia accounts for 1.88 million (2022), which means a **density of 3,947 people per km^2**. With its central geographical position and concentration of population, Riga has always been the **economic, infrastructural and transport hub of the Northern Europe**.

Regarding the climate, Riga has a **humid continental climate**, with average annual air temperature of 6.9°C. The year's warmest month is July with average temperature 17.0°C. The coldest month is February with average temperature 4.7°C. So far, the highest observed temperature in Riga was 32.8°C, the lowest -34.4°C. The average annual precipitation in Riga is 569 mm, about 33% higher than evaporation. The sun shines on average 1760 hours a year, which is about half of the possible sunshine duration when the sky is clear.

Over 60% of the **energy resources consumed** in the city are used as heat energy. In Riga, 85% of inhabitants live in **multi-apartment buildings**. Households use 36% of the energy in Riga, being the biggest energy consumer in the city.

Riga Technical University is undertaking a research project, modelling the **Positive Energy Block (PEB)** in a valuable environment of Historical Centre of Riga, the UNESCO heritage site. The research is exploring possibilities of **waste heat regeneration and on-site renewable energy technologies**. The goal of the research project is to assess different scenarios to reach PEB in densely populated historical urban environment under the specific baseline and urban planning preconditions in Riga city. Aim is to reduce the impact on climate change and regenerate the urban environment in a way that fully ensures the compatibility of energy supply and storage technologies with the traditional historical environment of Riga city.

Conditions to allow a Positive Energy Balance

The regulation on **energy certificates** will have strict requirements from 2021 onwards, **nZEB** class will be mandatory: 40kWh/m^2 for residential, and 45 kWh/m^2 for non-residential buildings.

Citizens or energy communities are not very well regulated in Riga, it's not a mainstream approach, but an experimental one, with certain limitations. There is a political breaking group for achieving **climate neutrality**, so that it climate neutrality is at the top political priorities. Riga is developing a roadmap to promote development of **energy communities** in the city. This includes the legal review and identification of the legislation to be amended and/or introduced. This law on energy communities will also regulate the **peer-to-peer exchange**.

Regarding **Hydrogen**, the city is working on a Hydrogen programme, committed with EU. 95% of H_2 is not green, and experiences for the city have not been good ones (experimental H_2-

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buses and refuelling stations). There is an overall legislation in Latvia about the possibility of mixtures to be injected in the gas transmission and distribution network. There are gas quality requirements in place defining the characteristics of the natural gas and overall ruling to deploy an injection site for the gas network, thus the allowed concentration of hydrogen at an injection level is set 0.1%.

For the **District Heating regulation**, target for Latvia **RES share in DH of 58%** (2030). By 2020 the city has already **DHN with 50% RES**, however, wood chips often come from remote locations and therefore are not considered as sustainable enough alternative.

District Heating generation in Latvia depends a lot on CHP (73%). Fuel wood and natural gas are mainly used for boiler house heat production. In 2018, 61.2% of the heat produced was produced in boiler houses using firewood, but 37.6% of the heat produced using natural gas. In Latvia, natural gas is used as the main fuel for the production of electricity and heat in cogeneration plants, although there are initiatives and plans to move towards RES or other alternatives to gas. *(In conditions for PED implementation, new innovative projects related to DHN are mentioned).*

The DHN is being modernised progressively during the last years. However, Latvia has very harsh winters therefore the (in/out) temperature in DHN is 118ºC/65 ºC, and this, despite all the modernisation works of DHN undertaken, means considerable heat losses.

One of the main priorities for the DHN operator is **affordable heating**. Riga used to have one of the lowest tariffs in Latvia, however, as the consequence of global energy crisis in 2022 the tariffs increased fivefold in Riga – from EUR 44.10 per MWh in 2021 to EUR 183.86 per MWh in the heating season of 2022-2023. In the beginning of the heating season 2023-2024 tariff in Riga is EUR 91.26 per MWh.

There is **only one DHN operator in Riga** – municipal JSC “Rīgas siltums” (RS), engaged in production, distribution and sale of thermal energy. RS also ensures technical maintenance of inner heat supply systems in buildings. A major part of thermal energy, around 70% of the total amount, is purchased from large cogeneration plants owned by the State JSC “Latvenergo”. Other small-scale producers supply around 0.05% of thermal energy. The rest amount of thermal energy is produced at the RS plants: five major district heating plants and several smaller boiler houses. RS manages and distributes 76% of the thermal energy in the city of Riga. 70% of the thermal energy are used for heating of residential houses and for preparation of domestic hot water (DHW) and 30% - for heating and DHW of public and commercial buildings. Total length of city's heating network is about 825 km where 698 km are owned by the city (RS) and 127 – by private owners.

Conditions to allow Renewable Energy Production

For the installation of some specific technology, it is possible only up to 11.1kW without any specific permission; larger projects need to obtain permission. Further, since 01.04.2020 **customers of RES production** (solar panels, etc.) are not required to pay the variable part of Mandatory Procurement Component (MPC) for electricity generated, fed into the grid and received back.

For electricity regulation, there are **limits to export energy** to the power grid for the citizens, which do not motivate or incentive them. Currently, the review is undertaken by the government and further improvements in the electricity regulatory framework can be expected soon.

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Regarding **geothermal energy**, in the entire administrative territory of Riga geothermal potential is low: 0 - 0.25 GJ/m^2

Riga has a success story about **biogas**, used for heating purposes in municipal landfill "Getliņi". "Getliņi" ecological landfill is one of the largest and most modern producers of green energy in Latvia. The source of energy is the landfill gas – natural gas which mainly consists of methane. It is formed in covered waste deposits – biodegradation cells, in which unrecyclable waste is stored and which have anaerobic environment, i.e., an environment protected from exposure to air or rainwater.

Conditions to allow Efficient buildings/ Building stock demand

Around 6,000 multi-apartment buildings were built during the post-war period with poor insulation, currently representing an aging urban infrastructure that needs to be managed in an intelligent way. However, the **energy renovation process** is slow, and the main reasons are the lack of awareness and unattractive financial instruments. Comparatively low energy prices are slowing down ESCO activities and private investments due to a long payback period (12-15 years on average).

A study (REA, 2017) has identified the potential for energy savings from energy renovation of the soviet era multi-apartment buildings up to 50%. Recently Riga adopted ambitious **renovation plans** – to renovate 50% of the outworn building stock (3,000 buildings) by 2030. However, the financing of such a massive renovation plan is a challenge.

Regarding the **CO_2 emissions**, the amount of calculated total emissions in 2020 has **decreased** by 27% compared to 2010. The fastest reduction of emissions compared to 2010 is observed from the final energy consumption (44%) in the individual and district heating system. Emissions from electricity consumption have decreased by 16%, while estimated emissions from road transport have increased by around 8% over this period.

Most of the total calculated CO_2 emissions in Riga in 2020 are accounted for: the road transport (46.5%), heat consumption in the district heating system (22.3%) and individual/de-centralised heating systems (17.3%) and electricity consumption (13.8%).

Social housing regulation is a big topic in Riga. The municipality has built quite a lot of buildings for social housing (big municipal priority for the last 10 years). Currently Riga City Municipality has a stock of 13,000 apartments/residential premises in Riga offered to city residents as social housing. Of these, 17 are social multi-apartment houses with about 1,500 apartments.

Regarding the **funding for energy saving renovations**, for 3 years Riga municipality had renovation programme for multi-apartment residential buildings. The programme provided support for energy retrofitting, including 50% co-financing for energy retrofitting, 80% co-financing for energy audits and free consultation. During 2018-2020, the municipality provided € 2.5 mln in co-financing and approved 154 applications. However, not all of these were deep renovation projects. The main challenge was to convince owners of apartments to go into deep renovation of the multi-apartment building in one single step due to a lack of their co-financing. They were more interested in a step-by-step approach. To respond to this challenge, the municipality decided not to limit the number of grants per each multi-apartment building, so it was possible to receive funding for separate stages of energy-efficient renovation works.

With the aim to accelerate energy renovation of multi-apartment residential buildings in the administrative territory of Riga city, currently the municipality is developing a large-scale

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rotation fund - “Riga Energy Efficiency Fund” (REEF). Development of the REEF concept and business model includes the establishment of legal framework and the governance structure of the fund, definition of the financing mechanisms including innovative funding schemes for multi-apartment residential building renovation based on investment in Energy Efficiency (EE), Renewable Energy Sources (RES) and low-cost EE measures. REEF concept has been developed in close collaboration with the key stakeholders, among them: (1) housing maintenance companies and ESCO’s, in order to understand their expectations of the market towards the REEF funding mechanisms and take an active role in the fund-making process; and (2) Riga city residents, house managers and households, in order to raise awareness on the EE measures and their benefits and to improve the EE indicators in their multi-apartment residential buildings.

Conditions to allow Liveability

Riga is already a **green city** with parks and green spaces. Natural and green territories — forests, forest parks, public gardens, watersides, family gardens, and open waters — are among the main spatial structures of Riga.

Modal split in Riga (updated at 2019) is 32% public transport, 52% private cars, 4% cycling and 12% walking. From this, main key facts are that high public transport usage in modal split; there is modern and sustainable public transportation (over 58% of public transport services are provided by electric power driven, hydrogen and other alternative zero emission vehicles); and that comparatively City has low car ownership rate: 381/1000.

Conditions to allow PED implementation

Latvian **National** Energy and Climate Plan 2030 sets the development of **DHN as the National-scale priority**; with complex and economically justified renovation of DH systems by improving energy efficiency, integrating RES solutions and non-emission technologies; an increased number of connections to district heating systems; and streamlined individual heat supply by installing RES and technologies.

Riga is implementing several **innovative projects**, piloting the shift to the 4th Generation District Heating (4GDH) under Latvian climate conditions, by integrating smart thermal grids and innovative, centralised and de-centralised RES solutions into future sustainable energy systems. Since if the temperatures in the DHN are not reduced, climate neutrality will not be possible for the city.

SWOT analysis results

Riga’s inputs are summarized in a SWOT table to identify which internal factors help or harm the PED implementation, as well as which external factors (National, EU level, etc.) creates opportunities and threats to the Riga context.

What can be conclude is:

- New buildings (from 2021) must be NZEB. Heat is the main energy carrier consumed and the DHN is committed to being decarbonised (already 50% comes from RES). Latvia has very harsh winters therefore the (in/out) temperature in DHN is 118ºC/65 ºC, and this, despite all the modernisation works of DHN undertaken, means considerable heat losses.
- Citizens or energy communities are not well regulated. But Riga is part of the national stakeholder group to change that.

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- There are some regulatory limitations in terms of individual self-consumption, especially in terms of maximum capacity to be installed of PV. No good experiences with hydrogen, but there are with biogas. Other alternatives are not financially attractive and no access to funds.
- Energy renovation is slow, but there have been programmes to provide co-financing. However, not all of these were deep renovation projects.
- Riga is already a green city with nice parks and green spaces. The city has low car ownership rate, and the public fleet is modern and sustainable.
- Riga is part of many pilots, collecting experiences and lessons learnt.

	HELPFUL	HARMFUL
INTERNAL FACTORS (City context)	STRENGHTS	WEAKNESSES
	High city density	Cold climate: 60% of energy resources consumed in the city are used as heat energy
	85% of Riga inhabitants live in multi-apartment buildings	36% of energy in Riga is consumed by households
	Research project on Positive Energy Block (PEB) in the Historical Centre of Riga (by the Riga Technical University)	Energy communities are not very well regulated in Riga.
	Climate neutrality is at the top of Riga's political priorities	95% of hydrogen is not green, and Riga has not good experiences with H_2 (in buses and refuelling stations)
	Riga is developing a roadmap to promote energy communities in the city, this will also regulate the peer-to-peer exchange	There is only one DHN operator in Riga (RS)
	The city is working on a Hydrogen programme	Limits to export energy to the power grid for the citizens (which does not encourage them)
	Affordable heating is one of the main priorities for the DHN operator in Riga	Low geothermal energy potential
	Installation of technologies are possible up to 11.1 kW without any permission	Around 6,000 multi-apartments buildings were built during the post-war period with poor insulation
	Customers of RES production are not required to pay the variable part for the electricity generated	Slow energy renovation process (due to lack of awareness and unattractive financial instruments)

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	Success story with biogas used for heating purposes in municipal landfill (one of the largest and most modern producers of green energy in Latvia)	The financing plan of the massive renovation included in the Renovation plan is still a challenge
	Study which identifies to up to 50% the potential for energy savings from energy renovation of soviet era multi-apartment buildings	
	Riga adopted ambitious renovation plans to renovate 50% of the outworn building stock (3,000 buildings) by 2030	
	CO_2 emissions has decreased (27% in 10 years), mainly due to reduction in final energy consumption in the individual and DH system	
	Riga municipality has a lot of buildings for social housing (big priority)	
	Renovation programme in Riga for multi-apartment residential buildings (funding support for energy retrofitting)	
	High use of public transport in Riga (32% from modal split), which is modern and sustainable	
EXTERNAL FACTORS (National, EU level)	OPPORTUNITIES	THREATS
	nZEB class is mandatory from 2021 for all buildings	DH generation in Latvia depends a lot on CHP (73%)
	District Heating regulation establishes a target of 58% of RES share in DH by 2030 (and by 2020 RES share in DH was already 50%)	Although DHN is modernised, harsh Latvian winters makes that despite all the works undertaken, considerable heat losses are still taking place.
	DHN is being modernised progressively during the last years	

Table 27. Riga SWOT analysis results

9.2. STEP 2: Selection of suitable area to design a PED

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

As said in section 3, from the preselected districts in proposal stage, a prioritization exercise is performed.

Riga identified two potential districts for the implementation of their PED, both marked by the Sustainable Development Strategy of Riga as the renovation wave pilot areas:

- Potential district #1: Skanste
- Potential district #2: Purvciems neighbourhood

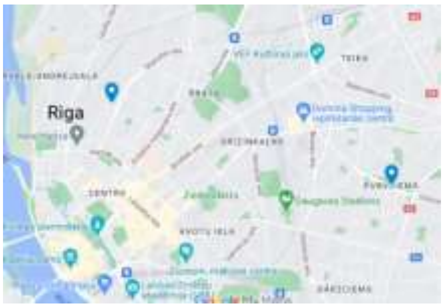

Figure 98: Riga pre-selected PED areas

The process of the methodology explained in *STEP 2: Selection of suitable area to design a PED* is followed to prioritize one of the two for performing the next steps (towards a PED detailed design).

STEP 2.1

To start assessing the districts, first (STEP1.2) the desired objectives or impacts to be achieved by the PED implementation are identified. The impacts are identified and the pairwise comparison is performed, which results in:

		A	B	C	D	E	F	G	H
RER (Renewable Energy Ratio)	A	1.00	5.00	1.00	1.00	5.00	0.20	1.00	5.00
Improve air quality	B	0.20	1.00	1.00	0.20	0.20	0.20	0.20	5.00
Reduce bills	C	1.00	1.00	1.00	5.00	5.00	0.20	1.00	5.00
Achieve zero energy imports	D	1.00	5.00	0.20	1.00	1.00	0.20	0.20	5.00
Positive Energy Balance	E	0.20	5.00	0.20	1.00	1.00	0.20	0.20	1.00
Efficient buildings	F	5.00	5.00	5.00	5.00	5.00	1.00	1.00	5.00
Affordable	G	1.00	5.00	1.00	5.00	5.00	1.00	1.00	5.00
Liveable	H	0.20	0.20	0.20	0.20	1.00	0.20	0.20	1.00
	ADDING VALUE	9.6	27.2	9.6	18.4	23.2	3.2	4.8	32

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Then, the impacts are compared with the city objectives, which results in:

FINAL WEIGHT (considering CITY PRIORITIES)	Ranking	
22%	**2**	RER (Renewable Energy Ratio) factor
9%	**6**	Improve air quality
12%	**3**	Reduce bills
10%	**4**	Achieve zero energy imports
9%	**5**	Positive Energy Balance
24%	**1**	Efficient buildings / Building stock demand
8%	**7**	Affordable
6%	**8**	Liveable

STEP 2.2

Using the City context template, city level details about the renewable energy source (RES) potential are asked in step 1.1 (such as maps, GIS data, etc.). This data potential at city level is used to analyse the RES potential at district level and compare the two areas. For Riga, as there was not sufficient data at city nor district level, a detailed analysis has been performed searching in the different open data platforms (sEEnergies, PVgis, Wind Atlas, geoDH map, etc.). A summary of the results is presented in the following table:

	PED 1	PED 2
High solar energy potential generation in the area (kWh/kW peak – PVgis)	*943*	*943*
High wind energy potential generation (W/m2 at 10 meters height – Wind Atlas)	*48*	*33*
Geothermal energy potential generation	*Low Tº, Needs heat pumps*	*Low Tº, Needs heat pumps*
There is a river/sea close from which could be possible to harvest energy	*River at 1.5 km distance*	*River at 6.3 km* Juglas Lake 5 km
There is an industry/ice rink/waste water plant, etc. from which could be possible to harvest energy (thermal/electric)	Yes, Supermarket, ice rink	yes
There is a forest from which could be possible to harvest forest waste	*Yes, the one in PED 2*	*Yes*
There is Gas grids access	*Yes*	*Yes*
There is a refuelling station near to the district	*Yes*	*No*
There is a centralized heating generation	*Yes*	*Yes*
There is RES production	*No*	*No*
Buildings already have ventilation or an air handling unit	*Generally, No*	*Generally, No*
Buildings already have heat pumps or splits	*No*	*No*
District heating connection	*Yes*	*Yes*
Supply Tº	*118ºC/65ºC*	*118ºC/65ºC*
Number of buildings connected	*>6*	*>18*
substations available on the buildings	*automated individual heating unit (one for each building)*	*old centralised network*

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district network provides cooling	*No*	*No*
There is an electric substation nearby	*Yes*	*Yes*
There is an existing district heating or cooling network nearby	*Yes*	*Yes*
There is Virtual Power Plant in the district	No	No
There is an Energy Community in the district	*No*	*No*
There is a waste management (at level district) or waste water plant nearby	*No*	*No*
There are energy intensive industries in the district	*No*	*No*

Both areas identified have access to a nearby district heating network according to sEEnergies Open Data platform. This has been confirmed by the city. Both seems to be connected already.

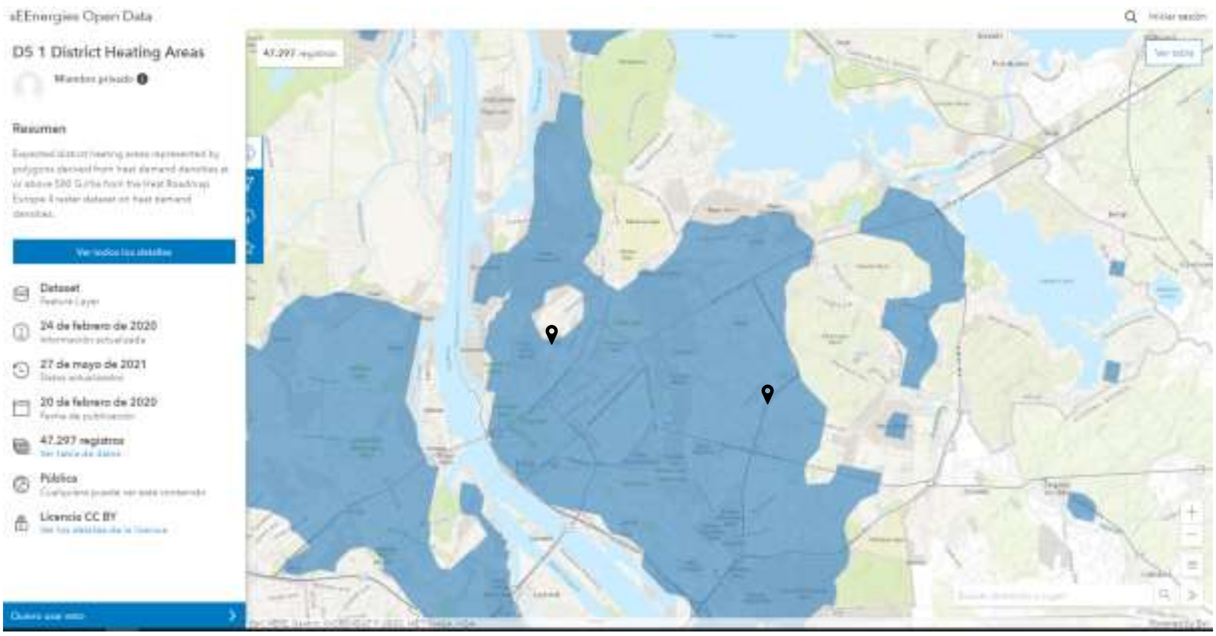

Figure 99: District heating areas in the city of Riga (sEEnergies Open Data platform)[31]. The points indicated in the map are the PED areas

Potential waste heat sources (industry, waste water treatment plants, among others).

No industry points close to the areas have been identified according sEEnergies Open Data platform. Nevertheless, there is one supermarket[32] in PED 1 and an ice rink.

[31] https://s-eenergies-open-data-euf.hub.arcgis.com/datasets/b62b8ad79f0e4ae38f032ad6aadb91a0_0/explore?location=48.133640%2C17.172547%2C12.87

[32] Supermarkets have potential of waste heat, especially those that have refrigerators and freezers. The condenser of the chillers can supply/sell waste heat to the district heating networks

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Figure 100: Potential waste heat sources (industry) (sEEnergies Open Data platform)[33]. The points indicated in the map are the PED areasNevertheless, in the PED area 2 there is one waste water plant (called Slovenský Vodohospodársky podnik petržalka), that according to sEEnergies Open Data platform, it could potentially provide their excess heat. But there is not district heating network close to provide the waste heat.

Figure 101: Potential waste heat source: Waste water plants (sEEnergies Open Data Platform)[34]. The points indicated in the map are the PED areas

[33]https://s-eenergies-open-data-euf.hub.arcgis.com/datasets/a6a1e8e95514413a90bbb2e40515fdb2_0/explore?location=44.450426%2C17.567450%2C4.70

34s-eenergies-open-data-euf.hub.arcgis.com/datasets/2357e5fcfb744d2f8f842cd7171a90a0_0/explore?location=48.135375%2C17.102720%2C11.88

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Geothermal potential

According to geoDH map, there is no geothermal energy potential. But according to Eihmanis, in Riga at around 500 meters depth from the surface 18-19 ºC can be found, and at around 1000 m aquifers can be found with a temperature of ~30ºC (Eihmanis, 2000). Thus, although in principal there is not high geothermal potential, ground-source heat pumps could be interesting if it is economically feasible.

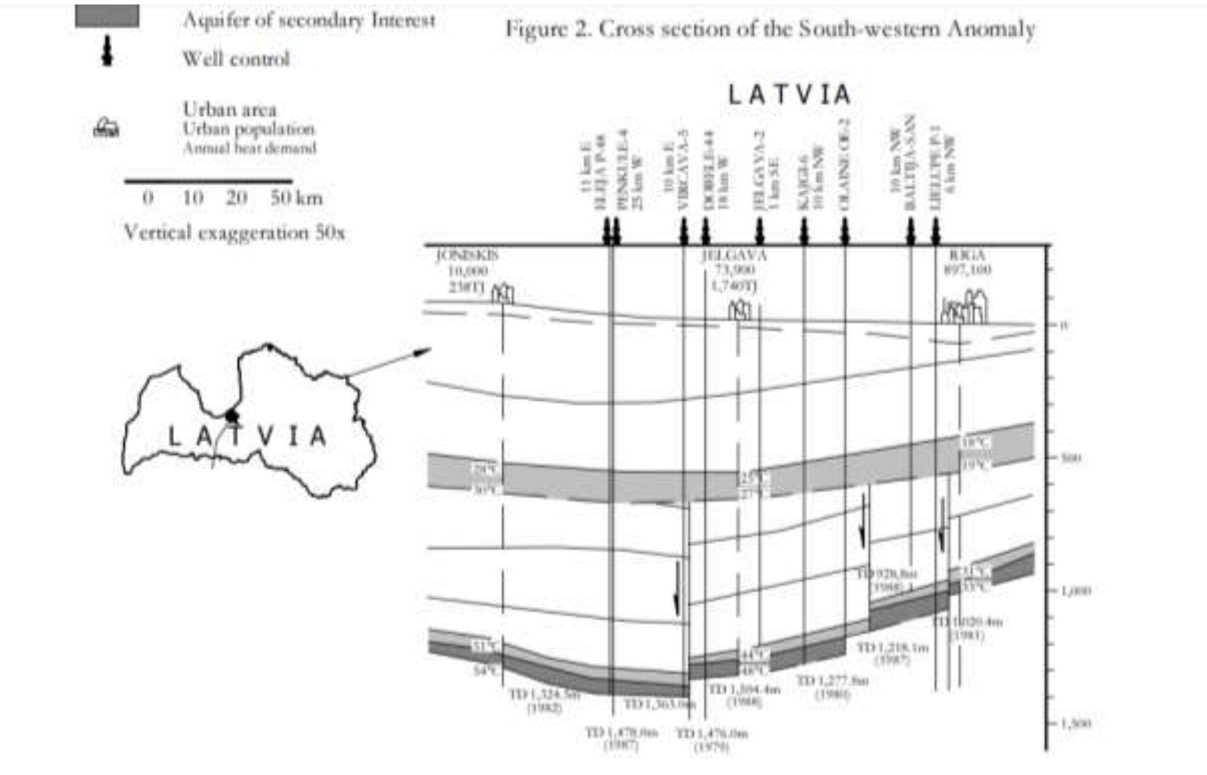

Figure 3. Cross section of the Central Anomaly

Figure 102: Geothermal potential (https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2000/R0236.PDF)

Analysis at district level (PED areas):

Using PVgis the PV potential is obtained for the optimal tilt and azimut for a location in the middle of the PED areas. Both areas have a potential of 943.18 kWh/year/kWpeak installed is obtained, with a tilt of 35º and azimut of 0.

In Wind Atlas, the wind potential is obtained for a location in the middle of the PED areas, and at a height of 10 meters (to allow mini wind turbines). For PED area 1, a potential of 48 W/m^2 is obtained for a height of 10 meters and a wind velocity of 3.26 m/s. For PED area 2 a potential of 33 W/m^2 is obtained for a height of 10 meters and a wind velocity of 3.01 m/s.

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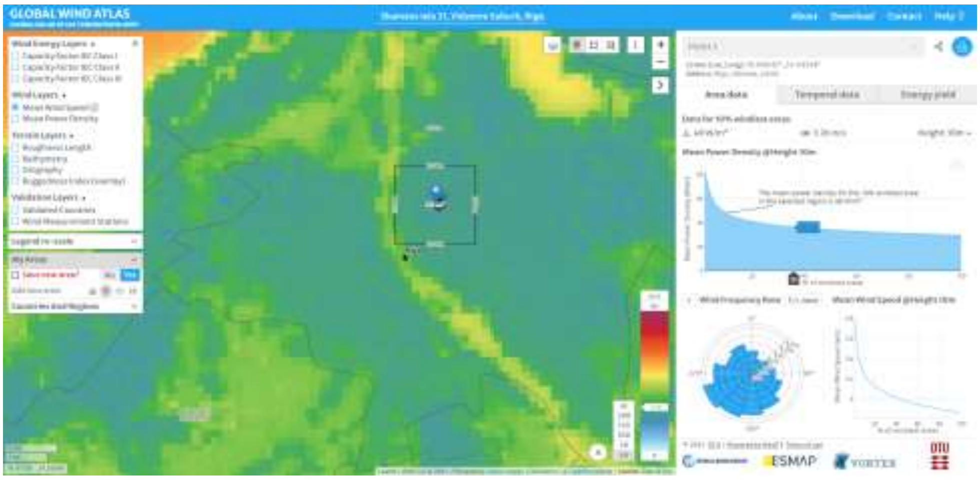

Figure 103: Wind potential in PED area 1

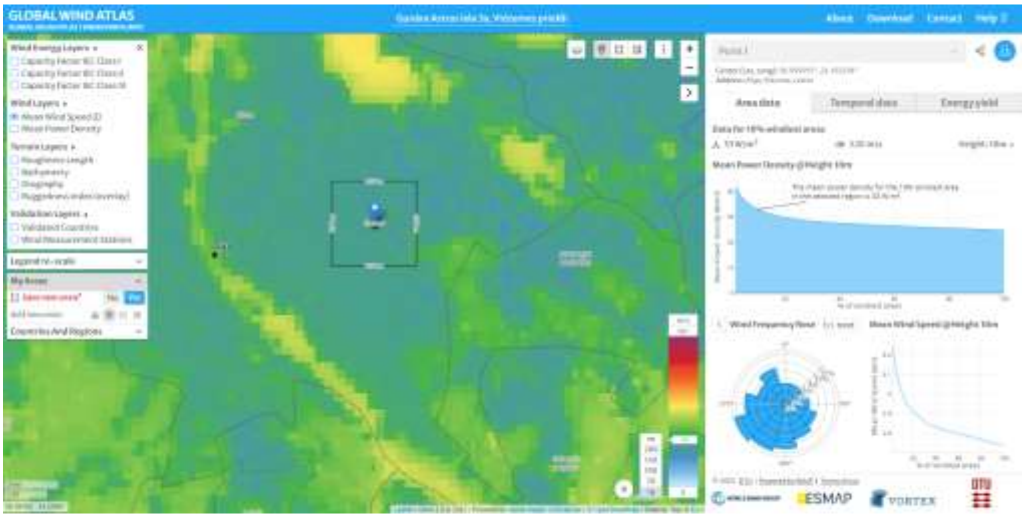

Figure 104: Wind potential in PED area 2

Lastly according to ChargeMap, in PED area 2 there is no recharging points and in PED area 1, there are some but standard ones (with a power no greater than 2-5kW).

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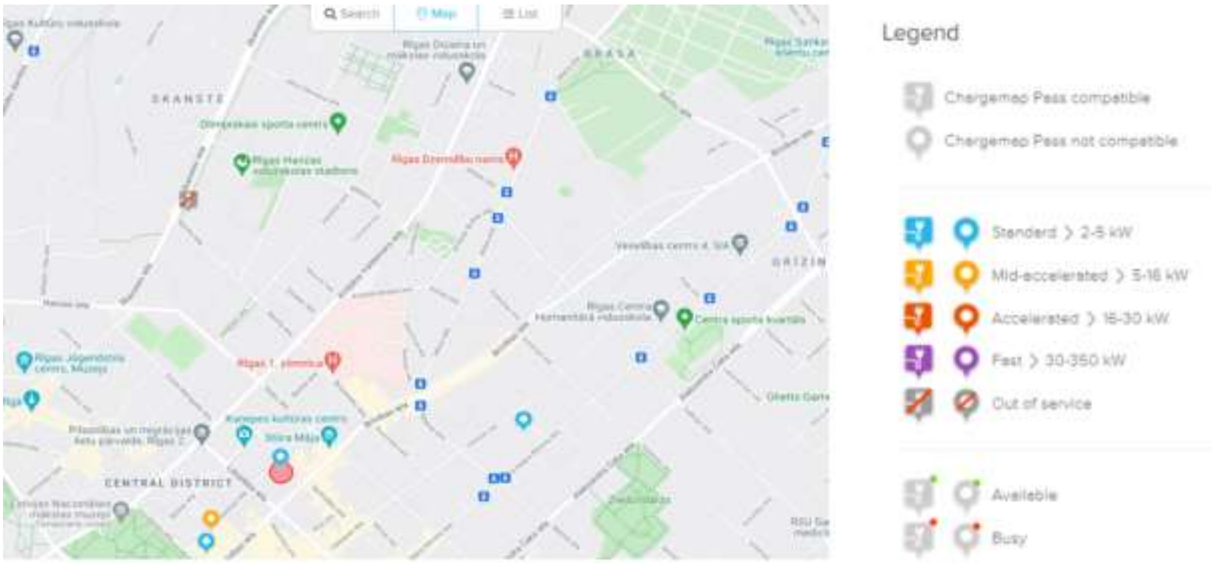

Figure 105: Charging points in PED area 2.

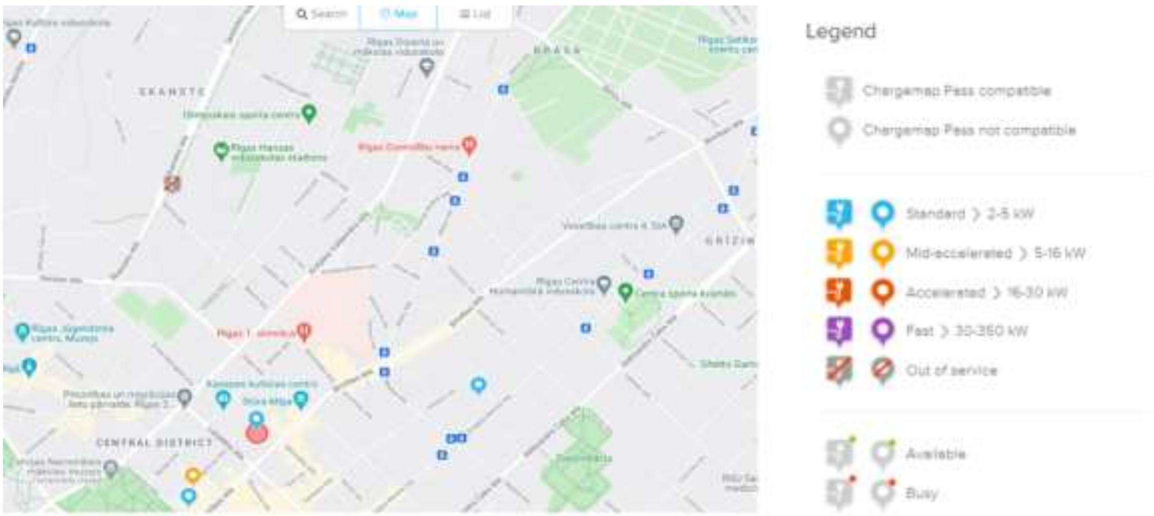

Figure 106: Charging points in PED area 1

All of these characteristics, as well as spatial, social and economic characteristics are weighted using the resulting scores from STEP 2.1 in next step.

STEP 2.3

Considering spatial, technological, social and economic factors, a composite indicator that ease the PED area prioritization is obtained for each of the areas. The process is validated by the city. PED area 1 obtained a final score of about to 0.91 whereas PED area 2 obtained a final score of 0.68. This is due to the fact that, PED 1 has, in principle, higher RES potential compared to that of in PED 2 and it is a new development area preferred by the municipality. Summary of the results are shown in Figure 107.

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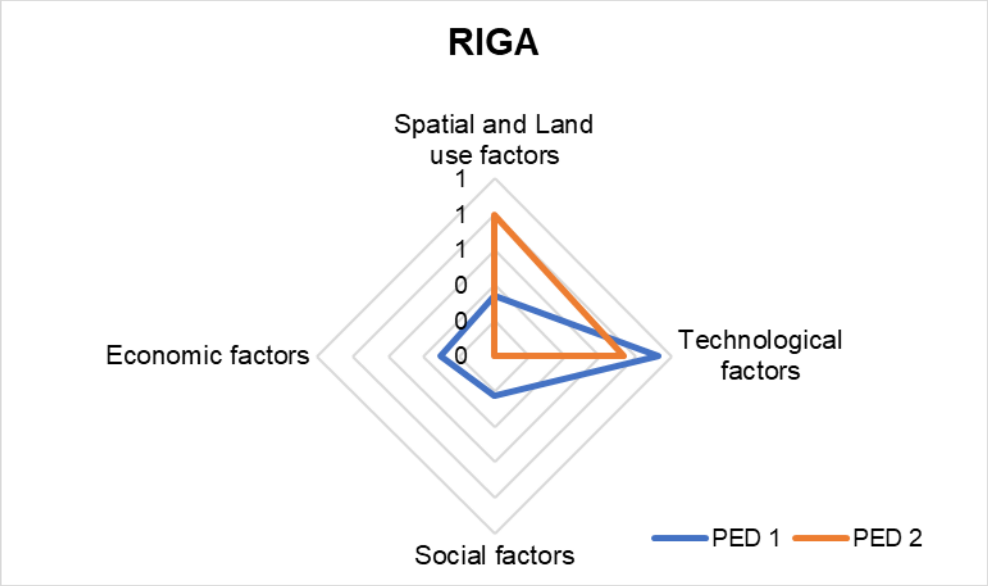

Figure 107: Final selection of PED and summary of scores, and final weights- Riga

9.3. STEP 3: Detailed design of PED

The district selected consists of a mixed-use district with 20 buildings. The type of building comprises: residential multi-storey buildings (accounting for 38% of the total area of the district), kindergarten and private schools (that occupies about to 5% of the total area of the district), offices (18%), parking lots (75) and sport buildings (32%).

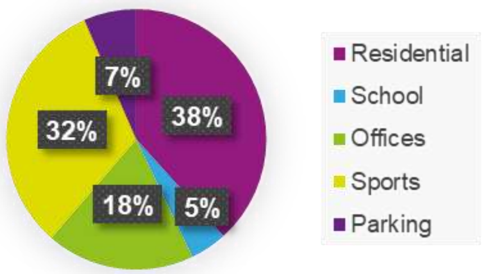

Figure 108 Type of buildings (according to m2) Riga

Figure 109 depicts an overview of the floorplan of the area. As it can be seen in Figure 110 and Figure 111 buildings are in a good shape and have been built recently. B8 and B9 are the biggest consumers, but there is enough potential of becoming big producers as well.

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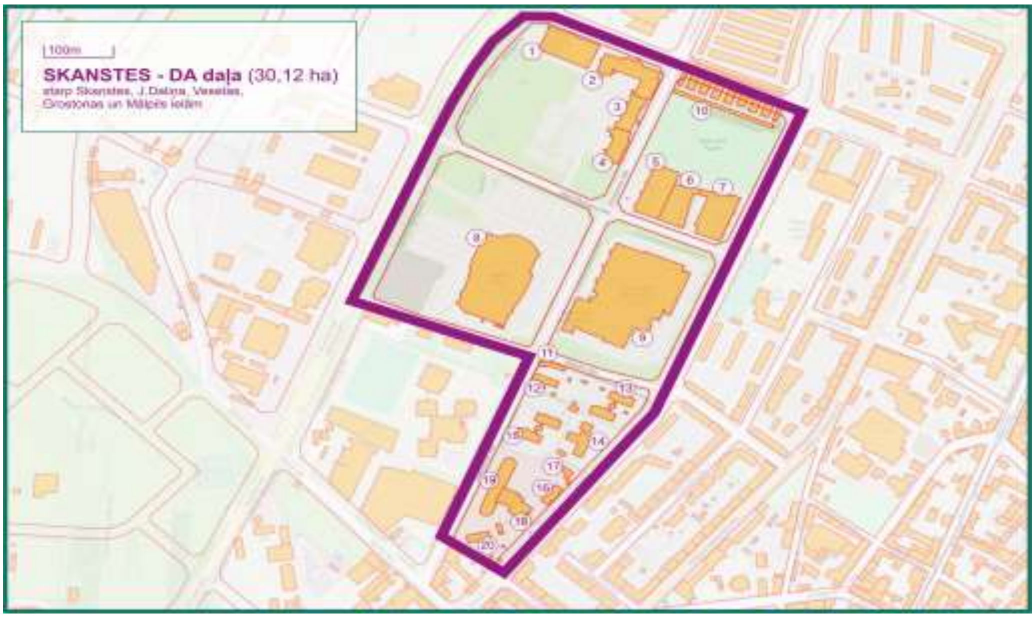

Figure 109 Overview of the area (floorplan – Riga- Skanste)

Figure 110 Biggest consumers and potential big producers

Figure 111 Residential buildings

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STEP 3.1: Baseline calculation

A 3D model using City Energy Analyst has been used to model the area. Floor plans, envelope performance characteristics, schedules and bills have been used to create and calibrate the model.

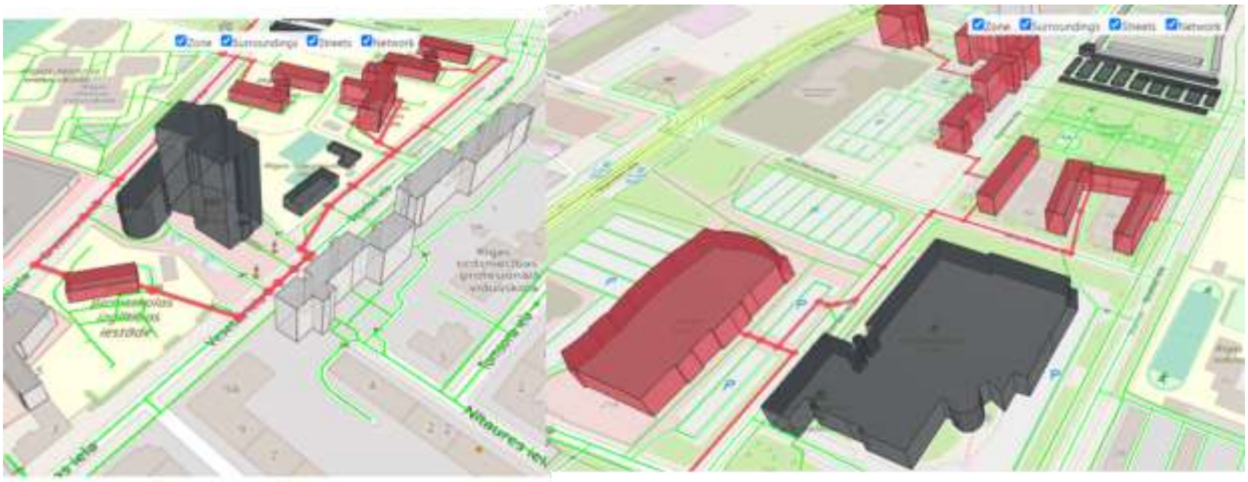

Figure 112 district overview City Energy Analyst (Riga)

Figure 113 shows an overview of the total electricity demand and total gas demand of building 1 plotted against the measured monthly data from the bills. Similar plots are obtained per building. Buildings were considered calibrated when NMBE and CVRMSE reached ASHRAE thresholds, ±5 and ±15, respectively.

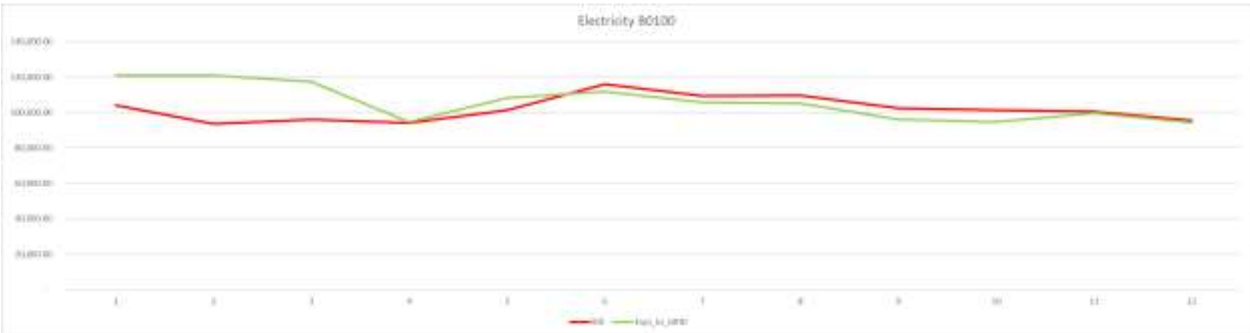

Figure 113 Calibration process Riga B1 – electricity

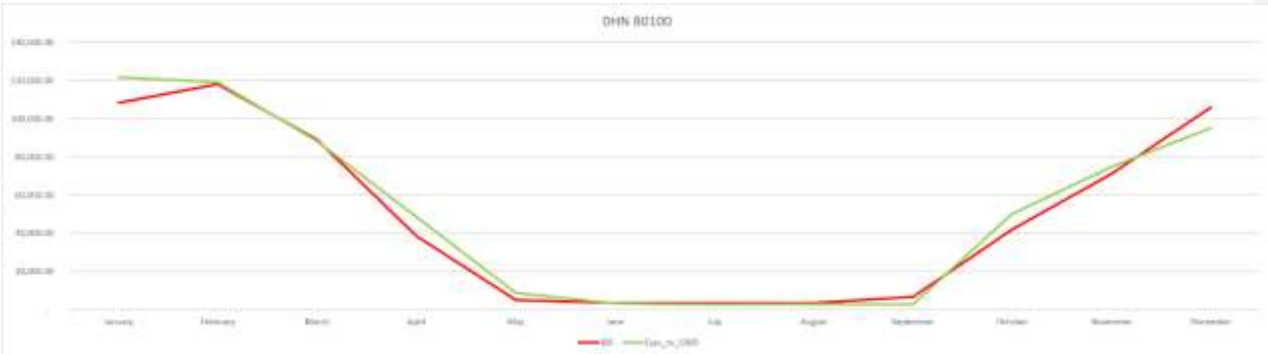

Figure 114 Calibration process Riga B1 – DHN

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Buildings in Skanste are already efficient (A or B class, except schools) or have been renovated recently. Deep renovation is expensive; and might not bring additional benefits for buildings that are already in good shape. Electricity consumption could be reduced through changing to more efficient appliances.

As a result, the current situation (baseline) of the buildings is the following:

Table 28 Summary of Baseline results Riga

kWh/m^2	Thousand m^2	Cooling	Heating	DHW	Lighting	Ventilation+ Appliances	Total El.	Total DHN	Total Gas
Residential	57.3	-	40.8	10.1	10.9	13.7	24.8	56.7	-
School	6.9	-	**172.8**	20.2	34.9	27.3	69.3	234.5	180.9
Offices	27.6	11.3	43.7	7.1	87.1	71.9	194.3	59.0	60.7
Sports*	48.0	4.0	45.8	43.3	45.7	45.7	76.6	27.8	187.7
Parking	9.8	-	0.0	0.0	2.0	4.5	6.5	-	-

Calculating the PED energy balance, results in:

Table 29 District balance

DHN delivered	5.96 GWh/year
GRID delivered	11.18 GWh/year
Gas delivered	5.82 GWh/year
PEBnren=	31.99 GWh/year
PEBnren/m2	213.85 kWh/m2
Emissions	3343.19 tons of CO2
Total costs	4,050,843.86 €
Total cost per month	337,570.32 €/month

STEP 3.2: Selection of potential solutions> define scenarios

The cities using the PED tool were exploring which scenarios could be applied to their context. The results are the following:

- Current DHN temperature is around 118ºC/65ºC, a measure to improve this in the area could be switching to low temperature district heating (Activated by ATES or nearby river, with distributed or central HPs.); supply when possible with biogas/biomass. Furthermore, in the Stakeholder workshop that took place in June 2023, the DHN operator said that there is interest from some stakeholders of the area (ice rink) to inject waste heat in the DHN.
- Solar technologies that could be applied are PV or flat plate collectors (FPC). The former technology is prioritized as the idea is to electrify as much as possible. PV could be included in all is forms (canopies in the parking lots, on the roofs, etc.).

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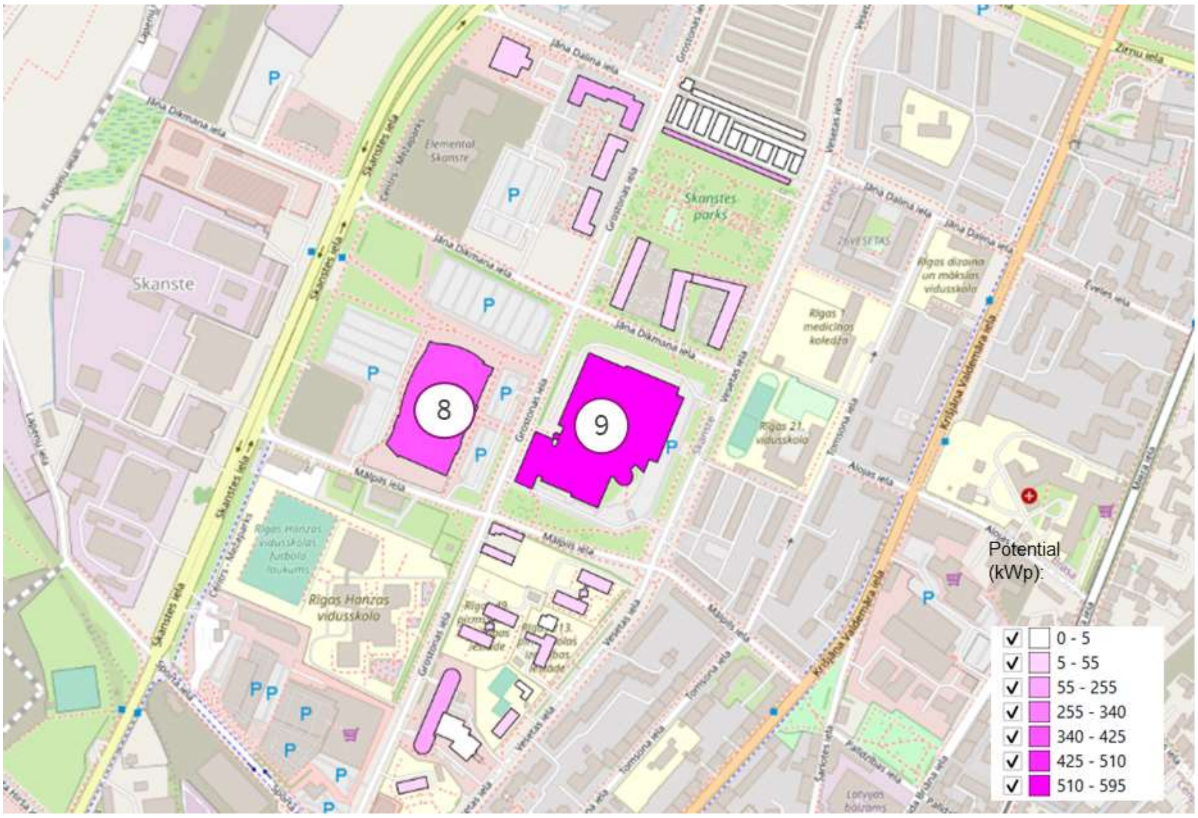

Figure 115 PV potential on roofs Riga

- Thermal storages possibilities for reducing peak demand and offer energy sharing and demand response, such as long-term storages or batteries or short-term storages.
- Creation of an energy community, and/or a market data platform. Plus, e-mobility and/or soft mobility applications (such as low-emission zone, pedestrian area) would be desirable for the city

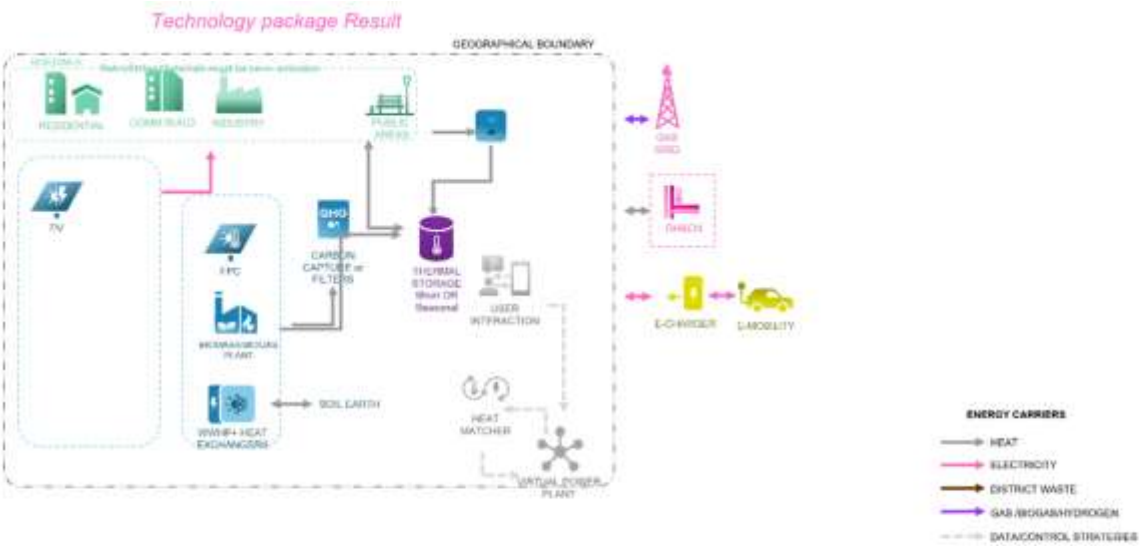

Figure 116 overview of Scenario 1 in the PED tool Riga

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Later, the city selected several potential solutions to define the scenarios at district level. Evaluating as well the co-benefits that could be obtained for each solution. An example is shown for one of the scenarios

IMPACTS / CO-BENEFITS:		SCENARIO 1 (Created in expert group within REA)					
		Technology 1	Technology 2	Technology 3	Technology 4	Technology 5	non-technical
		Photovoltaics (PV)	S11c Connection to the low temperature district heat	S12 a Building energy connectivity for energy sharing	S10c Thermal storage (short time)	S5c Demand Response Smart Grid	S25a creation of energy community
Climate resilience	Climate adaptation	*High*	*Medium*	*High*	*High*	*High*	*none*
	Climate mitigation	*High*	*Medium*	*High*	*High*	*Medium*	*none*
Local economy, entrepreneurship and innovation	Local economy enhancement	*Medium*	*none*	*Low*	*none*	*Low*	*High*
	Financial savings for citizens	*Low*	*none*	*Low*	*none*	*Low*	*Medium*
	Increase employment rate and jobs	*Low*	*none*	*none*	*none*	*none*	*Low*
	Decrease future maintenance costs	*Medium*	*none*	*Medium*	*none*	*Medium*	*Medium*
Social inclusion and education	Social cohesion (gender, minority groups)	*none*	*none*	*none*	*none*	*none*	*High*
	Enhance citizen participation, connectivity and community	*none*	*none*	*none*	*none*	*Medium*	*High*
	Improve access to information, Social capacity building	*none*	*none*	*none*	*none*	*High*	*High*
	Raise awareness/ behavioural change	*none*	*none*	*none*	*none*	*Medium*	*High*
Health and well-being	Improve air quality	*High*	*Medium*	*Low*	*Medium*	*Medium*	*High*
	Reduce noise pollution	*High*	*none*	*none*	*none*	*Low*	*Medium*
	Reduce hot stops/ urban islands in the city	*none*	*Medium*	*none*	*none*	*Low*	*none*
	Enhance attractiveness of the city	*none*	*none*	*none*	*none*	*none*	*none*
	Promote healthier and more attractive lifestyles	*High*	*none*	*none*	*none*	*none*	*Medium*
Biodiversity	Reduce ecological footprint	*none*	*none*	*none*	*none*	*none*	*none*
	Greater biodiversity	*none*	*none*	*none*	*none*	*none*	*none*
Resource management and efficiency *(circular economy)*	Waste efficiency	*none*	*none*	*none*	*none*	*none*	*none*
	Water efficiency	*none*	*Medium*	*Medium*	*Medium*	*none*	*none*
	Food efficiency	*none*	*none*	*none*	*none*	*none*	*none*
	Sustainable land use	*Medium*	*none*	*none*	*Low*	*none*	*none*

Figure 117 Overview of co-benefits for scenario Riga

The following scenarios evaluate the combination of PV, heat pumps, storage and lowering the temperature to around 45ºC of the DHN.

STEP 3.3: Scenarios evaluation and prioritization

The following scenarios are studied in detail:

1. PV on roofs: Considering the PV potential of the buildings, it is assumed that building produce and self-consume their full PV potential. Exports are injected to the grid.
2. Collective PV: Buildings produce and share energy within the district. If there is excess of PV, the excess is injected into the grid.
3. Collective PV & HPs: buildings with DHN are supplied at a lower temperature. For buildings with gas consumption is assumed that the gas network will be replaced with biogas with household waste
4. Collective PV and greener (biomass) DHN. For buildings with gas consumption is assumed that the gas network will be replaced with biogas with household waste

The results obtained are the following:

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Baseline

32 GWh/yr (not PED)	337.5 k€/month*	3343.2 tons CO_2	11.18 GWh from GRID	5.96 GWh from district heating network	5.82 GWh from natural gas

Variables	1. PV in roofs (net metering with excess)	2. Collective PV (12.5 MWp; sharing excess)	3. Collective PV & HPs (15 MWp; sharing excess) & biogas	4. Collective PV (13.75MWp) greener DHN & biogas
Economic savings	33 k€/month	163.8 k€/month	160 k€/month	147 k€/month
Environmental impact	265 tons CO_2 reduction	1266 tons CO_2 reduction	3062 tons CO_2 reduction	2785.7 tons CO_2 reduction
Local production	1.4 GWh/yr production of PV	11.6 GWh/yr production of PV	13.9 GWh/yr production of PV	12.7 GWh/yr production of PV
Primary energy balance	27.35 GWh/yr (not PED)	9.92 GWh/yr (not PED: thermal)	**-2.91 GWh/yr** (PED)	**-0.09 GWh/yr** (PED)
Investment	1.8 M€, payback in ~5 years	13.8 M€, payback in ~ 7 years	20 M€, payback in ~11 years	15.8 M€, payback in ~9 years

The first scenario shows that PED cannot be achieved by only installing individual PV installations on roofs. If collective PV is installed, including also other areas (such as parking lots and a solar farm outside the district boundaries) is possible to achieve a PED (scenario 2). To be energy positive (accounting only electricity demand), an area of 100,000-120,000 m2 is needed; or off-shore wind turbine of 3.45 MW, or a combination of both. Thus, virtual PED concept needs to be applied. PV on roofs (1702 kWp) and parking lots account up to 35,655.8 m2, i.e. a total of 4457 kWp. PV is much more feasible if the whole area invests together and shares the production.

Collective HPs produce ~6 MWh/yr. of heat (at 45ºC for SH and 60ºC for DHW) which improves the PED scenario, but requires an upgrade of the emitters (radiators to fan coils or ground floor heating) and an adaptation of the DHN to be supplied with a temperature of 3 to 12ºC[35]; and higher PV production.

Making greener the DHN (scenario 4) will allow to achieve similar scenario as scenario 3 but requires an increase in at least 5MW the biomass supply for the area.

The gas-fired boilers are assumed to use biogas[22] in the last two cases (scenario 3 and 4). Other option will be to replace it with AWHP but will increase the electricity consumption and the price of a heat pump might be a lot higher than adapting the current boilers to biogas.

Other options could be combining the above-mentioned solutions with: reduction of heat and electricity consumption of the buildings (through demand response, smarter buildings, adjust thermostats to lower temperatures in winter, behavioural change, etc.). Storage has not been considered yet due to the deadline to present the results with stakeholders. Further iterations of the scenarios could be made, once the feedback of the stakeholders is collected (on-going process).

Comparing scenario 1 (not a PED) and 3 (a PED is achieved), a calculation is made for each building to indicate how much each dwelling or user need to collectively to form a PED. As an energy community they could decide other business models or ways of investing together (depending on peak demand, depending on surface available, or totally optional: fixing an amount of €/kW).

[35] tap water has been assumed, as source. Similar results could be obtained with GSHP, but costs could be higher. Cost of replacement of emitters is not included. Cost of replacement to biogas not calculated

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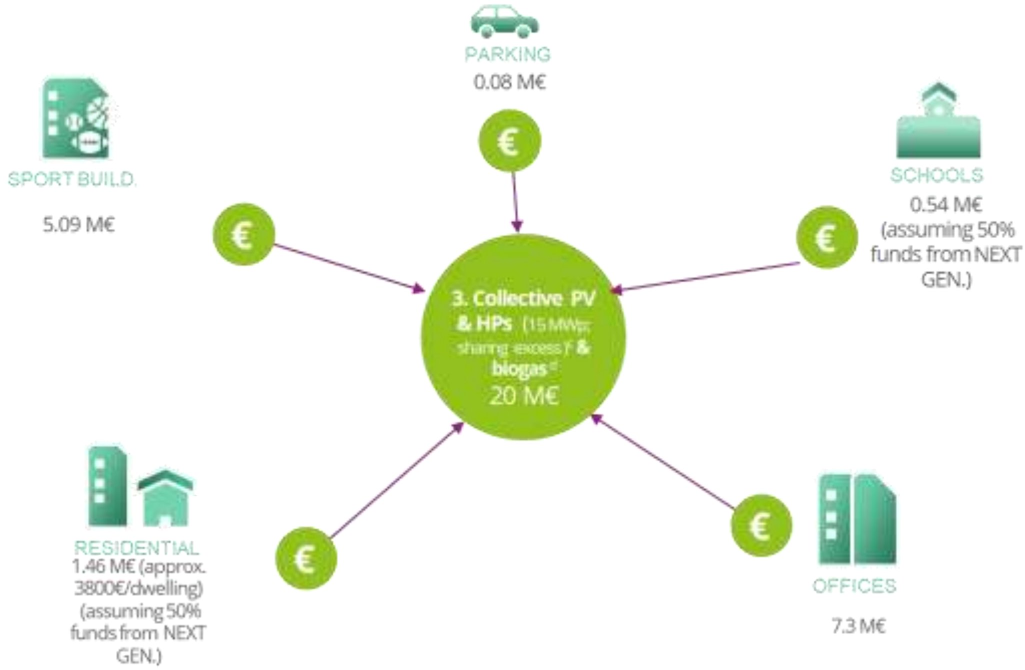

Figure 118 Collective investment

In most cases, participating in the collective PV with a shared of the investment provides benefits for the building itself and the district as a whole. B8&B9 will double the savings, by just investing 22% and 10%, respectively. RCC Rietumu Capital Centre (B18) gets 67.8(33.09% of investment, 4.96MWp), B19: 0.27 k/month (0.14%, 21kWp).

B1 needs to invest 1.8 M€ (11.2%) but increases a lot their cost savings. Residential buildings have savings of 18.76 k€/month (563€/year per dwelling) with an average investment per dwelling of 3760€/dwelling (in some energy communities this amount is to about 8000€/kW). Schools double their cost savings and becomes a PEB. Overall most parties can get benefits from the joint investment.

The benefits are summarized below:

Table 30 Investment and savings (energy, cost, emissions) per building for scenario 1 and 3.

		BASELINE			Scenario1 savings:					Scenario 3 savings:					
Nº	Use	PEnren (GWh/yr)	Tons CO2eq	k€/ month	Sav. PEnren (GWh/yr)	Sav. Tons CO2eq	€ Per month	INV. k€	PB[a]	Sav. PEnren (GWh/yr)	Sav. kTons CO2eq	k€ Per month	INV. M€	PB[a]	Invest ment share
Building 1	Offices	2.86	236.88	36.33	0.06	3.57	877.14	38.5	3.66	3.12	0.252	20.373	1.847	7.6	11.20%
Building 2	Residential[d]	1.06	181.85	8.17	0.06	3.38	1388	65.7	3.95	1.14	0.186	1.800	0.273	12.6	3.31%
Building 3	Residential[d]	1.34	148.70	14.93	0.05	3.02	743.41	32.7	3.66	1.46	0.155	6.547	0.409	5.2	4.96%
Building 4	Residential[d]	1.19	117.78	14.05	0.05	3.01	740.27	32.5	3.66	1.30	0.124	6.761	0.372	4.6	4.51%
Building 5	Residential[d]	0.62	88.92	5.81	0.05	2.81	1000.9	46.4	3.86	0.67	0.092	1.922	0.177	7.7	2.14%
Building 6	Residential[d]	0.34	59.43	2.49	0.02	1.26	595.01	41.1	5.75	0.36	0.061	0.335	0.086	21.3	1.04%
Building 7	Residential[d]	0.52	76.54	4.77	0.05	2.89	1244	59.6	4	0.56	0.079	1.401	0.148	8.8	1.80%
Building 8	Sports	5.39	385.06	71.77	0.50	28.82	8669	393.1	3.78	5.90	0.414	37.250	3.583	8.0	21.71%
Building 9 [b]	**Sports**	7.32	1,065.38	43.63	0.72	41.19	14167	654.4	3.85	5.68	1.076	35.294	1.509	3.6	9.15%
Building 10	Parking	0.01	0.47	0.12	0.001	0.05	100.07	200.7	167	0.01	0.001	0.068	0.006	88.9	0.03%
Building 11	Parking	0.03	1.88	0.46	0.01	0.59	180.37	13.1	6.06	0.04	0.002	0.226	0.022	8.3	0.14%
Building 12	Parking	0.04	2.11	0.52	0.01	0.65	198.12	14.4	6.06	0.04	0.002	0.249	0.025	8.4	0.15%
Building 13	School[d]	0.51	87.17	3.95	0.05	2.77	820.71	43.1	4.37	0.55	0.089	0.694	0.133	15.9	1.61%
Building 14	School[d]	0.64	88.79	6.08	0.05	2.98	773.31	34.2	3.69	0.69	0.092	2.497	0.179	12.0	2.16%
Building 15	School[d]	0.45	66.09	4.04	0.02	1.17	905.26	43.1	3.96	0.48	0.068	1.105	0.122	9.2	1.48%
Building 16[b]	School[d]	0.27	33.95	2.02	0.005	0.26	265.27	13.8	4.32	0.22	0.035	1.164	0.040	2.9	0.49%
Building 17[c]	Parking	0.01	0.43	0.11	-	-	-	-	-	0.01	0.000	0.045	0.005	9.6	0.03%
Building 18 [b]	**Offices**	9.12	667.14	115.41	0.4	22	2762.2	132	4	9.49	0.712	67.825	5.461	6.7	33.09%
Building 19	Parking	0.03	2.01	0.49						0.04	0.002	0.274	0.024	7.3	0.14%
Building 20	School[d]	0.24	32.63	2.41	0.01	0.32	288.59	13.8	3.97	0.26	0.034	0.532	0.070	10.9	0.85%

[a]simple payback period, for more detailed cashflow calculations, see later. [b]It is not feasible for these buildings to invest in heat pumps. [c]B17 has no space in the roofs, scenario 1 is not performed. [d]It is assumed that residential buildings and schools receive 40% of national funds (Next generation).

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STEP 3.4: Financing options

From the options presented in Table 14 and considering the selected area of Skanste the most feasible options are energy communities and the Investment Platform, as it has been studied before (see Figure 118). The implementation of the PED area should be also supported financially by a mix of municipal and external funds, and private ones. This way, external funds can be received in form of a 'Partial grant and partial self-finance' where monetary assistance would come from European and potentially from national, and regional funds as well.

Conclusions

Thanks to this process Riga was able to gather some insights for designing a tendering procedure that considers the necessary features to achieve and implement a PED in their area. For instance:

- There is a favourable environment in the city to deploy PEDs, as well as political commitment.
- The decarbonisation of the DHN is a must to allow achieving an economically feasible PED (and also avoid oversizing technologies). Otherwise "virtual boundaries" are needed to become PED (by investing in a solar park).
- There are some regulatory limitations, but the upcoming energy community's regulation seems promising to change this landscape.
- Investment platforms could allow bringing additional benefits and making the investment more feasible. In most of the studied cases, participating in the collective PV with a shared of the investment provides benefits for the building itself and the district as a whole.
- The involvement of a variety of stakeholders (residential, district heating network operator, product developers, etc. like the ones in Skanste) will allow to share the risks, investments and achieve a more ambitious PED concept.
- Success of PED implementation depends, in particular, on active participation of (as many as possible) stakeholders and their empowerment as "prosumers", producing and consuming renewable energy. Thus, the optimal PED solution should be an inclusive solution, involving the occupants of Skanste neighbourhood in order to provide them affordable renewable energy, as well as to produce an energy surplus, thus contributing to the achievement of Riga's climate goals by 2030.

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10. Discussion

WP6 of the ATELIER project focuses on creating a framework for the early replication of the ATELIER Positive Energy District (PED) concept and solutions across Europe, starting with the Fellow Cities of Bratislava, Budapest, Riga, Krakow, Copenhagen, and Matosinhos. The task has included: standardising the definition of PEDs for ATELIER, providing guidelines for adapting solutions to cities, energy modelling generation for some cities and capacity building activities.

With the information contained in this deliverable, each fellow city is delivering a PED execution plan and, if they have the resources, they could make it happen demonstrating the PED potential of the area and what can be done to achieve PEDs in their cities.

From the SWOT analysis it can be seen that generally it is possible to export energy, but self-consumption is prioritised (or incentivised by price). Peer-to-peer is not something regulated or promoted by the law, generally it is possible only in private grids. Feed-in-tariffs are somehow available but generally for big producers (which need a lot of bureaucracy). Hydrogen is not generally promoted although it is being considered in some cities plans and at national level (e.g. Portugal). A lot of opportunities are found with regards to energy efficiency policies and supporting programmes. Energy community's regulation or the social structure in the districts were not generally available in most cities at the time of the SWOT workshop (2021-03-23). But now things are improving, as demonstrated by Krakow, which is holding stakeholder workshops with regards to energy community's topic. Also, the Portuguese law is very favourable now (sep. 2023) to energy communities and Riga is participating in national calls to define regulations in the topic.

The design analysis has been focused on pre-selected areas from proposal stage. The results are shown in Figure 119.The overall replication of PEDs in fellow cities will be completed once the cities develop their Replication plans, which will include an analysis at city level, using GIS, of the potential of areas to become PED.

From the results, and the overall task insights, it can be concluded that:

- In the majority of these areas, the most significant factors for selecting an area (and therefore prioritise it for PED development) were of technological and governmental nature, aligning with pre-existing plans in some instances. It is crucial to emphasize that this methodology (step 2) holds validity solely within the context of these specific cities. Our intention is not to compare the different PEDs among the cities, as each city possesses distinct impacts and prioritization weights, reflective of their individual preferences, thus resulting in varying MCDA values.

- All cities recognize the feasibility of achieving a Positive Energy District, with specific scenarios or approaches identified as successful in each context. But according to Riga, legislation framework can be a strong barrier as the PED concept or the energy community concept, in this case, is not supported dand does not incentive stakeholders to invest.

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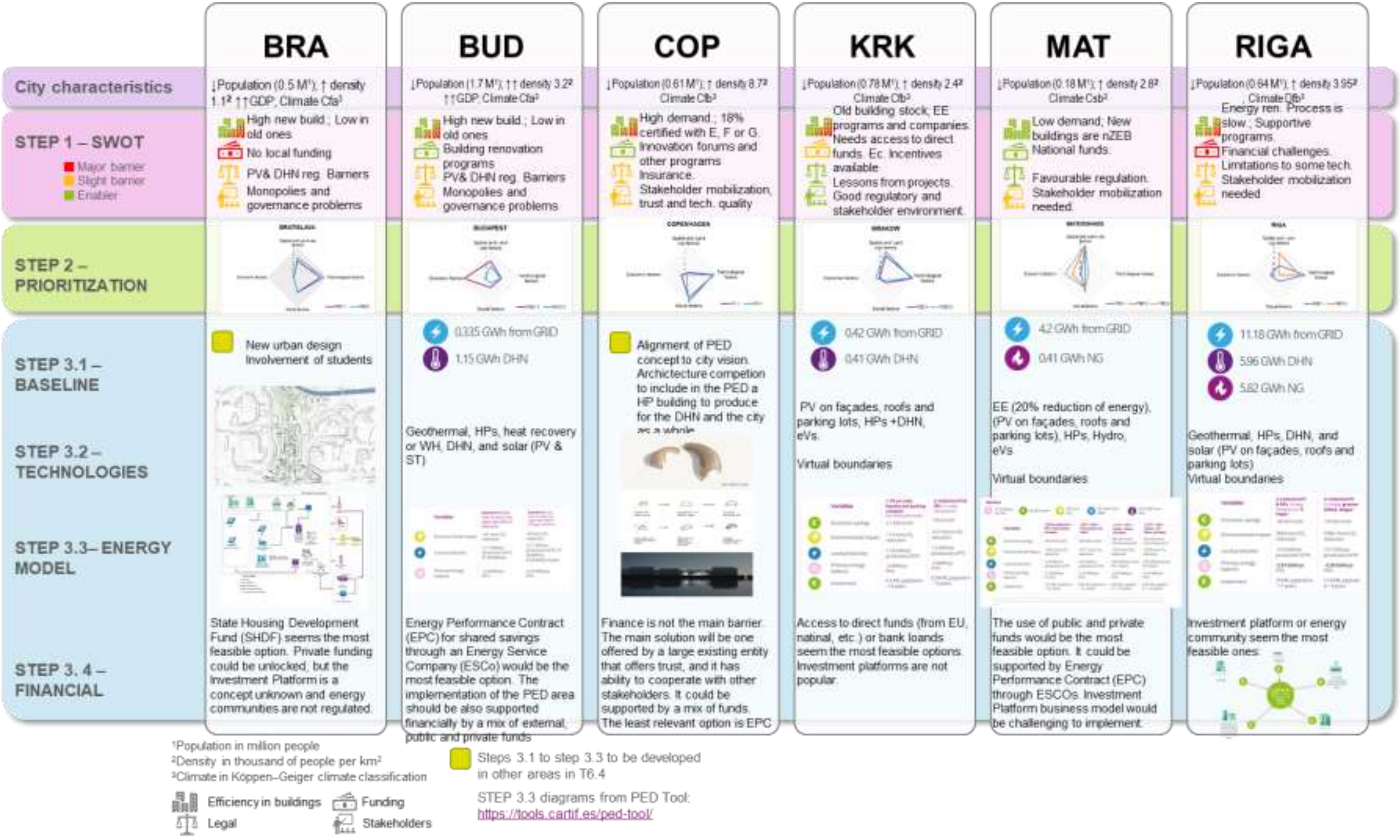

Figure 119 Summary of the results

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- Recommendations focus on integrating renewable energy sources like solar, wind, and geothermal for electricity and heat generation. All cities emphasize energy efficiency enhancements in buildings, such as insulation, efficient lighting, and appliances, as well as reduction in water energy demand through innovative solutions. Therefore, the decarbonisation of buildings in Europe relies on improving energy efficiency (EE) and utilizing renewable energy sources (RES). 100% of the cities agree that EE and RES are needed for achieving a PED that is economically feasible.
- All cities agree that PEDs can help in accelerating the achievement of decarbonisation goals, especially for the Mission cities that need to achieve climate neutrality by 2030.
- Cities agree that space availability of RES is always an issue in cities. The concept of virtual boundaries can help on adopting widely the PED concept across Europe. Nevertheless, according to Budapest infrastructure like DHN can be within the functional boundaries of the PED and still include RES within city limits to provide the PED with an environmentally sustainable option. Furthermore, Riga is exploring the concept of "temporary use" of space, allowing to use areas that cannot be regenerated in the short term and can be temporarily assigned to provide energy to a PED or urban area.
- PEDs offer advantages over Net Zero Energy Buildings (NZEBs), such as achieving a balanced energy demand and RES generation (which can lead to reduction of congestion management), and cost-effective energy management. Co-benefits include energy security, economic growth, job creation, reduced energy poverty, improved health, reduced ecological footprint, and climate resilience. Copenhagen agrees that specially existing areas cannot make it to NZEB standards, and PED can provide flexibility of demand and production.
- The development of PEDs requires involvement from local actors, political vision, attractive financing options (not necessarily funding), and consideration of specific preconditions related to funding, and regulations. Financing options can be a good business case or investment platform (as shown in this deliverable).
- Barriers to PED implementation include lack of funding, lack of data, ownership of buildings, lack of pilots to showcase benefits and reduce risks, lack of capacity in the city staff and overall workforce, supportive legislation/policies, stakeholder engagement, and business models.
- Public financing, EU grants, loans, and involvement of private investors have been used to support PED projects and are also preferred as financing options for the cities. Therefore, these are needed to lower the risk and to favour investments from stakeholders. This is because stakeholders are not familiar with the concept yet which increases risks (also, capacity building activities could be deployed to support that). Investment platforms with hybrid funds (public and private) could also help in establishing PEDs and divide the risks among stakeholders. Still, finance does not solve everything, overcoming the above-mentioned barriers is needed too.
- Although regulatory limitations and restrictions (e.g. at national level: lack of energy communities' transposition, limitations on RES capacity to be installed without permits, etc.; at local level: increase of data platforms, of local ordinances or tax bonifications to support RES and energy communities, etc.) are recognized as possible obstacles, cities are hopeful about impending energy community legislation and other beneficial improvements.

Overall, the cities recognize the importance of renewable energy, energy efficiency, stakeholder engagement, and overcoming regulatory barriers to achieve their PED goals. Each context presents unique challenges and opportunities, influencing the preferred decisions in this document and financing options. Still, the decisions can change when the process

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continues as new barriers can appear. Nevertheless, overall strategies of the cities can still be considered in the process to ensure the concept goes towards PEDs (although does not necessarily achieve it).

Although the results of the present document are site specific and country specific, guidebook or steps to consider stakeholders, choose technologies, and having a “recipe” can help to work towards PEDs, although relevant of things or options are different from side to side. Having other cities to compare and exchange learnings have been useful for cities.

The present deliverable will be translated into a guidebook or step-guidance, easy-to-use, so as to cities know how to initiate a PED. So far, the approach has been mostly focussing on new areas to be built (Copenhagen, Budapest, Bratislava) or areas with high performance (Riga). For these areas can make sense to build scenarios but, in most cases, cities won't be exploring new areas but existing old areas. As long as the ambition is going towards PED and strive to get as close as possible with existing buildings, infrastructures, etc., it will be made in a sustainable way. Most of the processes presented in the deliverable are top down and with existing cities you need a pragmatic approach, and sometimes bottom-up. But at least for Riga it has been useful to present the scenarios to stakeholders. Now the area could be extended as more people wants to join the Skanste project, but still the regulatory framework is necessary (now it is not existing, and it is an obstacle). The question of having boundaries and why are they useful is under discussion in Riga.

Based on ATELIER project findings and cities’ experiences, the main identified conditions for upscaling and replication for PEDs in D6.2 are reviewed hereafter:

Political support and commitment

- strong political commitment is crucial for a successful transformation in the city. Large-scale transformations demand collaboration, coordination, and resources across departments.
- Six out of the eight ATELIER cities (Amsterdam, Bratislava, Budapest, Copenhagen, Krakow and Riga) are now part of the 100 climate-neutral and smart cities by 2030, which allows to accelerate the achievement of decarbonization.
- Involving a variety of stakeholders is crucial. **Innovation Ateliers or Smart City Planning Groups (SCPG)** are proposed to lead not only the long-term city strategy but also the PED replication and upscaling plans design and implementation.

Stakeholders’ involvement

- PED design and implementation require collaboration among diverse stakeholders within the local ecosystem, influenced by national legal and regulatory contexts.
- Successful PEDs require active engagement of citizens and various stakeholders. Enabling policies empower communities to develop district concepts and play their role in decarbonization.

Public participation is a pending topic for fellow cities.

- It is a common understanding that the successful development and implementation of Positive Energy Districts requires the support of citizens, but so far it has been difficult to involve them. Only Riga has been in contact with some housing associations in their Innovation Ateliers.

Trained municipal staff on innovation management

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- PEDs, requires continuous learning and incorporation of new technologies into government operations. The city events have helped to achieve this and also disseminate the learnings with external stakeholders in some cities

Provision of finance support

- Involvement of diverse stakeholders, including residential, municipal, and business entities, in a form of energy communities or Investment Platforms or Innovation forums are seen as essential for sharing risks, investments, and achieving ambitious PED goals.

In a nutshell, cities do think PED concept is useful for accelerating their climate neutrality targets, but they find difficult to engage with stakeholders and find the funding to invest in such huge installations. Further policy incentives at national and European level are needed to boost these kinds of approaches across Europe.

11. Conclusions

WP6 aims to create a necessary framework to foster early replication of ATELIER PED concept and solutions across Europe starting with our Fellow Cities (Bratislava, Budapest, Riga, Krakow, Copenhagen and Matosinhos). Section 1 introduces the purpose of the report, contribution of partners and deviations from the Grant Agreement No 864374. Section 2 summarizes the objectives of the report and expected impact. The PED design framework that has been followed in this document is defined in section 3 in a series of steps methodology. a comprehensive roadmap spanning multiple steps.

Commencing with STEP 1, which entails a holistic understanding of the city's context, involving an in-depth survey, meticulous analysis of plans (WP2), and city context questionnaires. These initial efforts converge into a SWOT analysis, providing a strategic foundation. Progressing to STEP 2, the focus shifts towards identifying a suitable area for PED implementation. This involves a precise prioritization of impacts, further characterization of preselected zones from the proposal phase, and a thorough assessment of these zones based on the prioritized impacts. The outcome is a composite indicator, facilitating the selection of the most fitting area for PED integration within the city. Upon selecting the area, STEP 3 is enacted. This phase encompasses baseline establishment through modelling, exploration and selection of potential technical solutions, leading to tangible outcomes. These findings are then presented to stakeholders, fostering discussions to evaluate challenges, strengths, and the formulation of a financial model. Throughout this entire process, capacity building initiatives from WP3 and WP6 play a pivotal role.

Later, each step is deployed and developed for every fellow city in Section 4-9. Each city section aims to be independent from one another so it can become an input for a PED tendering process or PED guidelines for each city. Section 10 discusses a comparison between the cities (although it is not the aim of this deliverable) and extracts some lessons learnt from it.

In summary, cities do believe the PED concept is valuable for expediting their climate neutrality ambitions, but they struggle to engage stakeholders and secure the funds necessary to invest in such massive installations. To support these kinds of methods across Europe, more policy incentives at the local, national and European levels are required (see section 10 for more recommendations).

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

ANNEX 1- CITY CONTEXT TEMPLATE

CITY CONTEXT for PED concept replication

City				Country				
BASIC INFORMATION								
Which specfic **objectives** do you want to face by PED implementation from the ones established at **city level**?								
What range of implementation **time** is suitable for you for deploying your PED?								
In what range would you like to **invest (€)** in your PED?								
What **Return on Investment (ROI)** do you expect from the PED implementation?								
Do you already have a plan to develop a specific PED option? If yes, which one?								
Could you identify a list of potential stakeholders? Potential local stakeholders (energy trading companies, technology suppliers, ESCOs,..)								
Impacts to achieve by PED implementation: From them, you consider **more important…**	Impact **A:**	Impact **B:**	Impact **C:**	Impact **D:**	Impact **E:**	Impact **F:**	Impact **G:**	Impact **H:**
A or B?		B or C?		C or E?		D or H?		
A or C?		B or D?		C or F?		E or F?		
A or D?		B or E?		C or G?		E or G?		
A or E?		B or F?		C or H?		E or H?		
A or F?		B or G?		D or E?		F or G?		
A or G?		B or H?		D or F?		F or H?		
A or H?		C or D?		D or G?		G or H?		

POTENTIAL RESOURCES		
Solar energy potential generation	Has your city performed a study on the identification of potential areas for solar energy installations (at clear areas, roof/façade level)?	
	If yes, do you have it on GIS format (.shp file)?	
	If you do not have it on a GIS format (.shp file), in which kind of format is it? Please specify	
Wind energy potential generation	Has yor city performed a study on the indentification of potential areas for wind energy installations?	
	If yes, do you have it on GIS format (.shp file)?	
	If you do not have it on a GIS format (.shp file), in which kind of format is it? Please specify	
Geothermal energy potential generation	Does your city have geothermal potential maps? What about type of soil?	
	If yes, do you have it on GIS format (.shp file)?	
	If you do not have it on a GIS format (.shp file), in which kind of format is it? Please specify	
Energy potential generation	Is there a river/sea close from which could be possible to harvest energy?	
	Has your city performed a study on the energy potential generation (thermal/electric)?	
	If yes, can you provide it?	
Waste heat potential	Is there an industry/ice rink/waste management plant,etc. from which could be possible to harvest energy (thermal/electric)?	
	If yes, specify type of facilities from which you waste heat can be recovered	
	Do you have any waste heat potential maps at city level?	
	If yes, do you have it on GIS format?	
Forest waste	Forest from which could be possible to harvest forest waste?	
	If yes, do you have it on GIS format (.shp file) or could you identify them in a map (or list of coordinates)?	
Gas grids	Do generally buildings have access to gas grids?	
	What are the national regulation regarding % of Hydrogen in the gas grids and/or biogas injection?	
Refueling Stations	What type of refueling stations are available within the city? (e.g. diesel/bio-diesel/natural gas/gasoline/hydrogen/electric charging stations…)	
	Do you have it on GIS format (.shp file) or could you identify them in a map (or list of coordinates)?	
Others	Is there other resource that can potentially be used by city/district? e.g. storage facilities, other energy source… Please specify	

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ANNEX 2- POTENTIAL PED TEMPLATE

	PRE-SELECTION OF A SUITABLE AREA TO DESIGN A PED							
City					**Country**			
Potential district #1								
BASIC INFORMATION								
Description (update it if necessary)								
Area (Km2)								
Are there other similar areas in the city? (in order to upscale the solutions afterwards)		Which ones? (identify them on a map?)			What common aspects do they share?			
Nº of buildings within the district (quantify size if possible)								
Building use category								
Percentage per use (%)								
Construction period per use								
Construction status per use								
Ownership								
m2 of roof available								
m2 of Land available /(Or space in a technical room)								
Population living (inhab)								
Population density (inhab/Km2)								
Is there any expected new development area in the district?		If yes, which is the expected use?						
Is there any expected regeneration/ refurbishment plan in the district?		If yes, which is the target of the plan?						
Is there any expected investement from the municipality to carry out the interventions?		If yes, which is the amount of budget?						
CURRENT ENERGY GENERATION								
Building use category (previous ones)								
Do buildings have a centralized heating?								
Do buildings have RES production? If so, what?								
Do buildings have ventilation or an air handling unit?								
Do buildings have heat pumps or splits?								
Is the district connected to a district heating?								
If the answer is yes, what is the supply Temperature? How is working (existing energy systems)								
If the answer is yes, how many buildings are connected?								
If the answer is yes, which type of substations is available on the buildings?								
If the answer is yes, does the distrit network provide cooling as well?								
		Details if yes					**Number**	**Map/Coord.**
Do buildings have a substation (electric) nearby?			If yes, specify how many and identify them on a map (if possible, or give coordinates)					
Do buildings have a district heating or cooling network nearby?			If yes, specify how many and identify them on a map (if possible, or give coordinates)					
Is there any Virtual Power Plant in the district?			If yes, specify how many and identify them on a map (if possible, or give coordinates)					
Is there any Energy Community in the district?			If yes, specify how many and identify them on a map (if possible, or give coordinates)					
Is there any waste management (at level district) or waste mangament plant nearby?			If yes, specify how many and identify them on a map (if possible, or give coordinates)					
Is there any Energy intensive industries in the district?			If yes, specify how many and identify them on a map (if possible, or give coordinates)					
SOCIAL WELLBEING :								
Any potential people with risks of social exclusion or energy poverty? Explain								
From your experience, do you feel citizens living there will accept the deployment of new technologies?								
			Number		**Units**		**Further comments**	
Accessibility (measured as distance in meters or time minutes) to urban green spaces for population								
Accessibility (measured as distance in meters or time minutes) to end-user activities (food markets,etc.)								
Accessibility (measured as distance in meters or time minutes) to transport								
Do you know the average people's incomes in the area?								
Average age in the area								
Any other particularity?								

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ANNEX 3- BIOCLIMATIC DESIGN ANALYSIS

ANNEX 3.1. BRATISLAVA LOCAL CLIMATE ANALYSIS: CURRENT CLIMATE

GENERAL CLIMATE VALUES

- Climate: Moderately Continental
- Elevation*:* 130m
- Geographic data: Longitude: E 17,2°, Latitude: N 48,2°
- Mean annual temperature of around 10.5 °C
- Average temperature in warmest month: 21 °C in July
- Average temperature in coldest month: 0 °C in January and February

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MONTHLY MEANS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Global Horiz Radiation (Avg Hourly)	85	164	244	309	372	359	396	372	267	211	109	82	Wh/sq.m
Direct Normal Radiation (Avg Hourly)	63	187	228	201	283	237	301	295	207	204	89	77	Wh/sq.m
Diffuse Radiation (Avg Hourly)	67	89	131	179	182	193	185	175	149	120	77	61	Wh/sq.m
Global Horiz Radiation (Max Hourly)	308	525	679	815	893	909	896	833	743	576	414	279	Wh/sq.m
Direct Normal Radiation (Max Hourly)	577	816	877	829	875	879	874	850	781	756	668	519	Wh/sq.m
Diffuse Radiation (Max Hourly)	189	265	345	434	454	445	492	434	382	296	205	162	Wh/sq.m
Global Horiz Radiation (Avg Daily Total)	740	1625	2839	4171	5600	5675	6117	5225	3314	2236	1004	675	Wh/sq.m
Direct Normal Radiation (Avg Daily Total)	542	1845	2611	2718	4256	3749	4663	4142	2569	2152	827	638	Wh/sq.m
Diffuse Radiation (Avg Daily Total)	581	884	1547	2419	2744	3057	2849	2464	1850	1276	705	501	Wh/sq.m
Global Horiz Illumination (Avg Hourly)	9485	17849	26583	33774	40806	39840	43606	40886	29498	23025	12037	9013	lux
Direct Normal Illumination (Avg Hourly)	5251	17180	21726	19691	27530	22481	28715	28197	19385	18708	7870	6317	lux
Dry Bulb Temperature (Avg Monthly)	0	0	5	10	15	18	21	20	15	9	5	1	degrees C
Dew Point Temperature (Avg Monthly)	-2	-2	0	3	8	12	13	13	11	5	2	-1	degrees C
Relative Humidity (Avg Monthly)	85	84	67	61	63	72	62	65	75	76	85	81	percent
Wind Direction (Monthly Mode)	310	40	320	310	320	310	310	310	340	40	40	40	degrees
Wind Speed (Avg Monthly)	2	3	3	3	3	3	2	2	2	2	3	2	m/s
Ground Temperature (Avg Monthly of 3 Depths)	6	4	2	3	5	8	12	15	17	16	14	10	degrees C

Figure 120: General Weather data summary- Bratislava

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

TEMPERATURE ANALYSIS

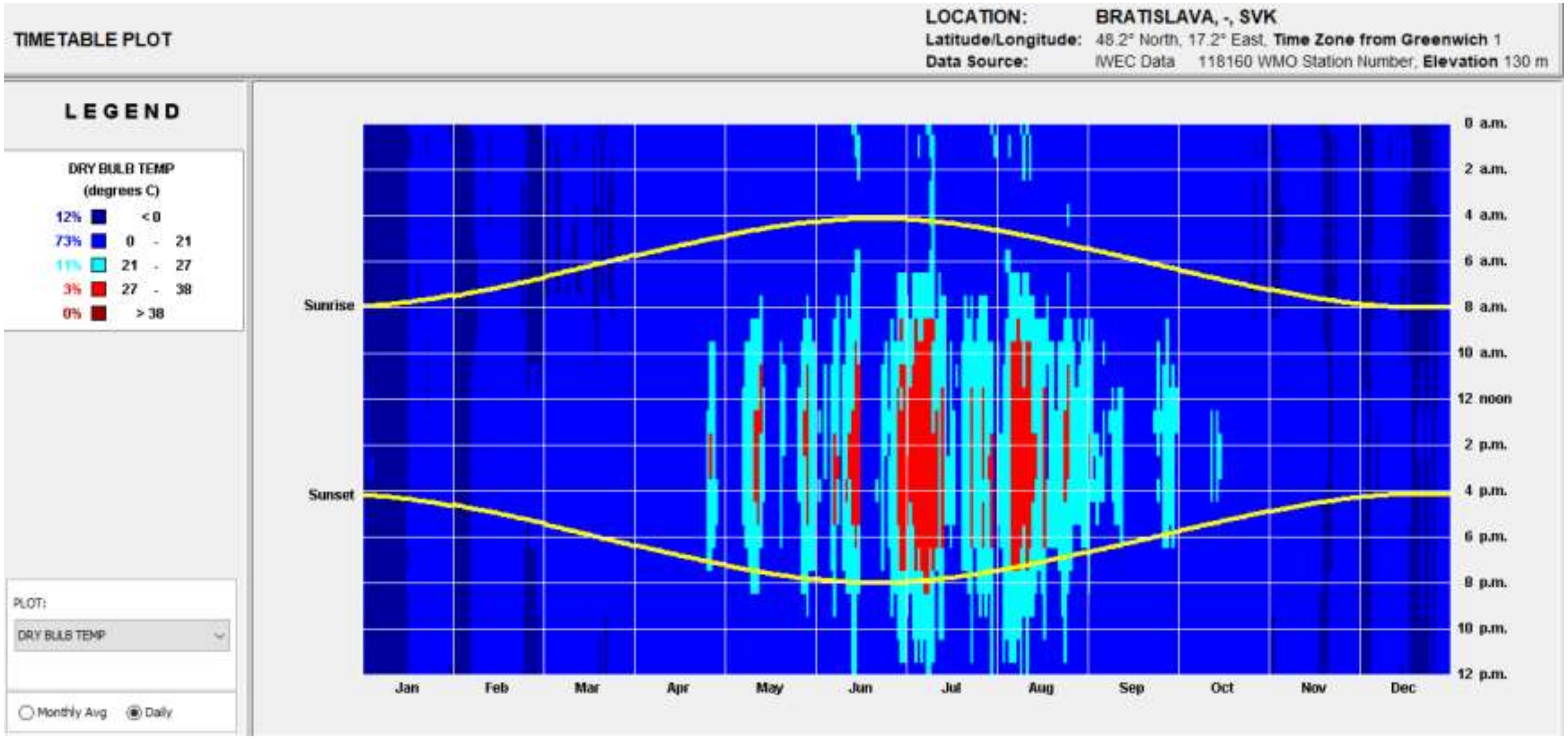

Figure 121: Dry bulb diagram- Bratislava

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

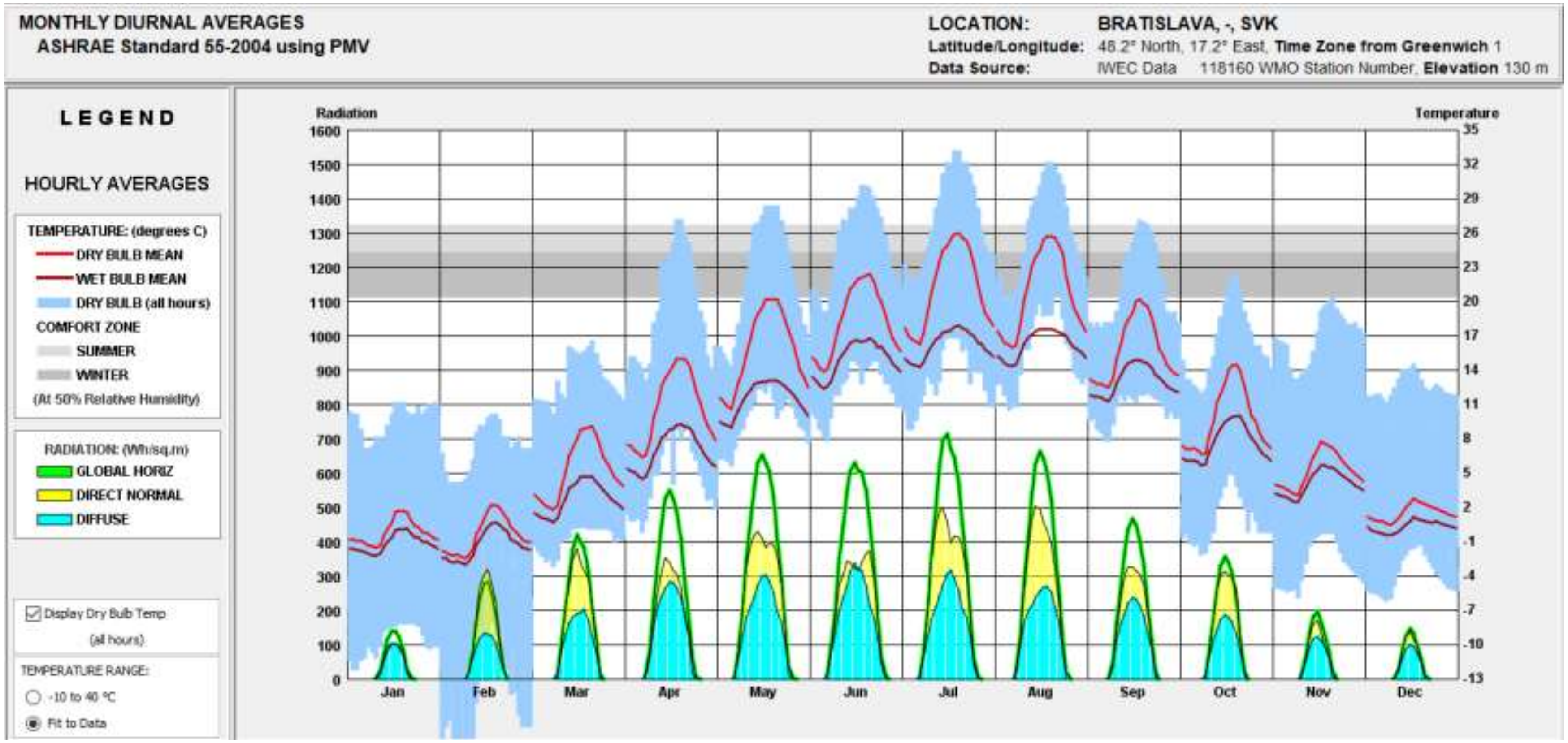

Figure 122: Diurnal average diagram- Bratislava

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

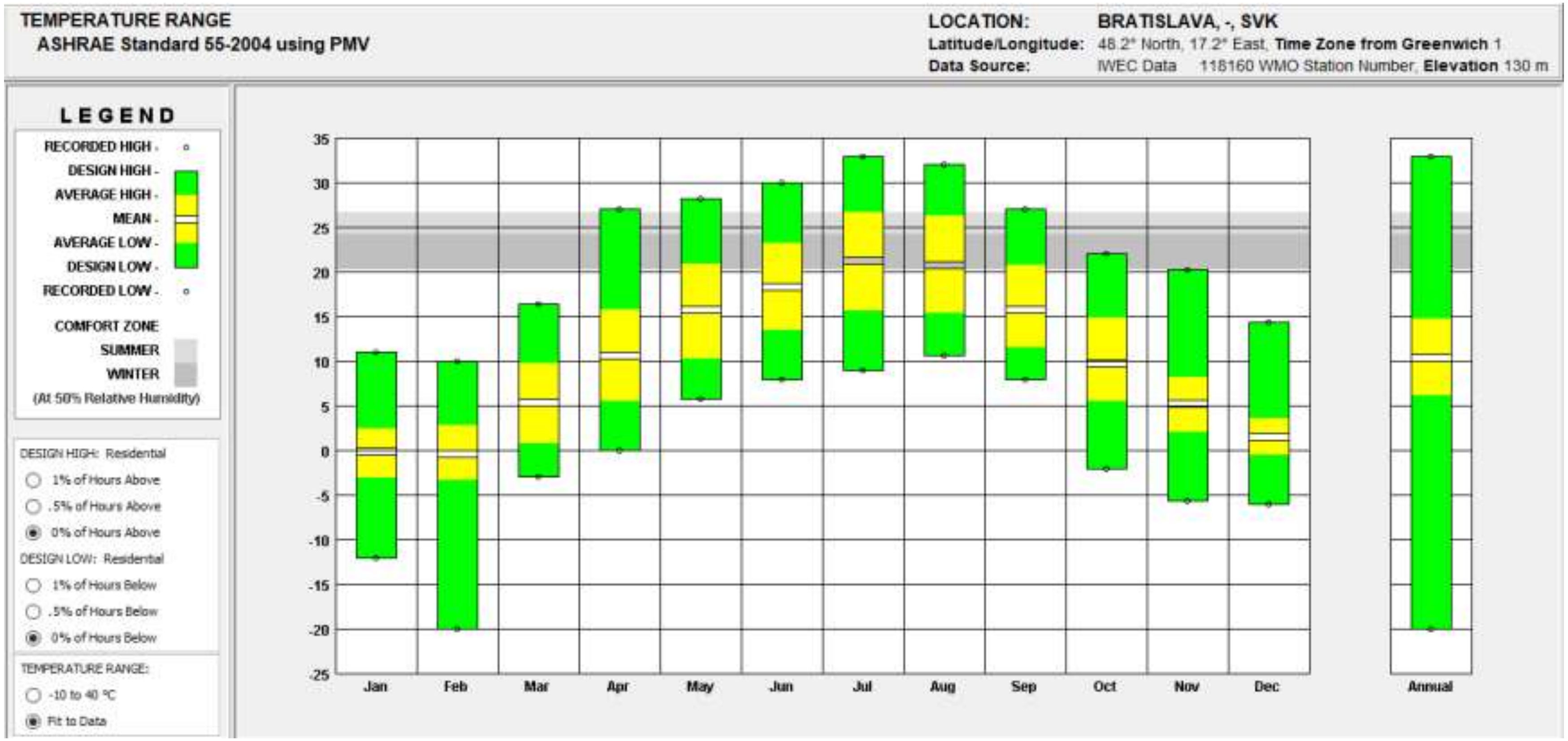

Figure 123: Temperature range diagram- Bratislava

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

RELATIVE HUMIDITY

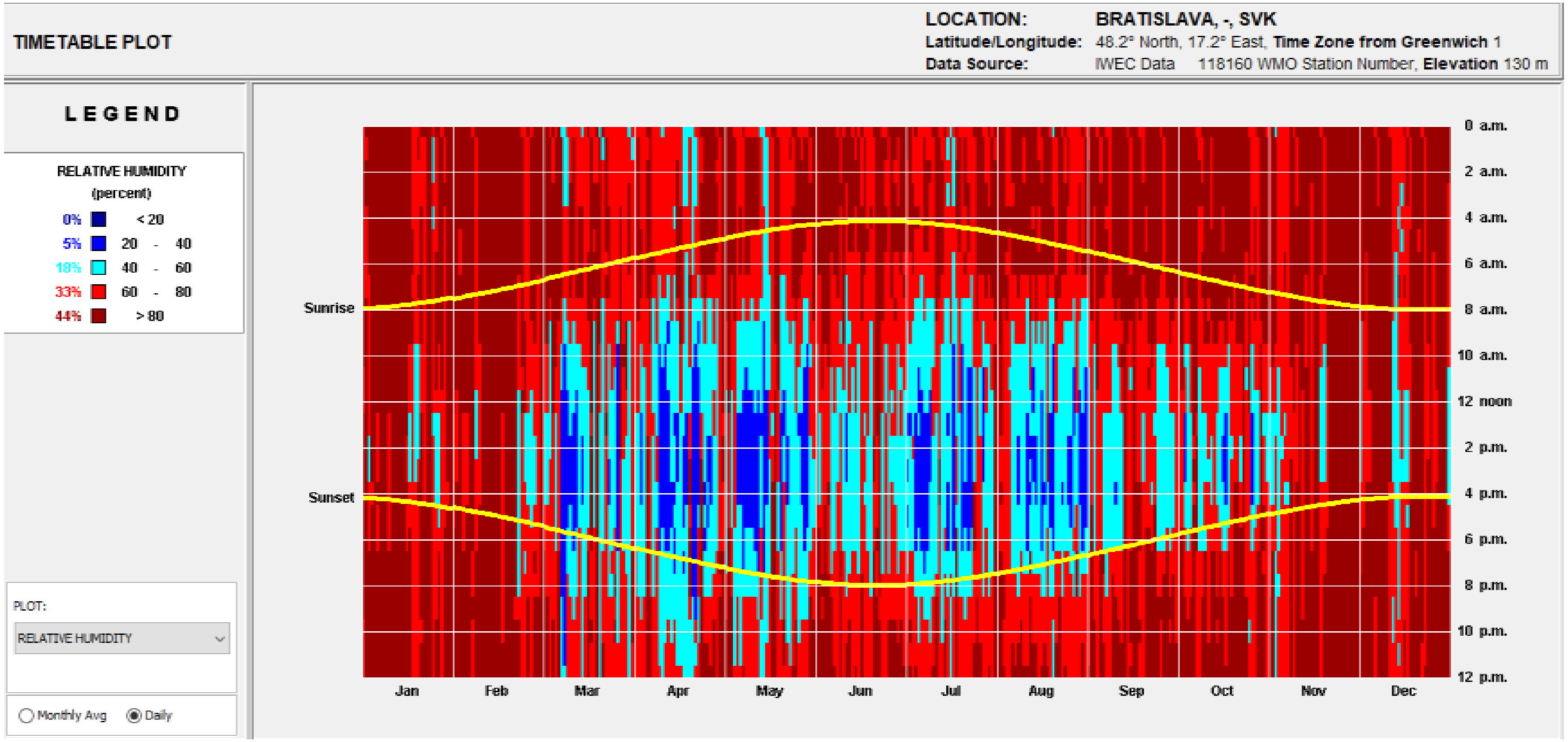

Figure 124: Relative humidity diagram- Bratislava

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

SKY COVER

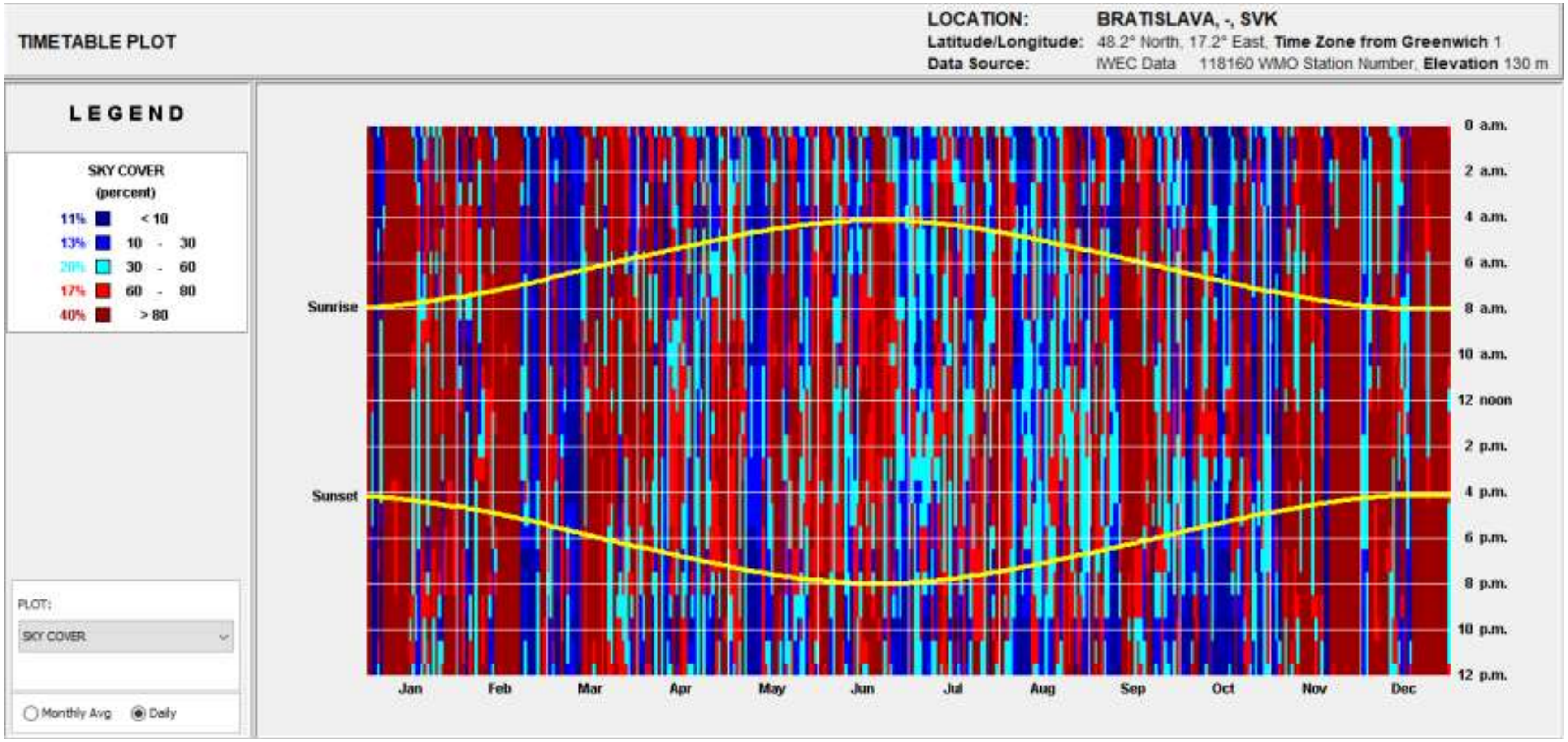

Figure 125: Sky cover diagram- Bratislava

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

WIND ANALYSIS

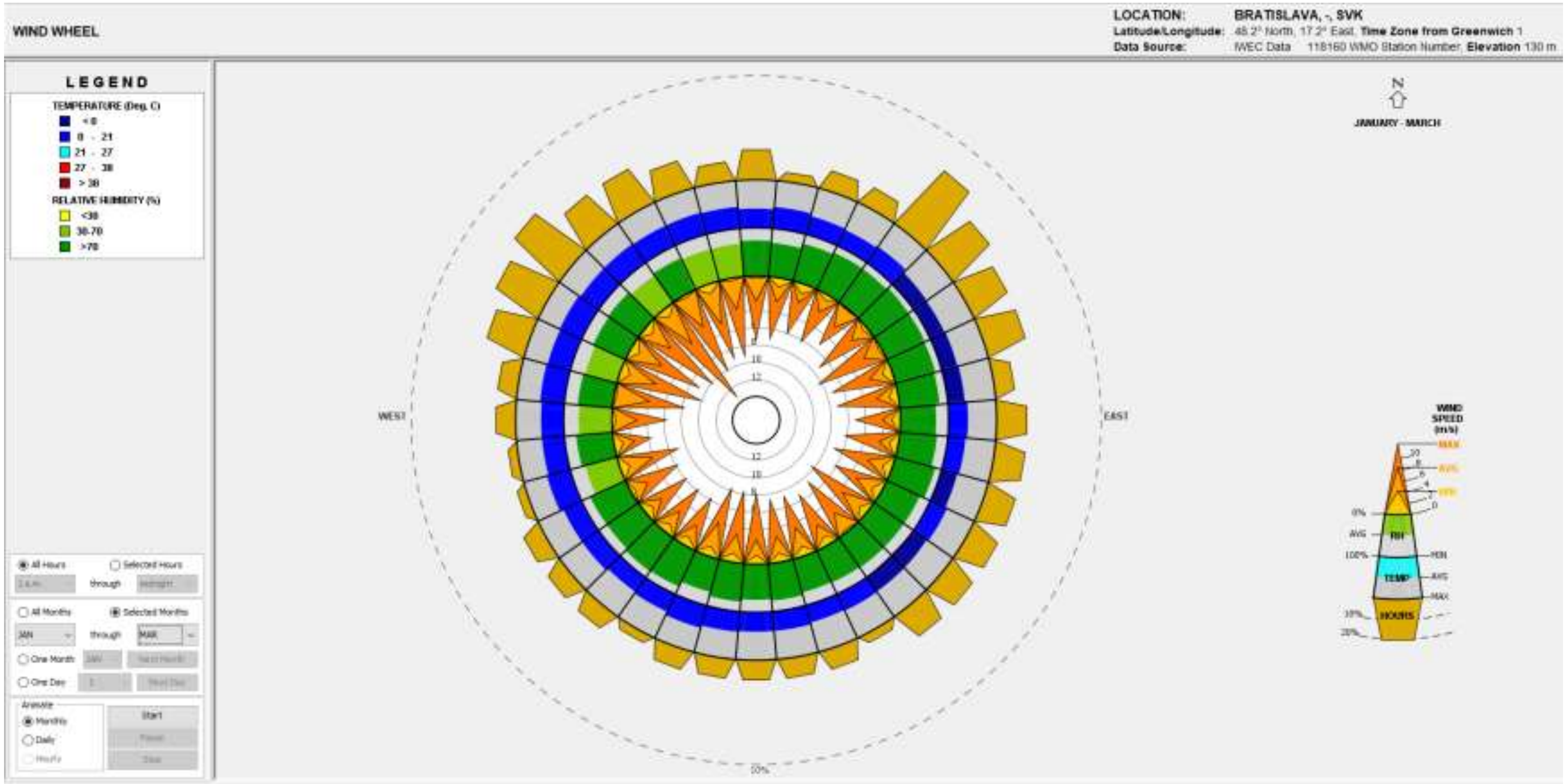

Figure 126: Wind wheel_JAN-MAR- Bratislava

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

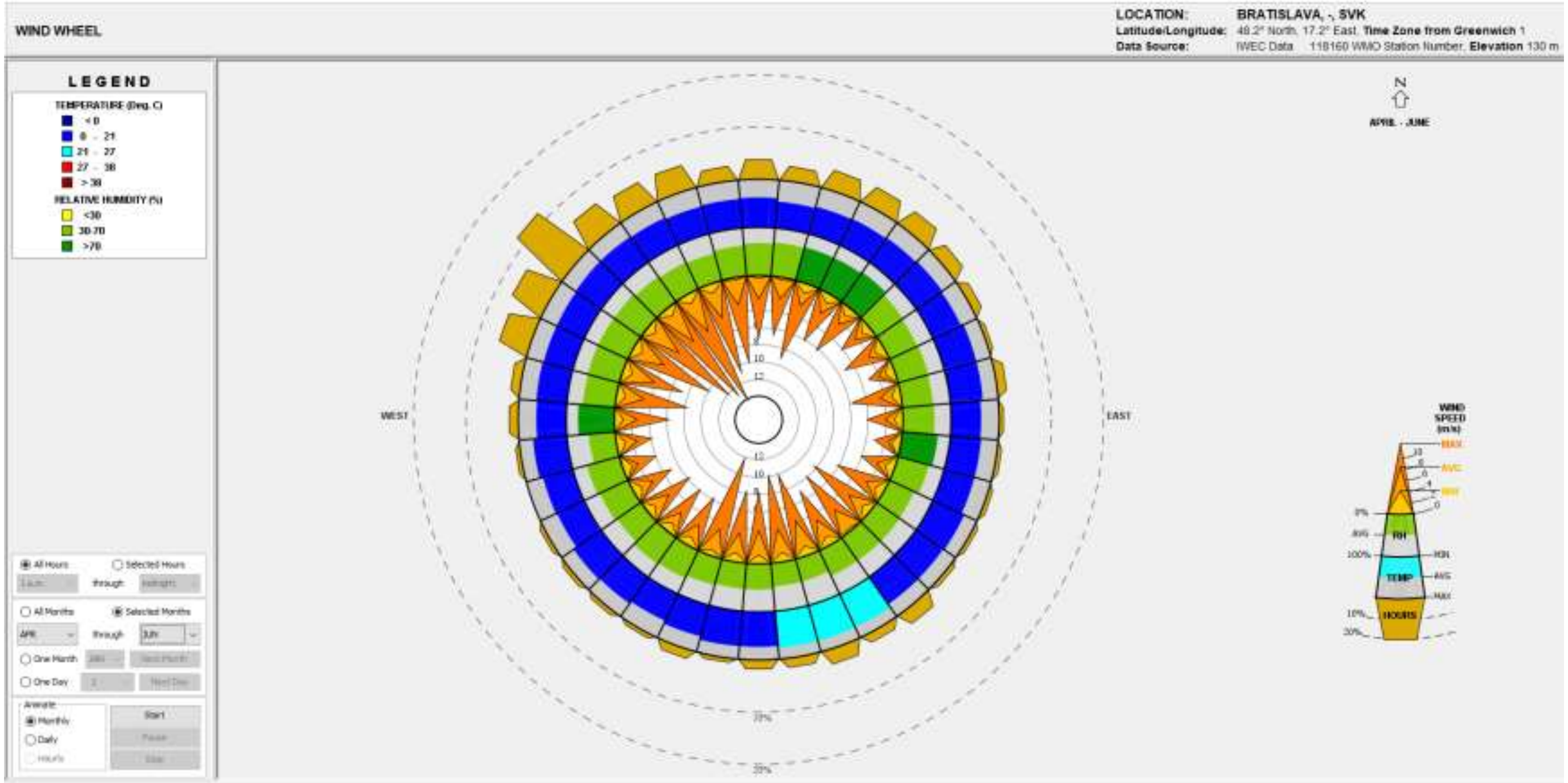

Figure 127: Wind wheel_APR-JUN- Bratislava

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

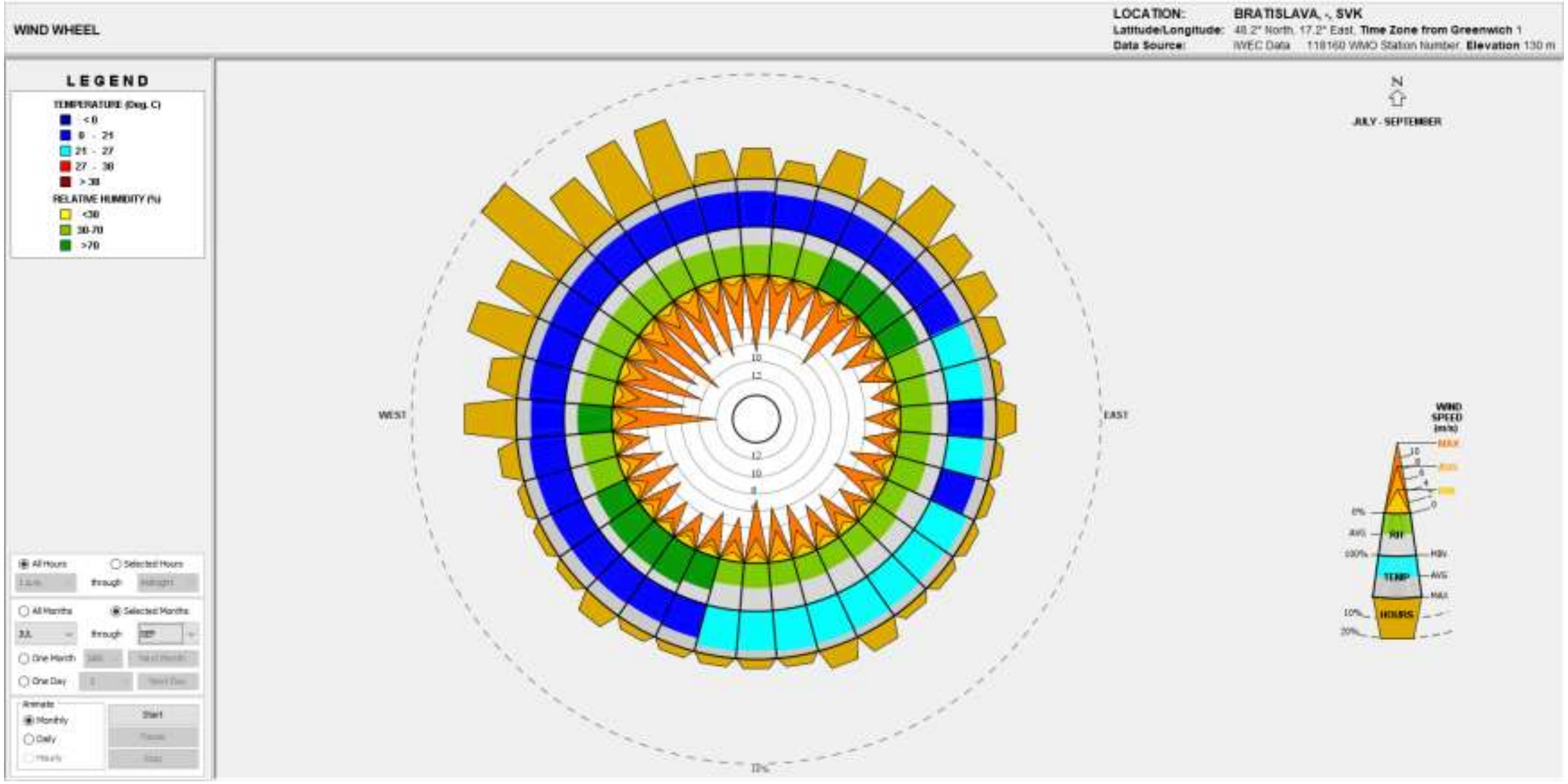

Figure 128: Wind wheel_JUL-SEP- Bratislava

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

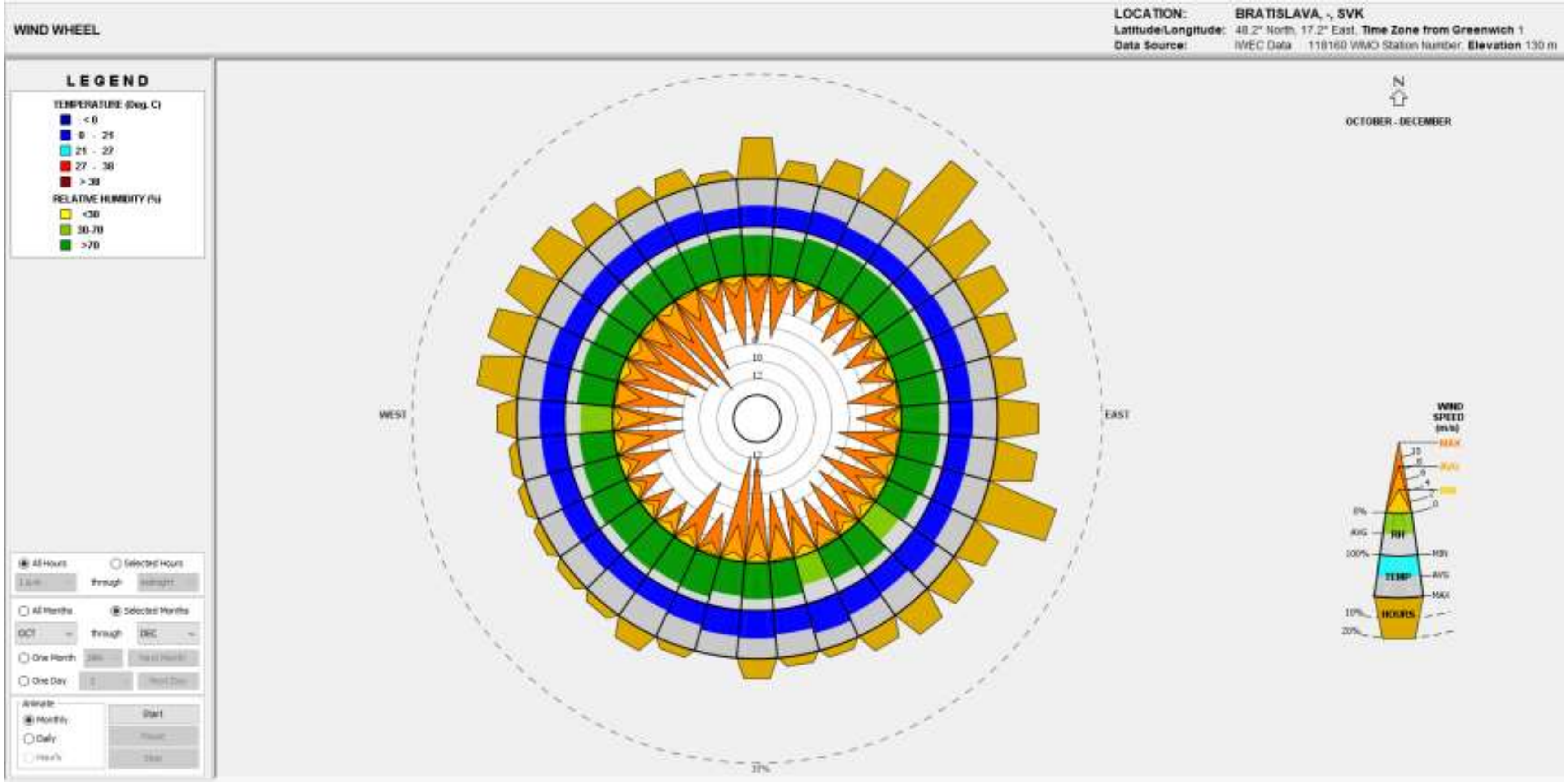

Figure 129: Wind wheel_OCT-DEC- Bratislava

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

SUN SHADING ANALYSIS

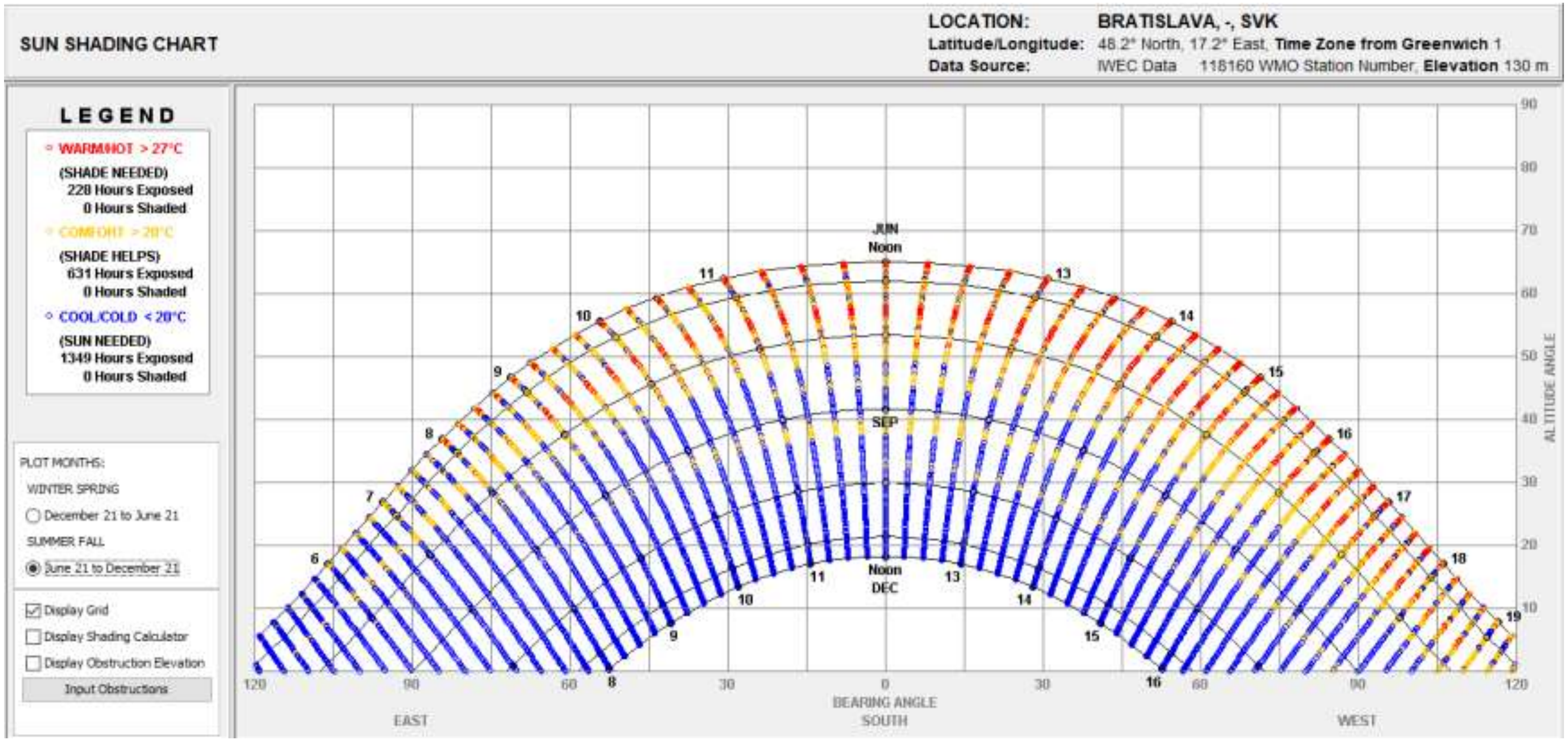

Figure 130: Summer fall chart- Bratislava

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

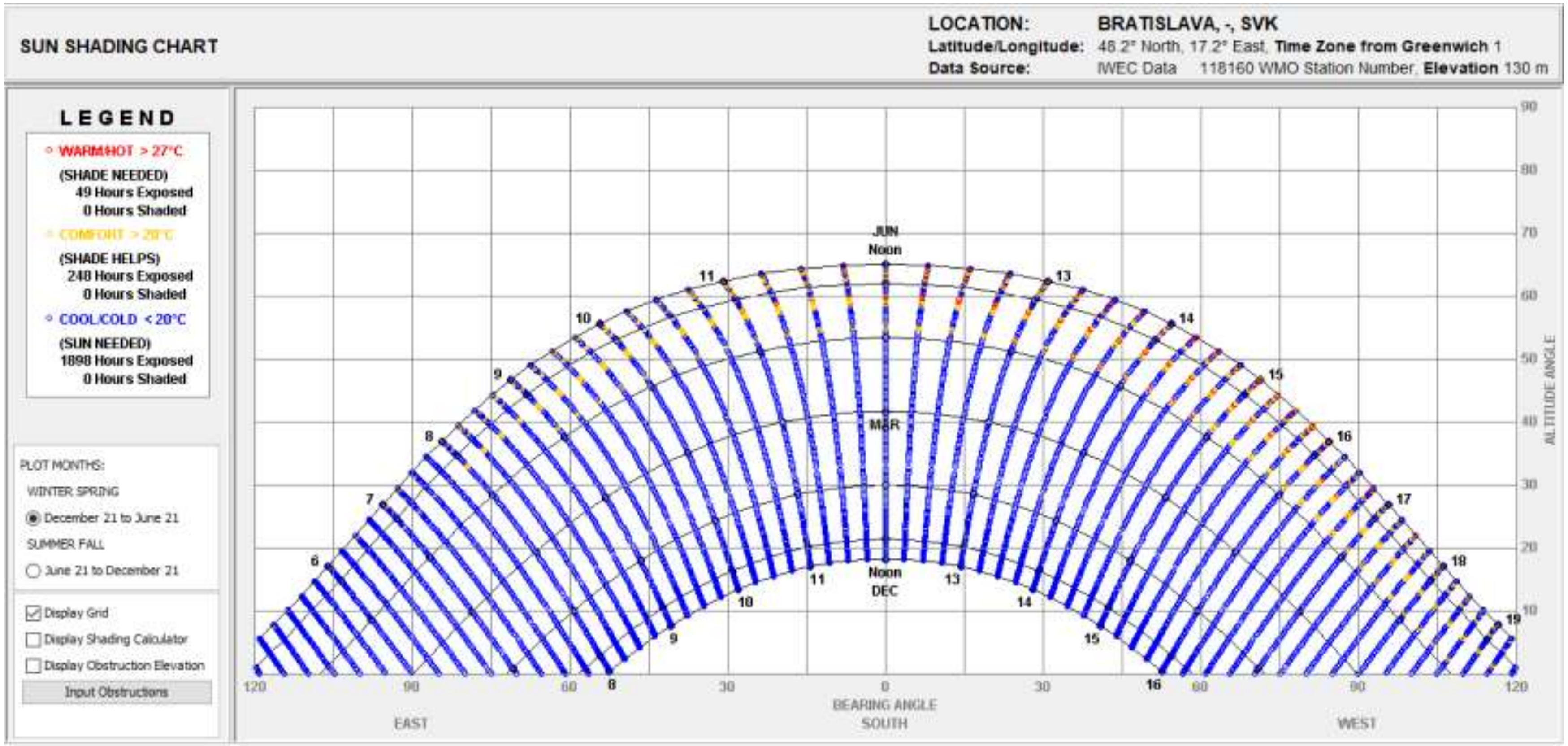

Figure 131: Winter spring chart- Bratislava

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

BIOCLIMATIC CHART – GIOVONNI DIAGRAM

According to the climate data gather, the following bioclimatic charts show the time when comfort is accomplished inside the buildings through the year time, without taking in consideration specific design strategies.

During winter, building interiors will never be comfortable without some architectural strategies, which primarily provide warmth.

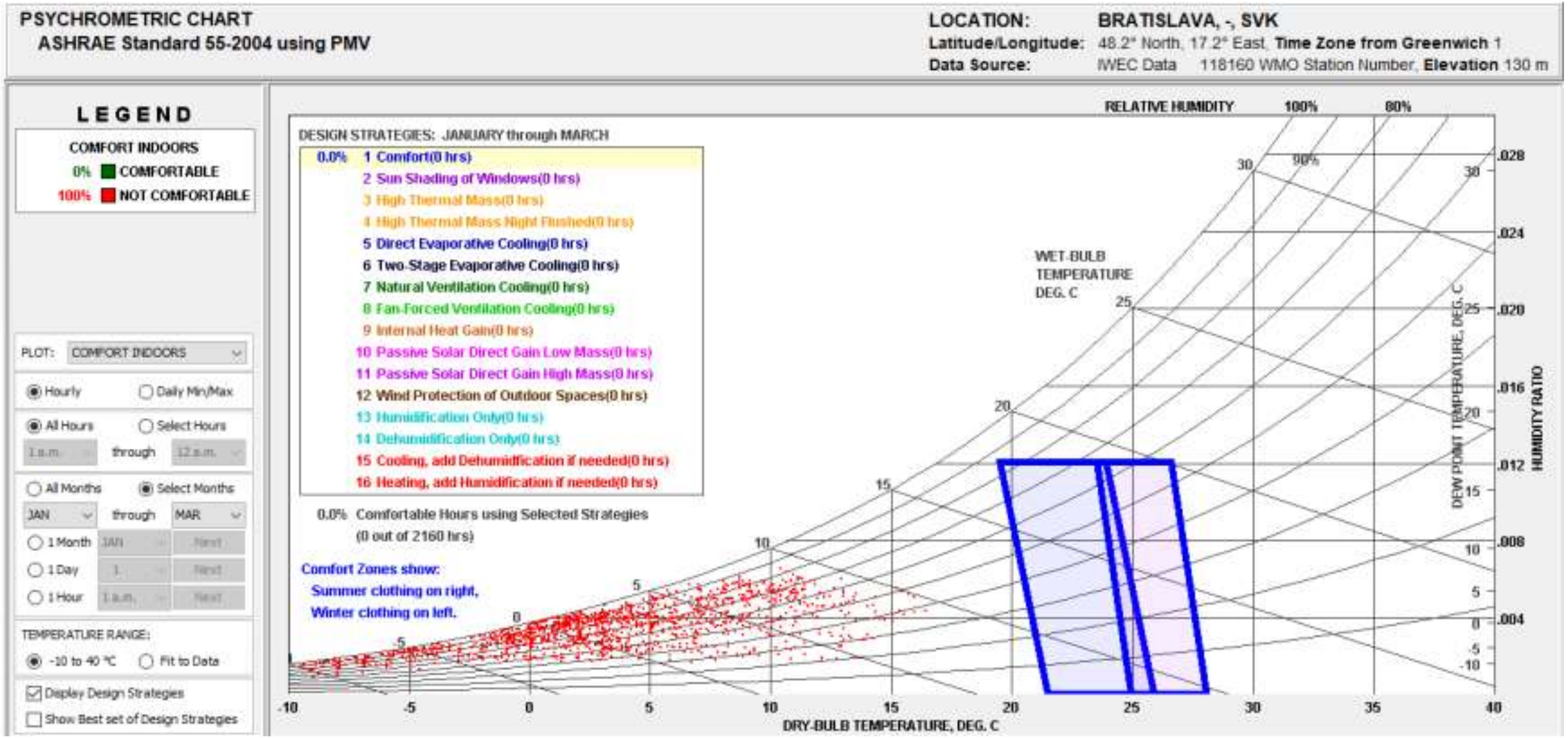

Figure 132: Psychometric chart without any strategy JAN-MAR- Bratislava

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In this city, there would be a specific period of time (14%) in the spring, when it would be comfortable inside the buildings without using any architectural strategies. It is still necessary to implement specific strategies to archive comfort most of the time.

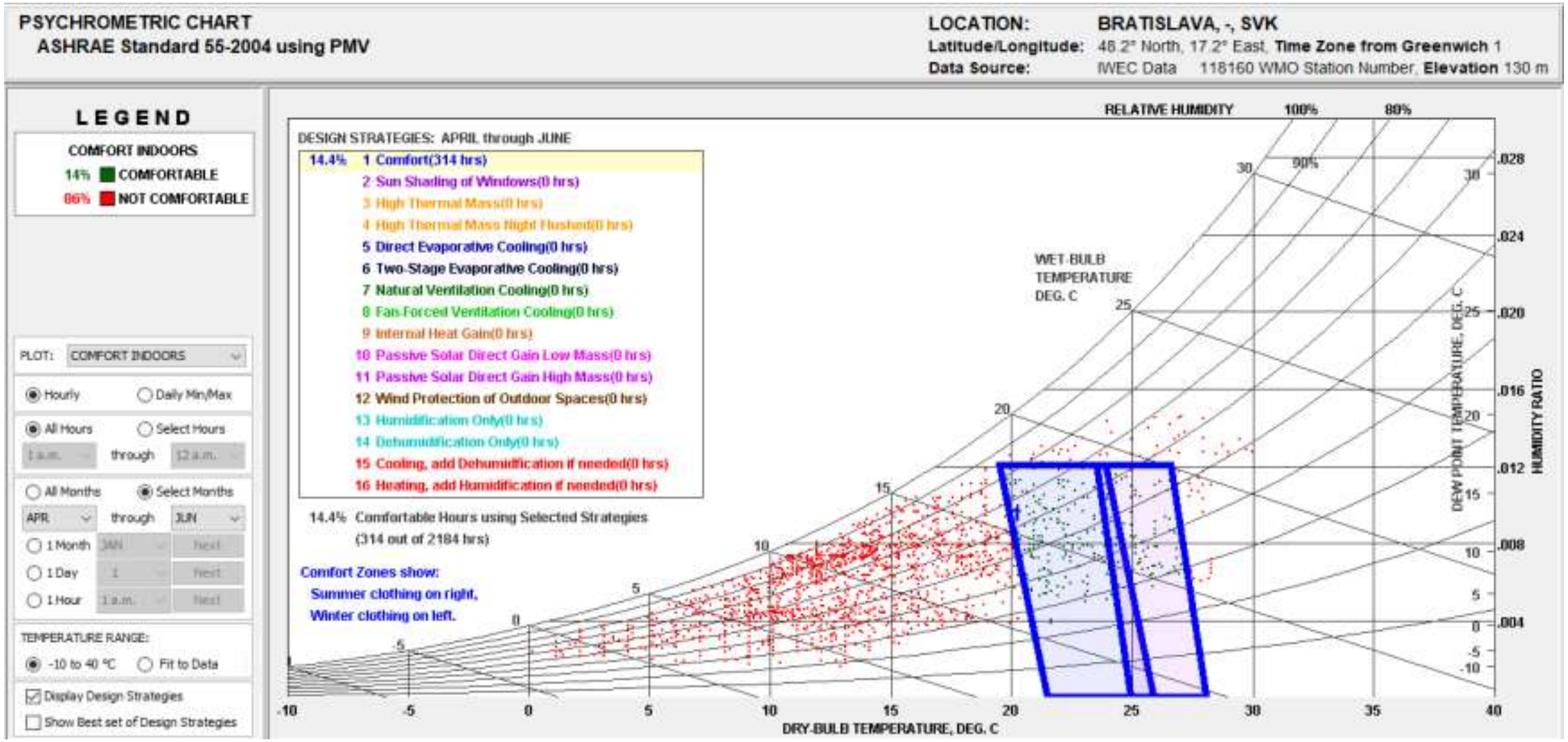

Figure 133: Psychometric chart without any strategy APR-JUN- Bratislava

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

Summer would be the most comfortable period, even when no design measures were used it would be comfortable inside the buildings a large period of time (27%).

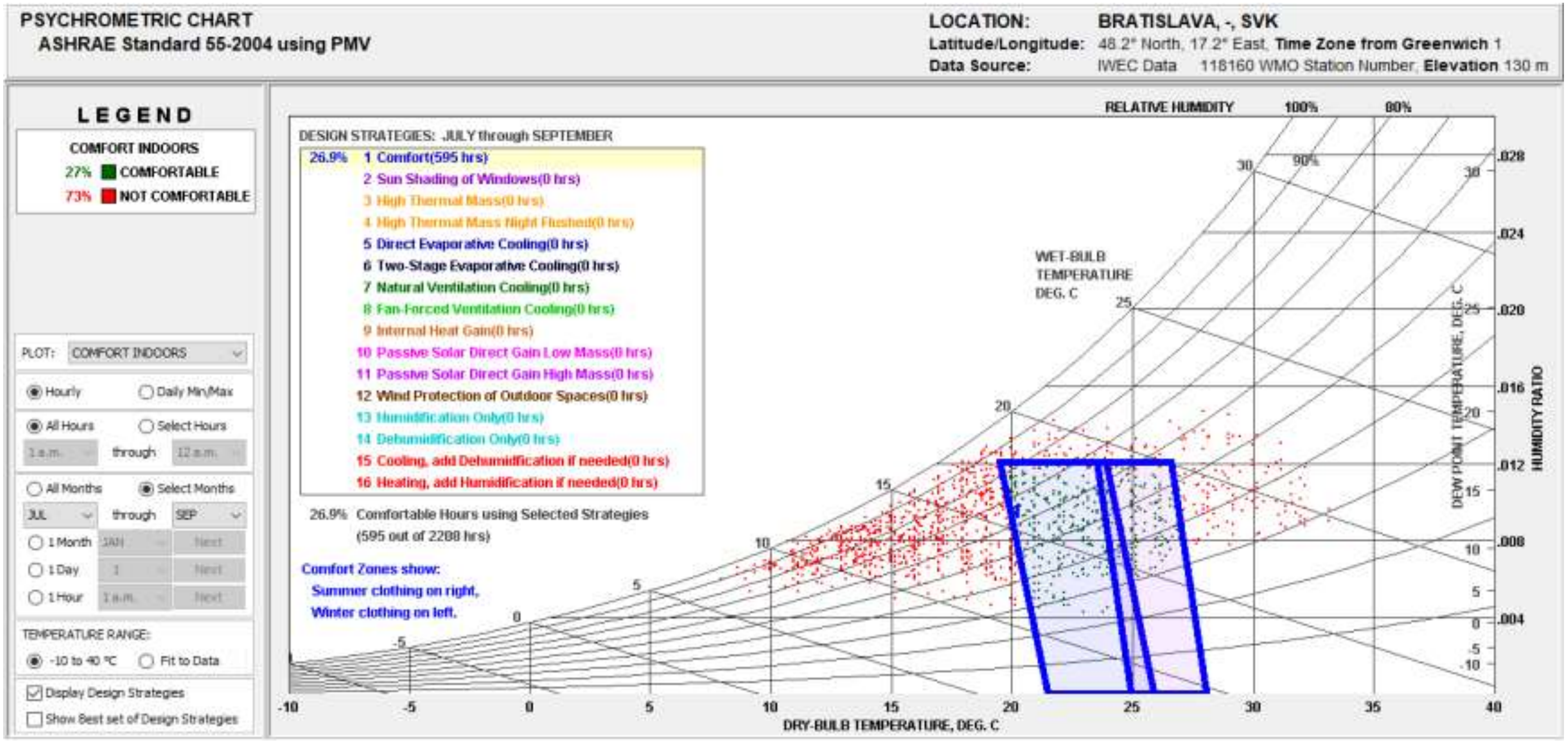

Figure 134: Psychometric chart without any strategy JUL-SEP- Bratislava

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

There would almost never be a time in the fall when the building´s interior would be pleasant without the use of any architectural techniques.

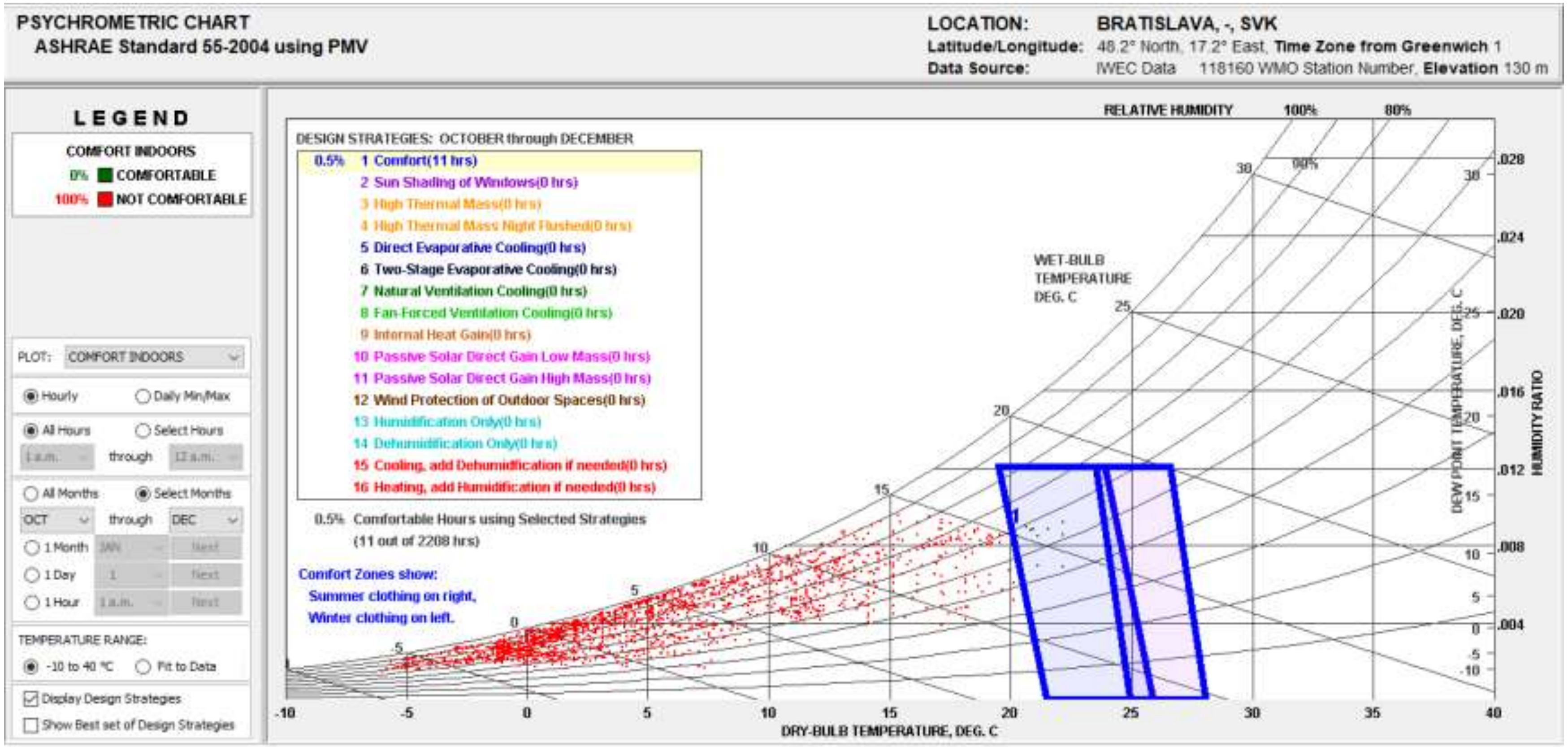

Figure 135: Psychometric chart without any strategy OCT-DEC- Bratislava

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 864374.

ANNEX 3.2. BUDAPEST LOCAL CLIMATE ANALYSIS: CURRENT CLIMATE

GENERAL CLIMATE VALUES

- Climate: Wet Continental
- Elevation: 139m
- Geographic data: Longitude: E 19,1833°, Latitude: N 47,4333°
- Mean annual temperature of around 12 °C
- Average temperature in warmest month: 21,1 °C in July
- Average temperature in coldest month: −1,4 °C in January

MONTHLY MEANS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Global Horiz Radiation (Avg Hourly)	137	208	294	360	378	381	387	372	301	233	153	107	Wh/sq.m
Direct Normal Radiation (Avg Hourly)	209	320	362	403	367	374	396	395	367	331	224	160	Wh/sq.m
Diffuse Radiation (Avg Hourly)	73	82	111	126	142	133	126	122	104	88	79	64	Wh/sq.m
Global Horiz Radiation (Max Hourly)	385	549	712	844	864	877	879	808	723	562	405	308	Wh/sq.m
Direct Normal Radiation (Max Hourly)	738	812	842	868	812	802	823	787	824	782	683	693	Wh/sq.m
Diffuse Radiation (Max Hourly)	166	216	294	354	372	347	324	278	258	215	186	137	Wh/sq.m
Global Horiz Radiation (Avg Daily Total)	1205	2087	3457	4834	5663	5978	5938	5214	3749	2483	1404	893	Wh/sq.m
Direct Normal Radiation (Avg Daily Total)	1835	3224	4252	5395	5502	5881	6078	5544	4573	3529	2049	1332	Wh/sq.m
Diffuse Radiation (Avg Daily Total)	638	820	1301	1697	2129	2095	1934	1712	1294	937	723	536	Wh/sq.m
Global Horiz Illumination (Avg Hourly)	15407	22528	31958	39078	41237	41577	42523	41144	33301	25502	17150	12234	lux
Direct Normal Illumination (Avg Hourly)	22343	32326	37766	40164	35621	35479	37777	39393	36835	33205	23685	16192	lux
Dry Bulb Temperature (Avg Monthly)	1	2	6	13	16	21	22	22	17	12	7	1	degrees C
Dew Point Temperature (Avg Monthly)	-1	0	-1	4	9	12	14	13	9	8	2	-1	degrees C
Relative Humidity (Avg Monthly)	83	77	60	60	66	61	63	60	64	79	74	83	percent
Wind Direction (Monthly Mode)	90	320	100	330	320	310	310	320	300	90	100	320	degrees
Wind Speed (Avg Monthly)	2	2	2	2	2	2	2	2	1	2	2	2	m/s
Ground Temperature (Avg Monthly of 3 Depths)	4	5	7	9	14	17	18	18	15	12	8	6	degrees C

Figure 136: General Weather data summary – Budapest

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

TEMPERATURE ANALYSIS

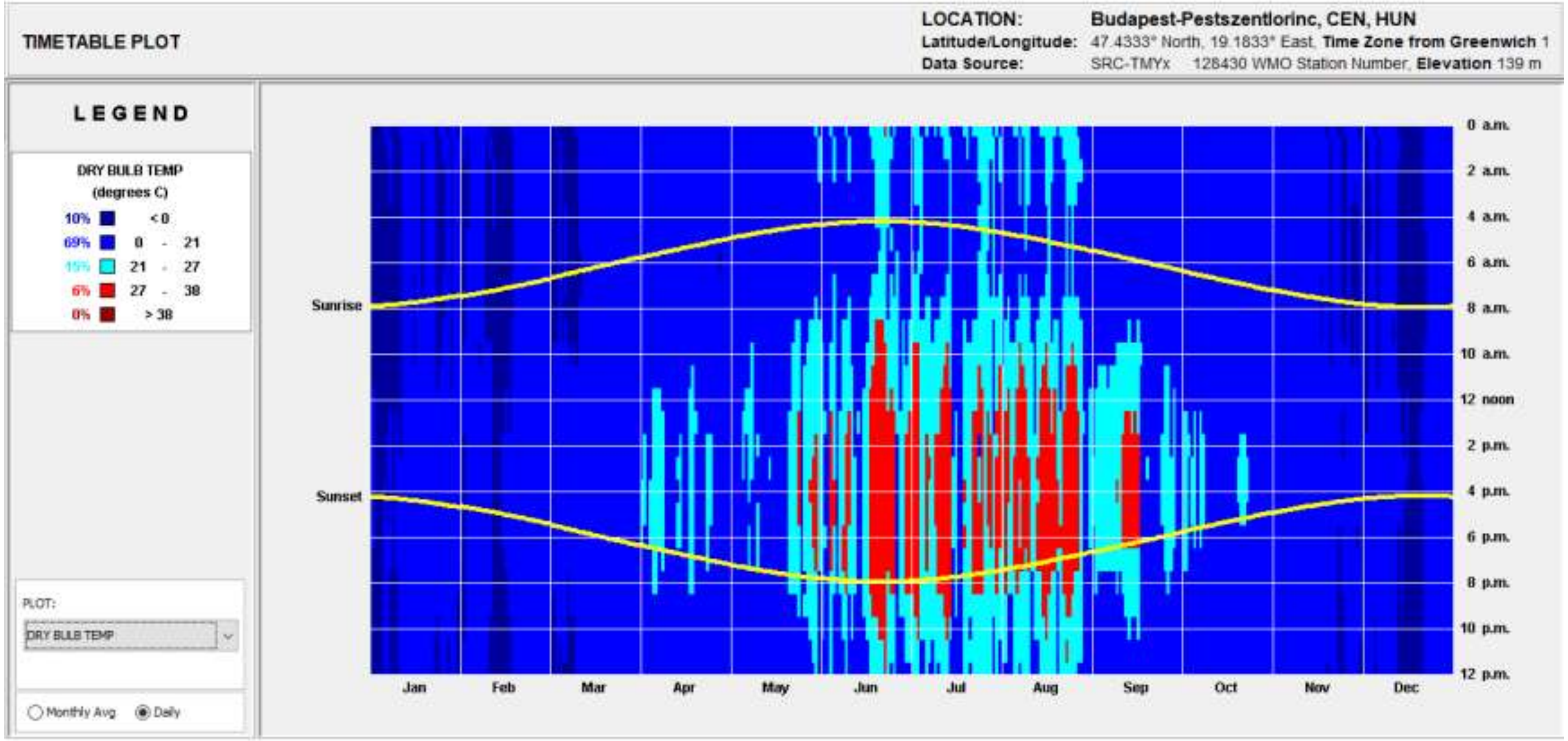

Figure 137: Dry bulb diagram– Budapest

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

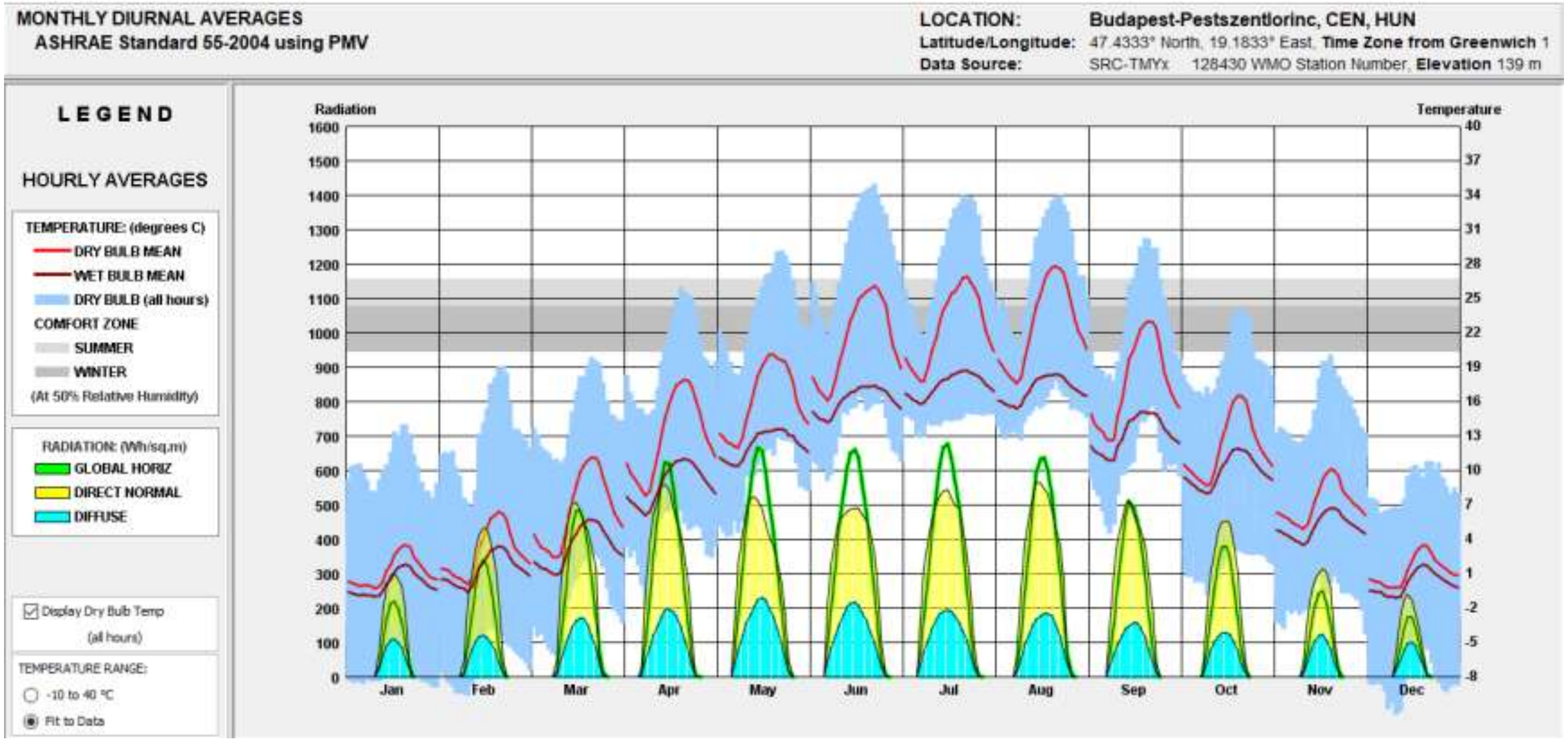

Figure 138: Diurnal average diagram– Budapest

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

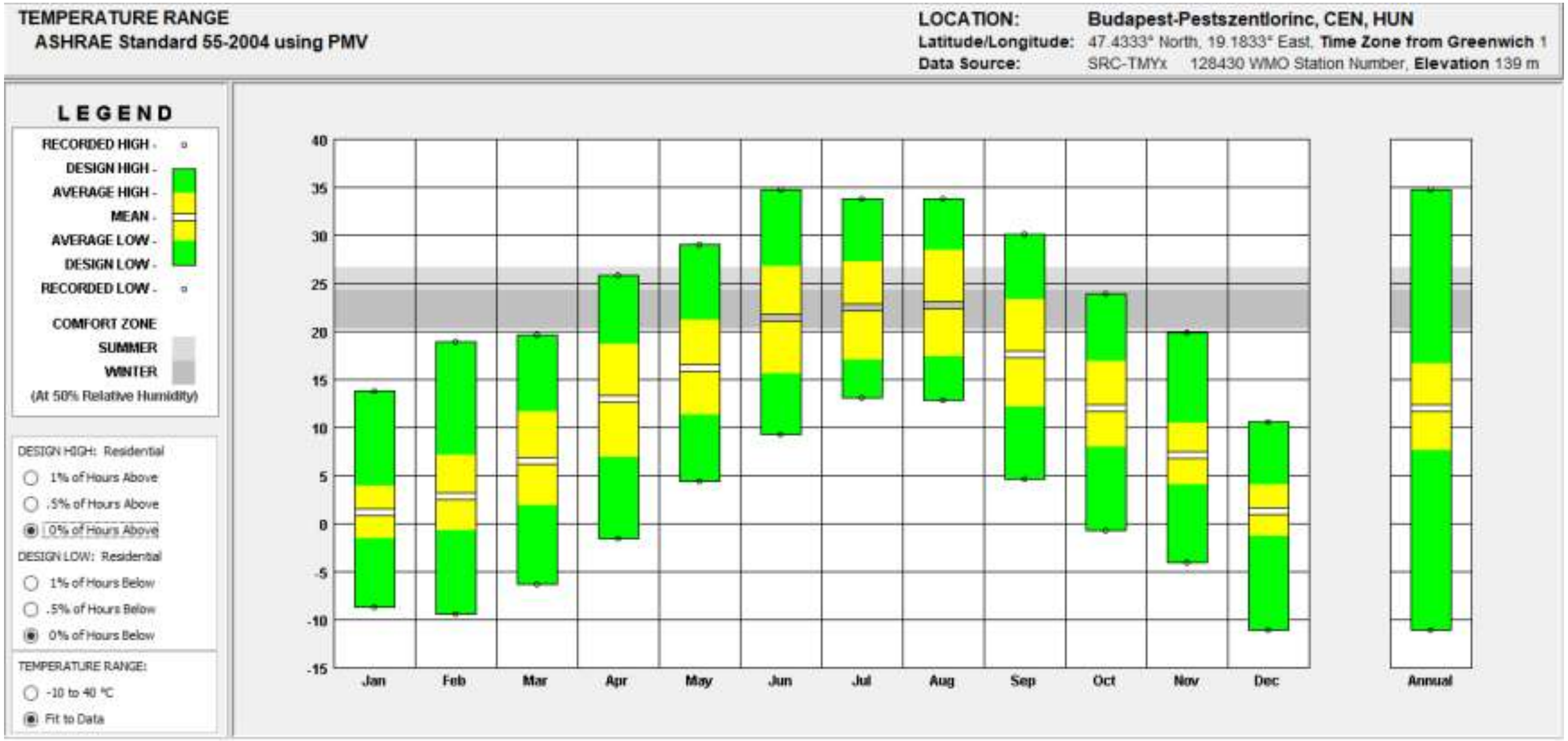

Figure 139: Temperature range diagram– Budapest

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

RELATIVE HUMIDITY

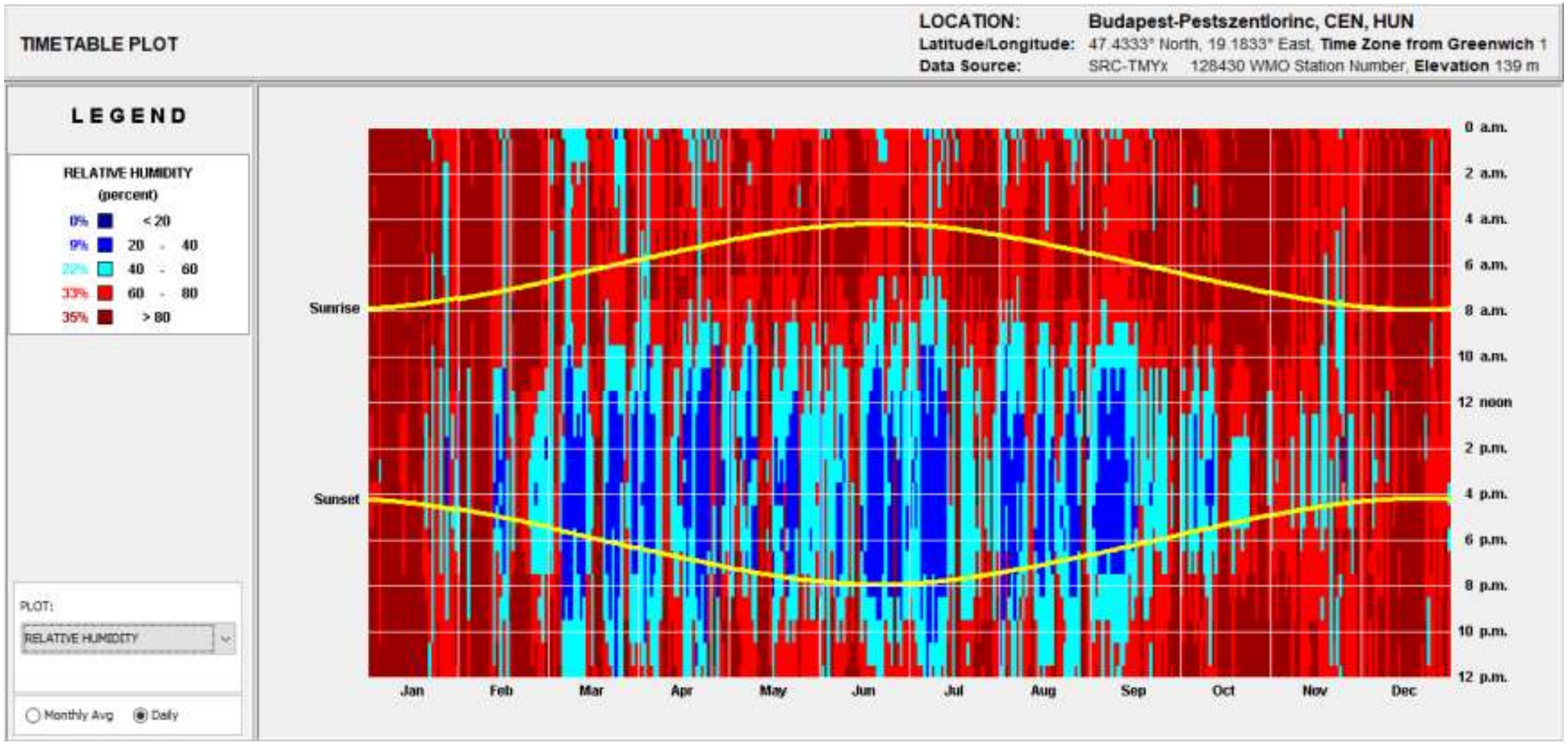

Figure 140: Relative humidity diagram– Budapest

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 864374.

SKY COVER

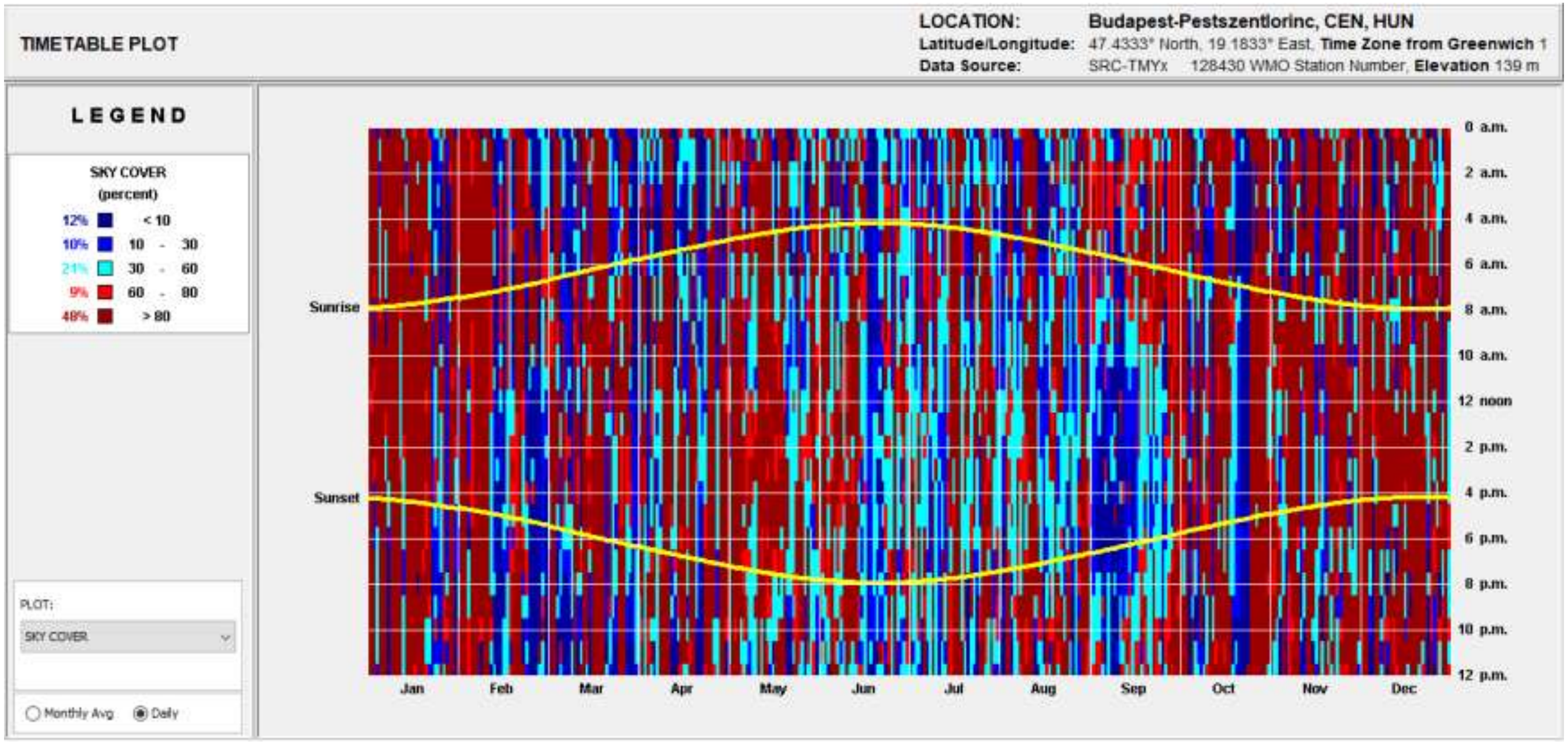

Figure 141: Sky cover diagram– Budapest

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

WIND ANALYSIS

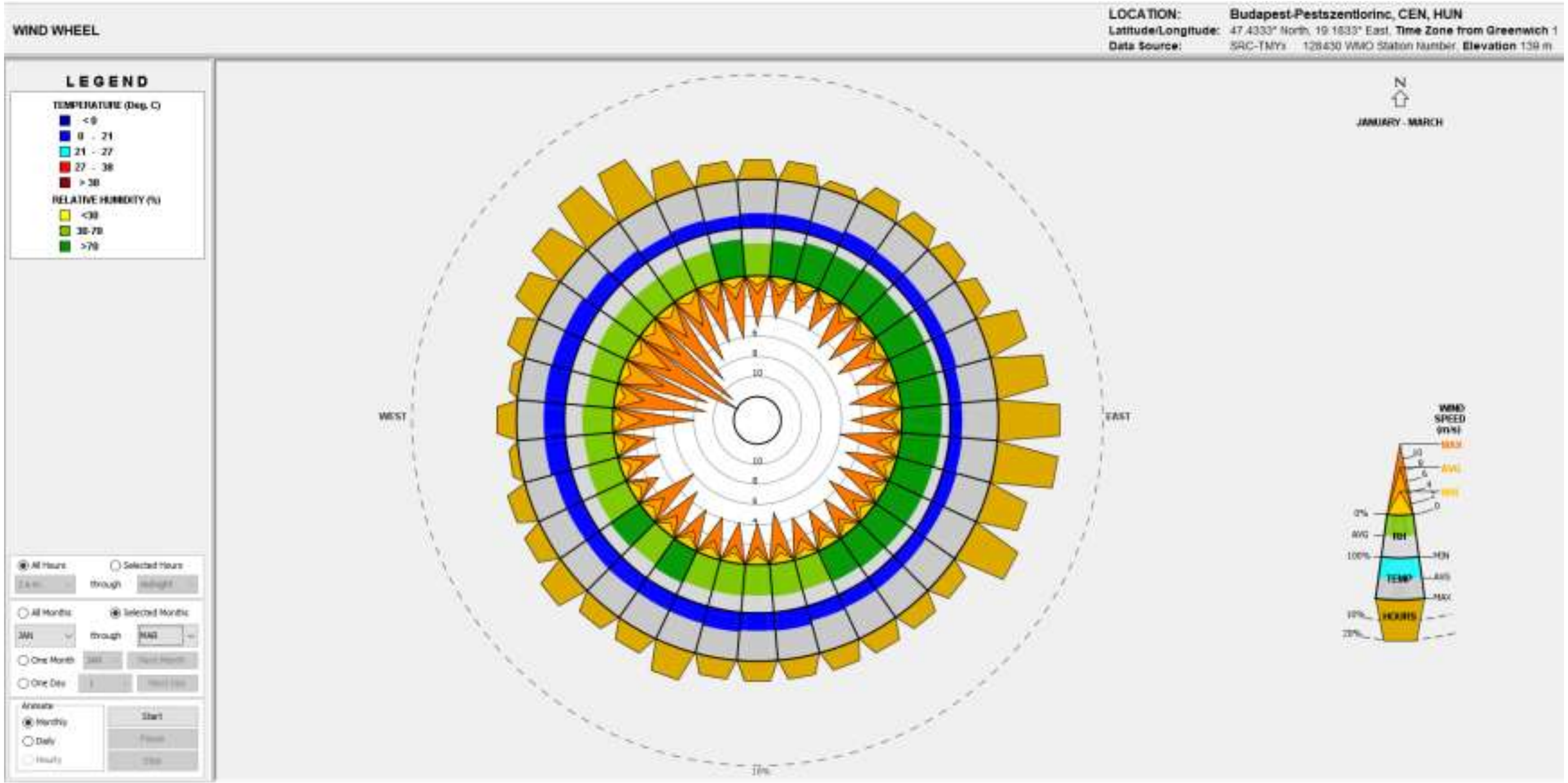

Figure 142: Wind wheel_JAN-MAR– Budapest

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

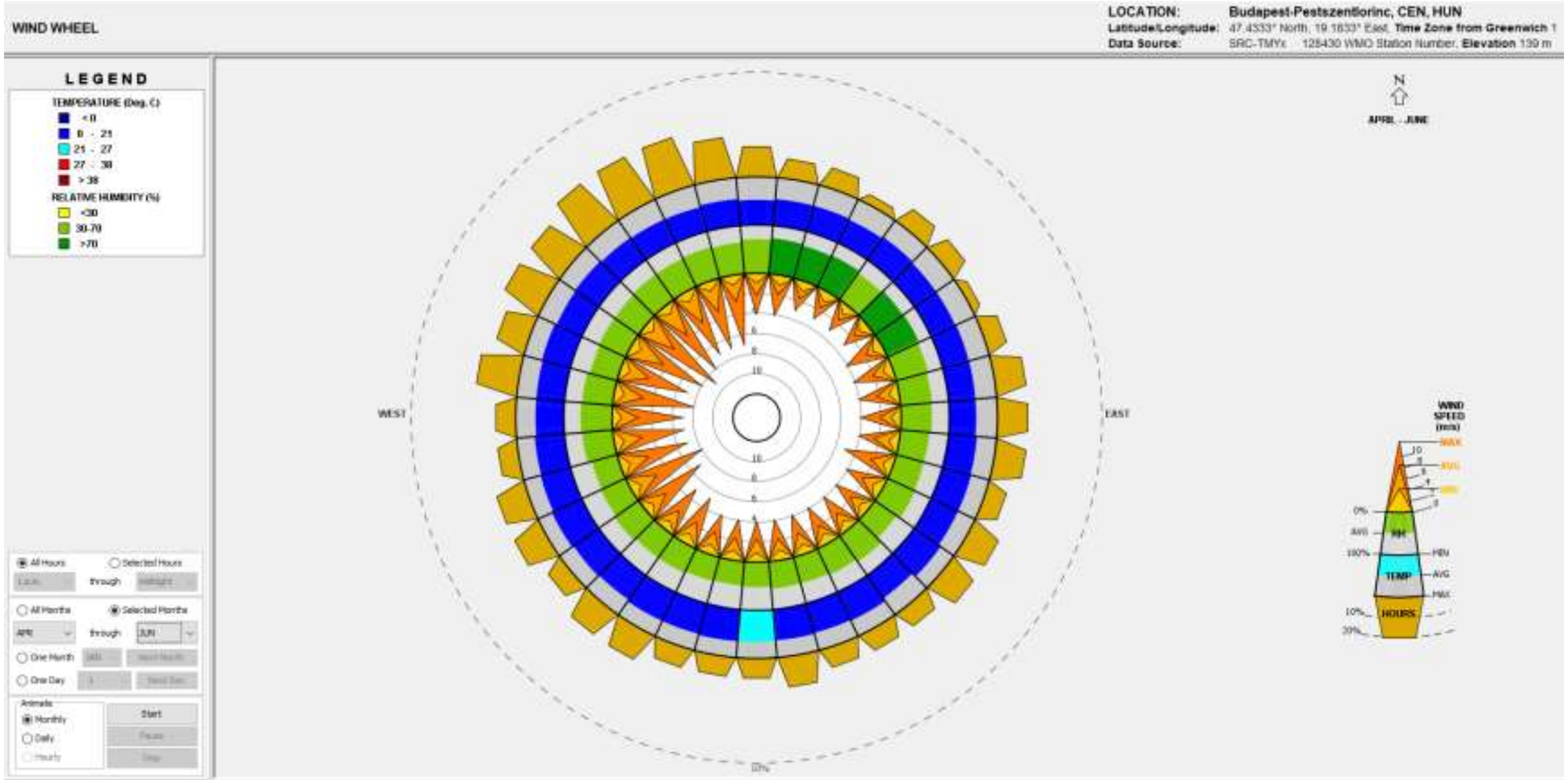

Figure 143: Wind wheel_APR-JUN– Budapest

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

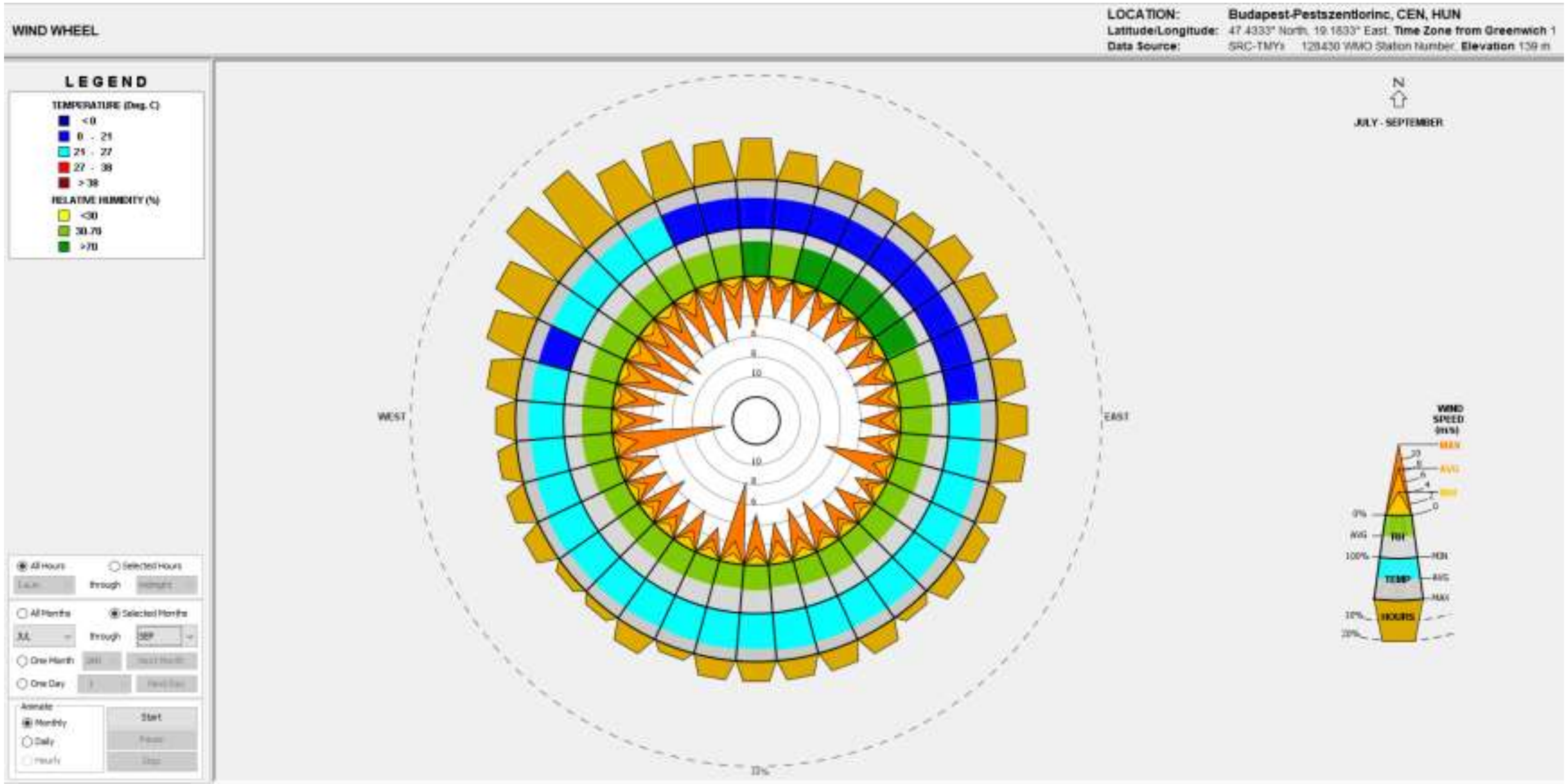

Figure 144: Wind wheel_JUL-SEP– Budapest

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

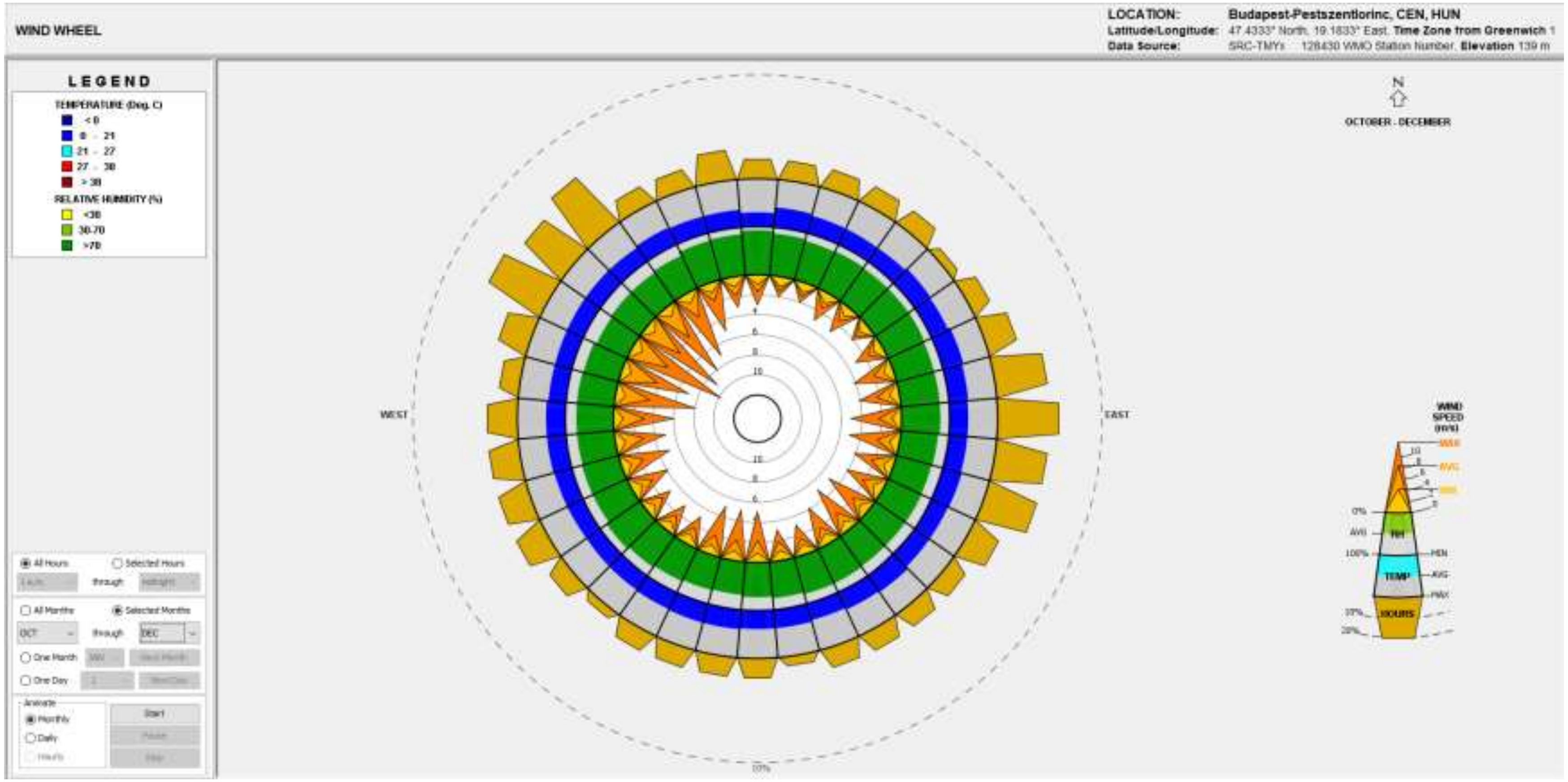

Figure 145: Wind wheel_OCT-DEC– Budapest

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

SUN SHADING ANALYSIS

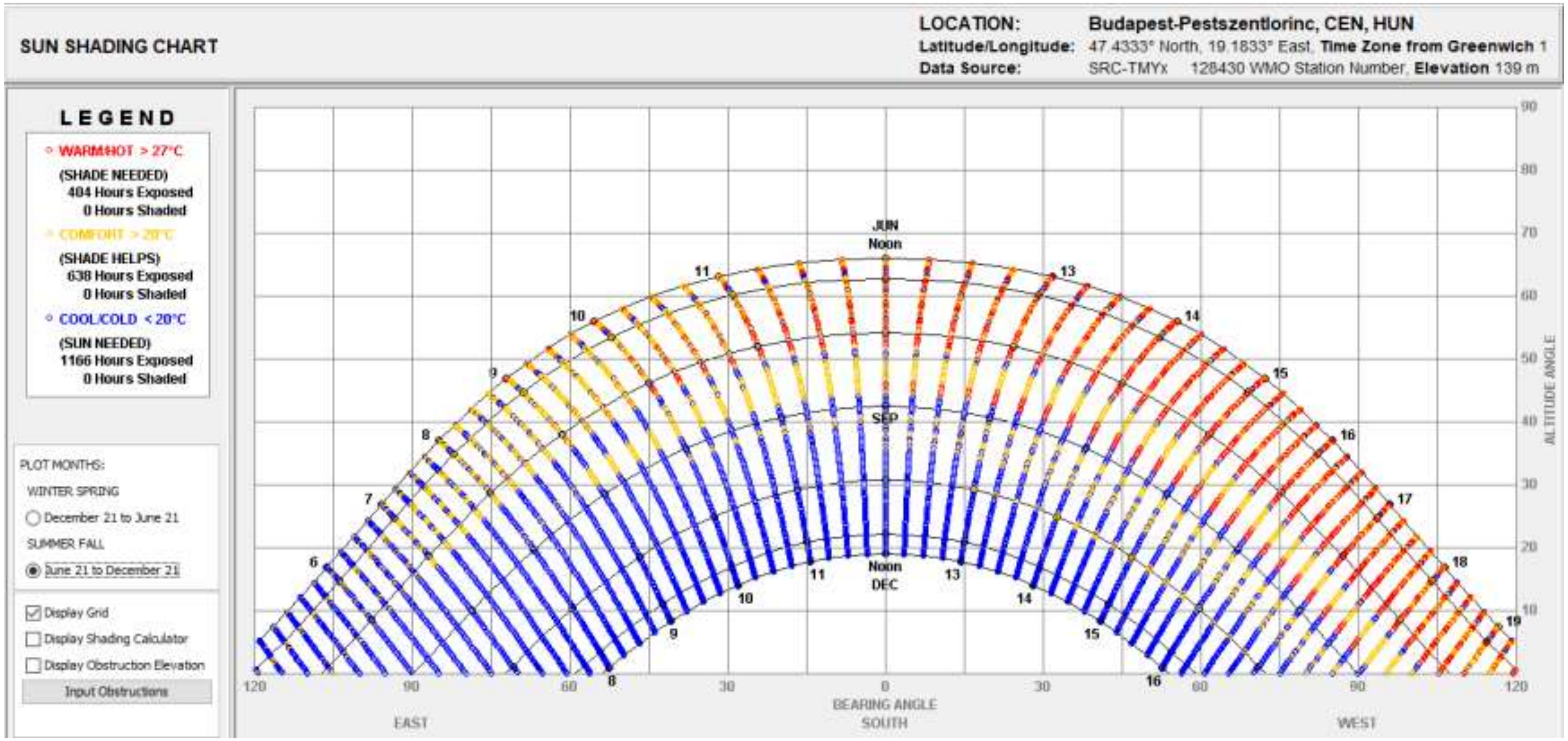

Figure 146: Summer fall chart– Budapest

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

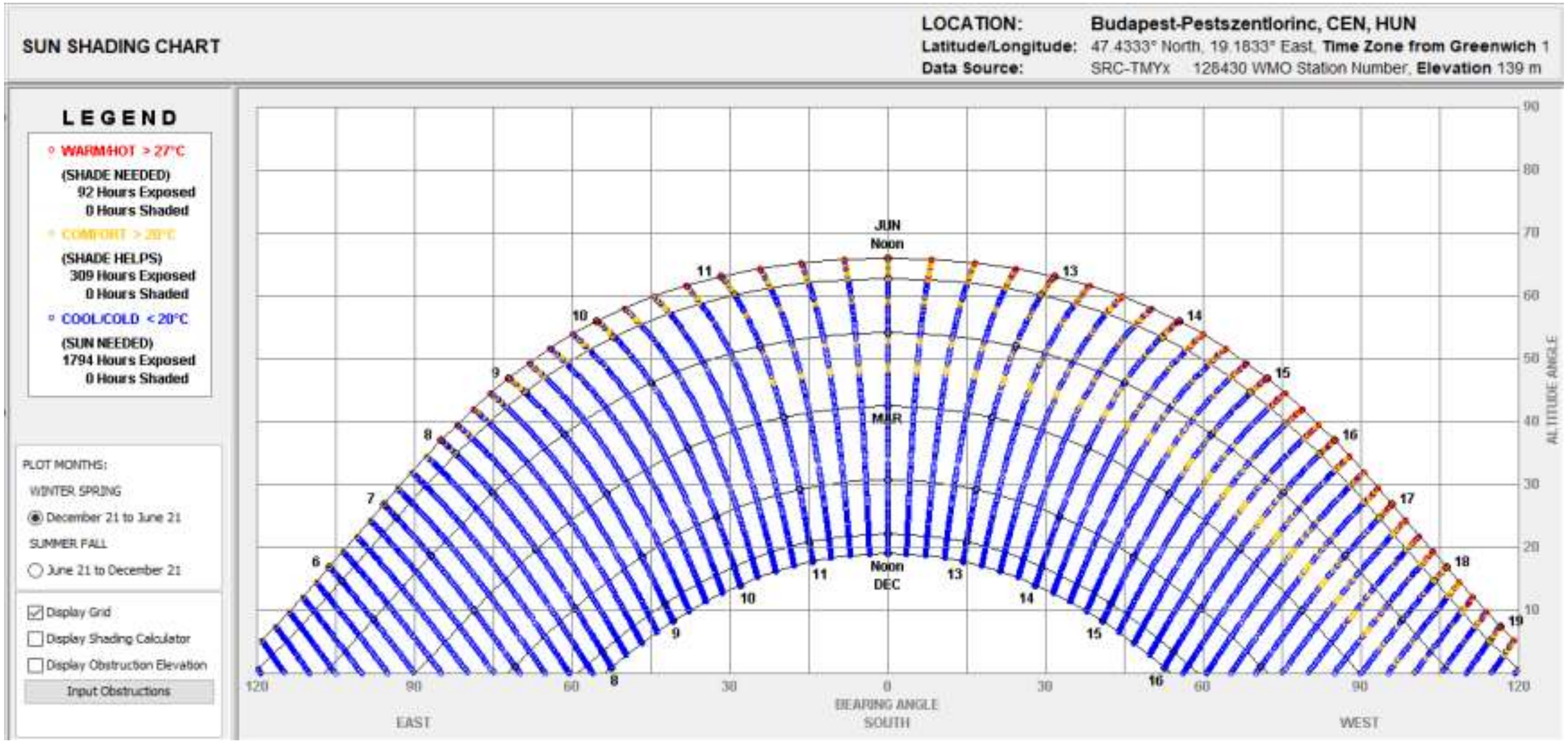

Figure 147: Winter spring chart– Budapest

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

BIOCLIMATIC CHART – GIOVONNI DIAGRAM

Without some design modifications, the interiors of the buildings would never be comfortable during the winter.

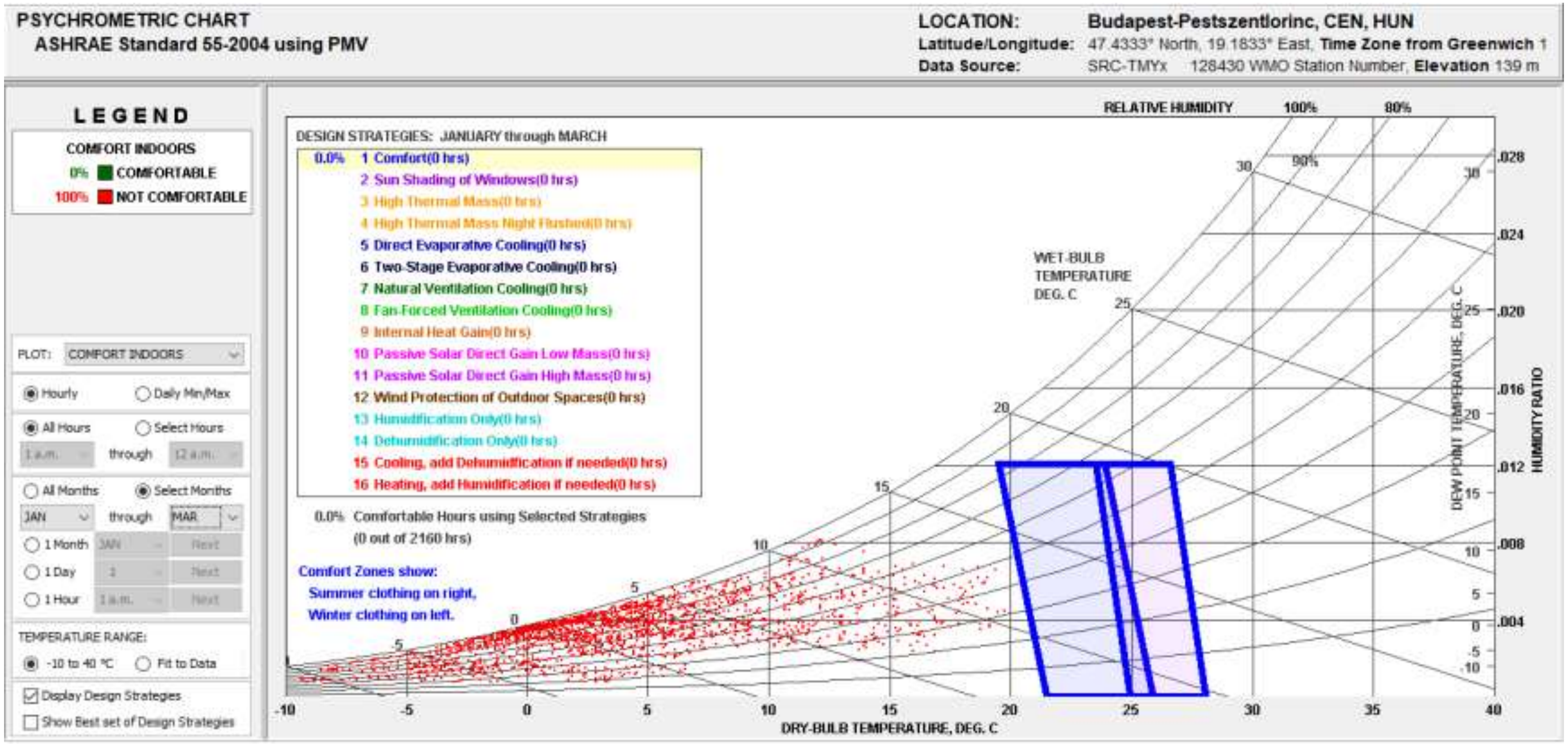

Figure 148: Psychometric chart without any strategy JAN-MAR– Budapest

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

In this scenario, there would be a period in spring months (21%) when the buildings´ interiors would be comfortable without the use of any design strategies.

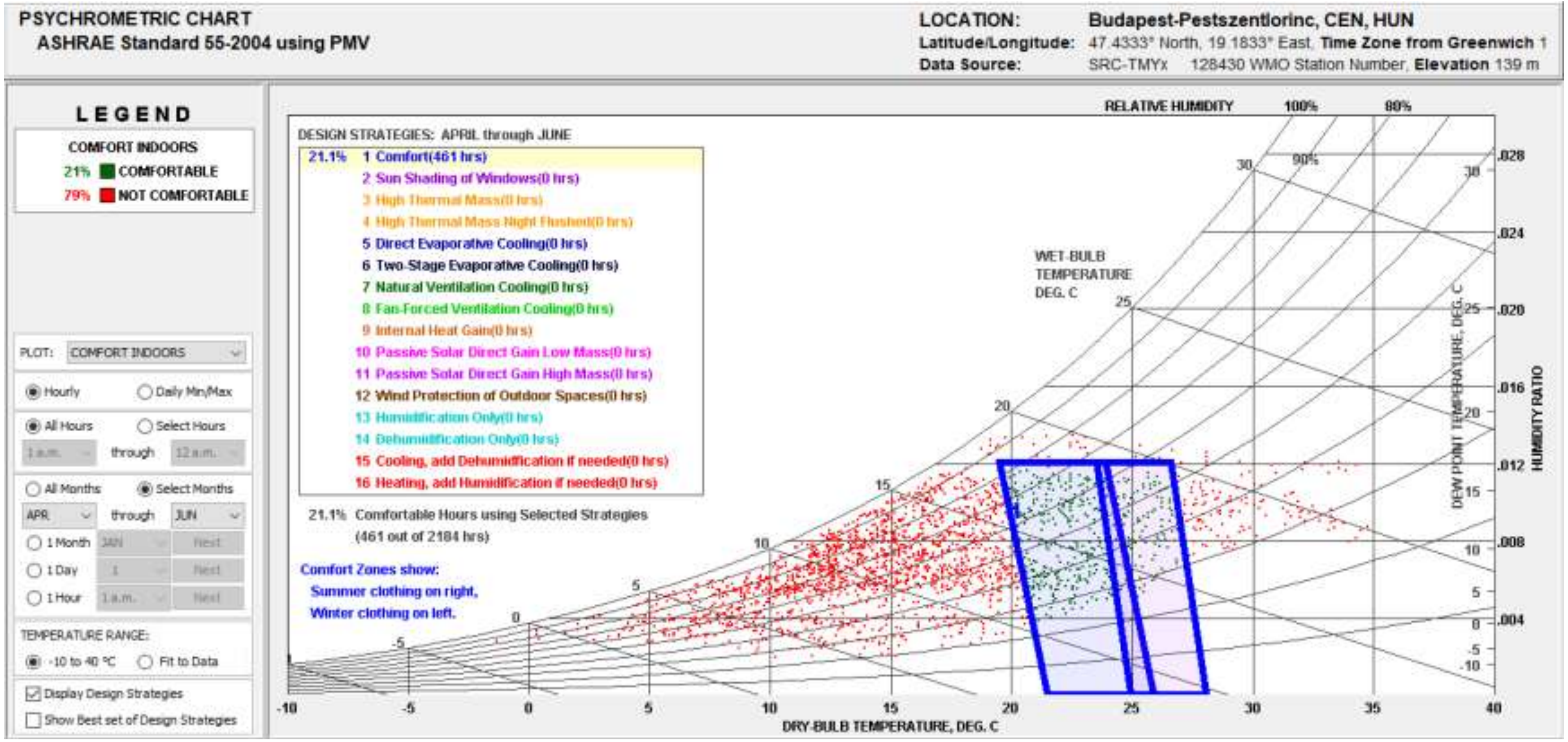

Figure 149: Psychometric chart without any strategy APR-JUN– Budapest

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

Without using any design strategies, summer time would be the most comfortable time inside the buildings (29%).

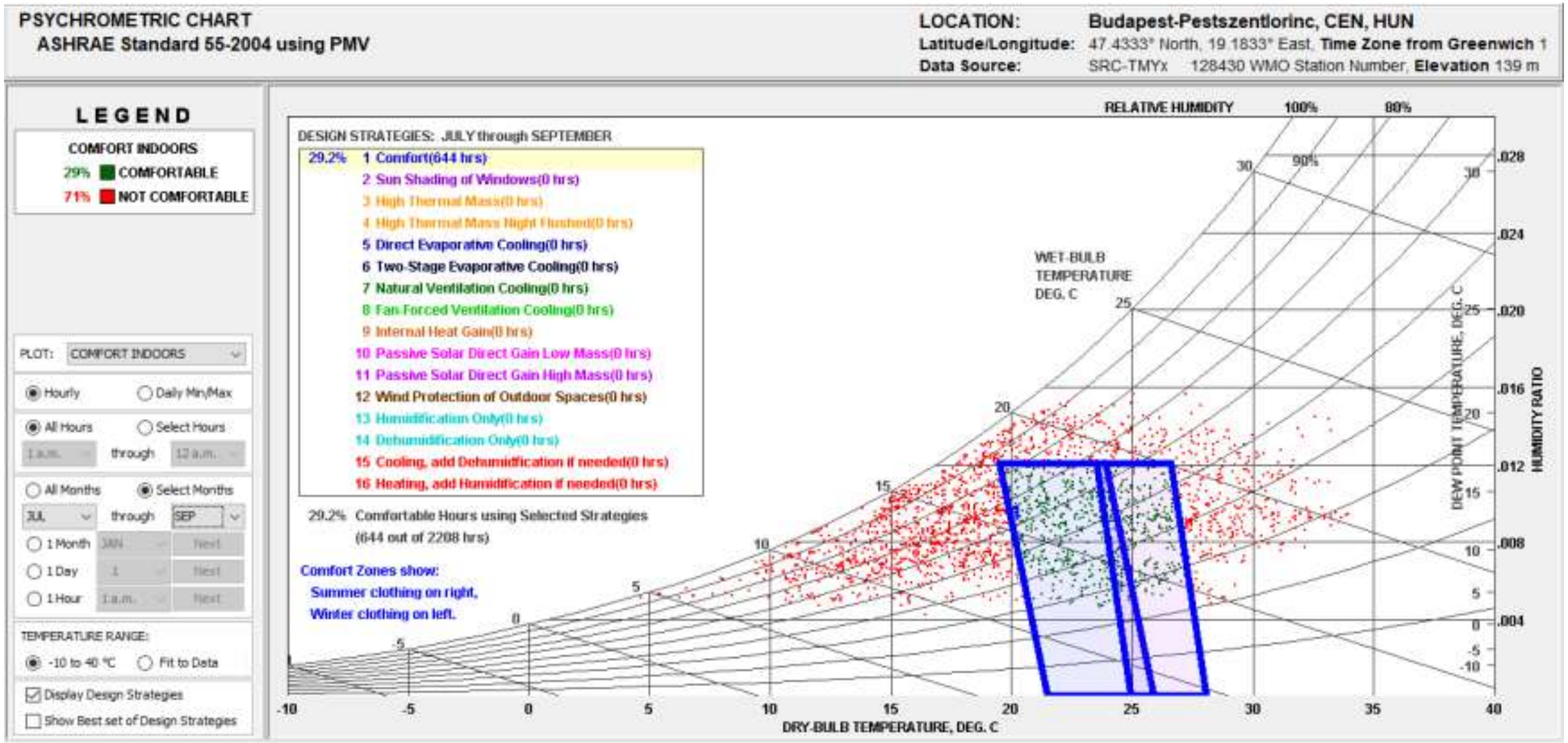

Figure 150: Psychometric chart without any strategy JUL-SEP– Budapest

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

Last but not least, there would be a brief window of time (2,2%) during the autumn months when it would be comfortable inside the buildings without using any design strategies.

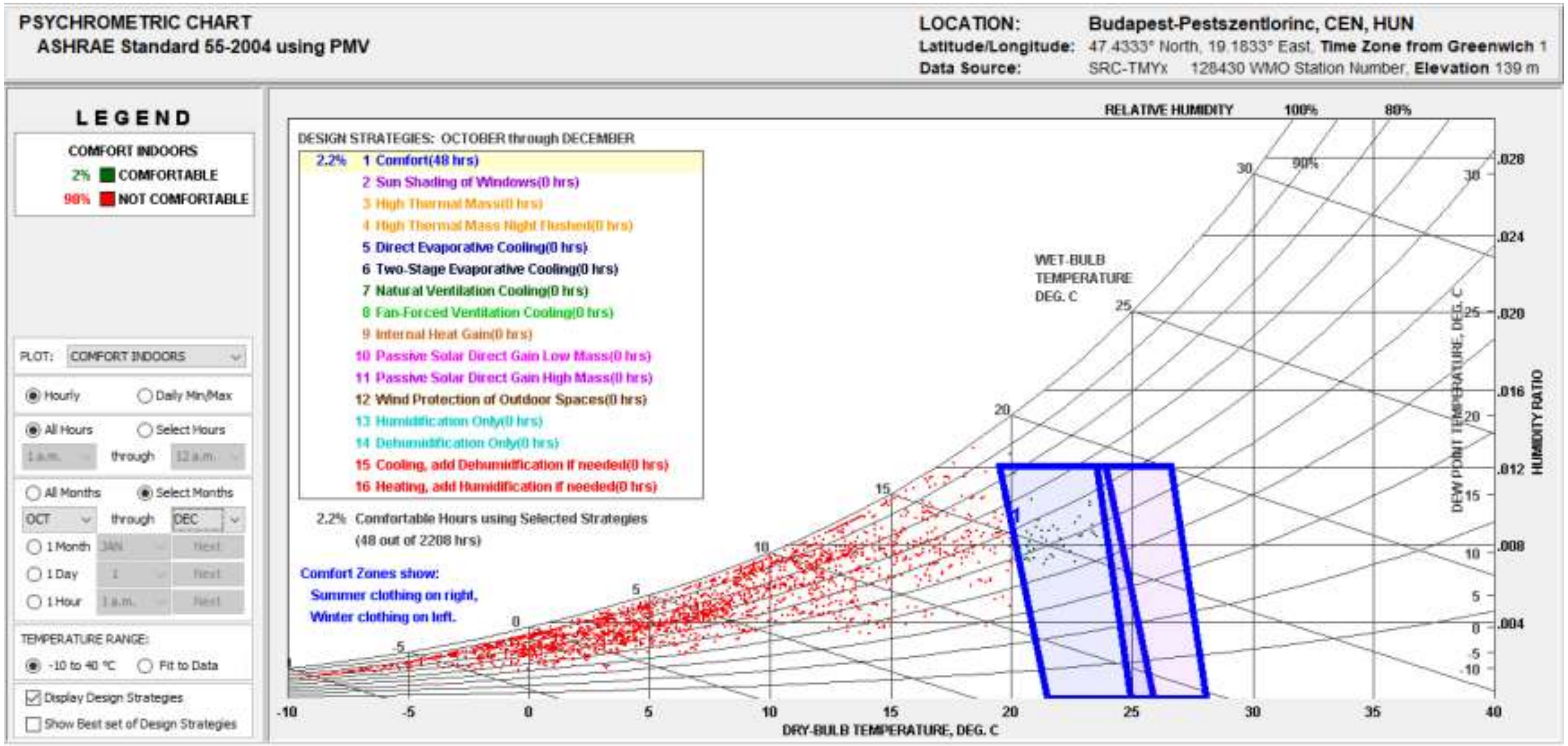

Figure 151: Psychometric chart without any strategy OCT-DEC– Budapest

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

ANNEX 3.3. COPENHAGEN LOCAL CLIMATE ANALYSIS: CURRENT CLIMATE

GENERAL CLIMATE VALUES

- Climate: Oceanic
- Elevation: 5m
- Geographic data: Longitude: E 12,6453°, Latitude: N 55,6142°
- Mean annual temperature of around 10.5 °C
- Average temperature in warmest month: 18 °C in July
- Average temperature in coldest month: 1 °C in February

MONTHLY MEANS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Global Horiz Radiation (Avg Hourly)	68	140	209	306	343	333	341	295	230	144	79	46	Wh/sq.m
Direct Normal Radiation (Avg Hourly)	124	252	278	381	387	350	371	323	293	212	144	93	Wh/sq.m
Diffuse Radiation (Avg Hourly)	44	67	97	116	119	125	123	118	98	72	47	32	Wh/sq.m
Global Horiz Radiation (Max Hourly)	223	382	528	727	797	811	814	715	572	430	286	147	Wh/sq.m
Direct Normal Radiation (Max Hourly)	545	758	794	863	875	806	852	801	758	699	665	501	Wh/sq.m
Diffuse Radiation (Max Hourly)	121	159	240	327	312	347	323	316	224	178	103	80	Wh/sq.m
Global Horiz Radiation (Avg Daily Total)	519	1308	2451	4262	5516	5714	5657	4355	2862	1470	647	319	Wh/sq.m
Direct Normal Radiation (Avg Daily Total)	936	2351	3248	5282	6212	5990	6162	4761	3622	2161	1168	637	Wh/sq.m
Diffuse Radiation (Avg Daily Total)	336	627	1136	1627	1927	2151	2039	1752	1230	728	382	222	Wh/sq.m
Global Horiz Illumination (Avg Hourly)	7849	15547	23124	33343	37515	36927	37621	33089	25887	16324	9052	5340	lux
Direct Normal Illumination (Avg Hourly)	12537	25367	27934	38327	38626	34540	36645	31989	29444	21385	14367	9267	lux
Dry Bulb Temperature (Avg Monthly)	1	2	3	7	12	17	18	17	14	10	6	3	degrees C
Dew Point Temperature (Avg Monthly)	0	0	0	2	7	11	12	13	11	7	4	1	degrees C
Relative Humidity (Avg Monthly)	87	84	78	71	73	72	70	76	83	84	86	86	percent
Wind Direction (Monthly Mode)	40	250	280	280	160	150	280	240	250	220	160	250	degrees
Wind Speed (Avg Monthly)	5	5	6	5	4	4	4	4	5	5	5	5	m/s
Ground Temperature (Avg Monthly of 3 Depths)	3	4	5	7	11	14	15	14	12	10	7	4	degrees C

Figure 152: General Weather data summary - Copenhagen

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

TEMPERATURE ANALYSIS

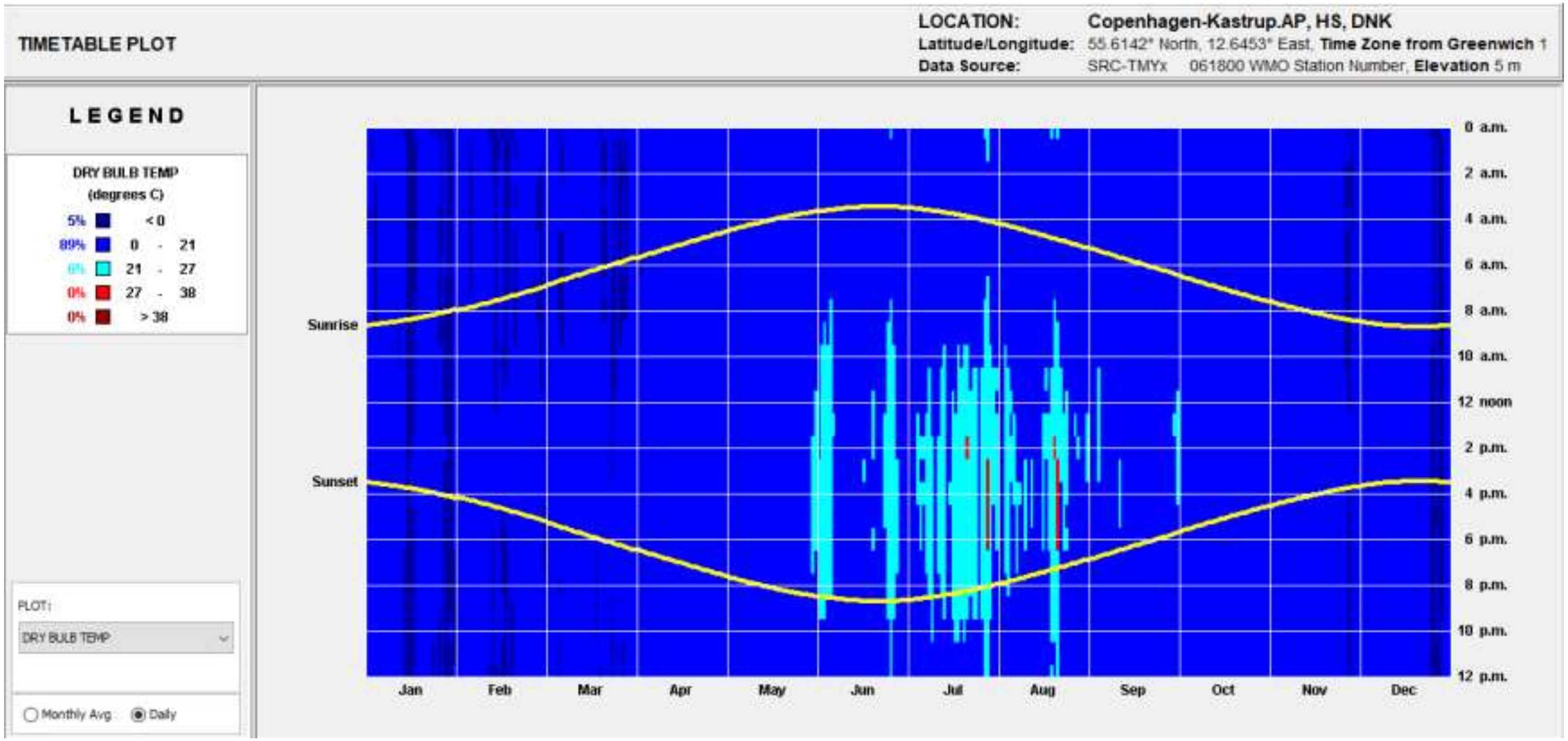

Figure 153: Dry bulb diagram- Copenhagen

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

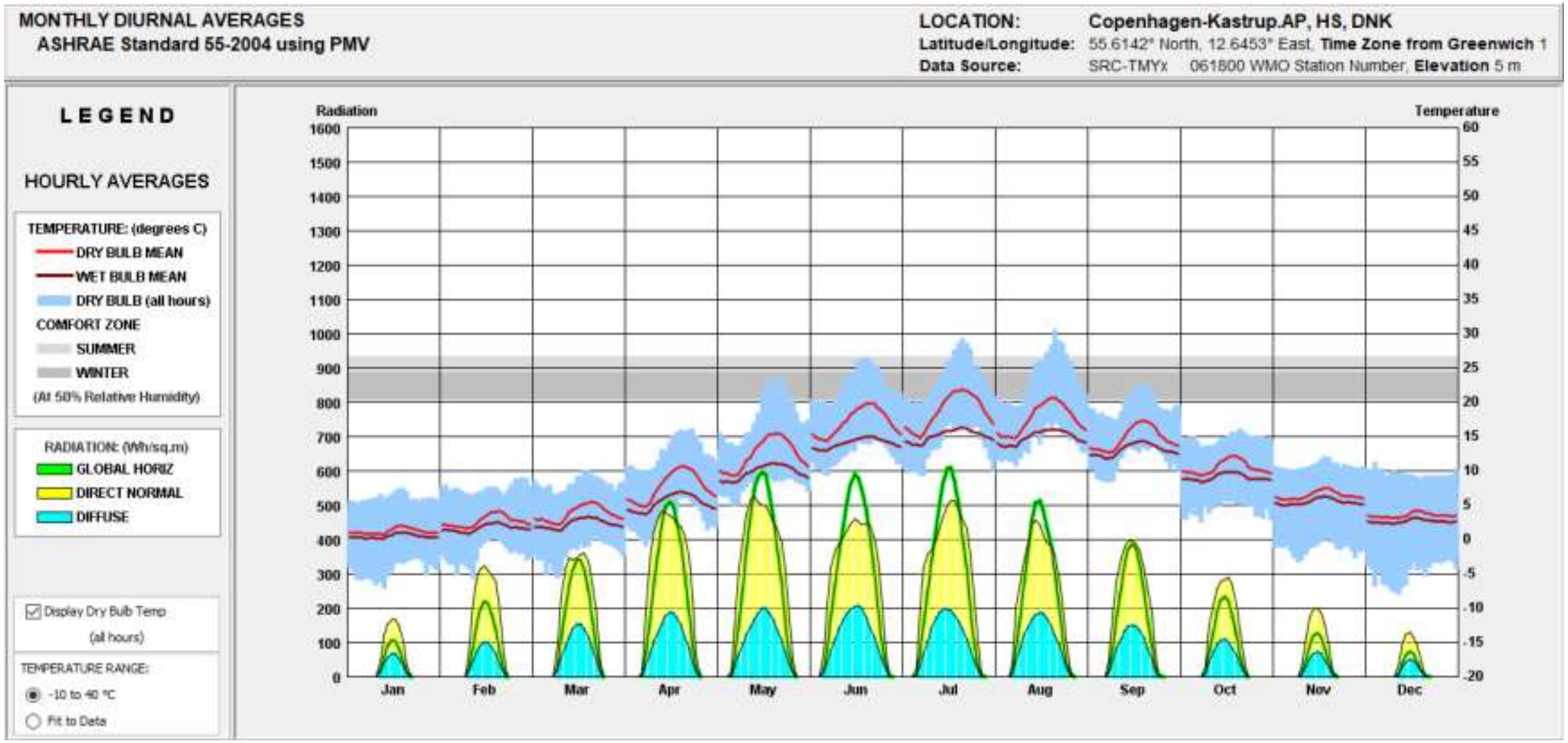

Figure 154: Diurnal average diagram- Copenhagen

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

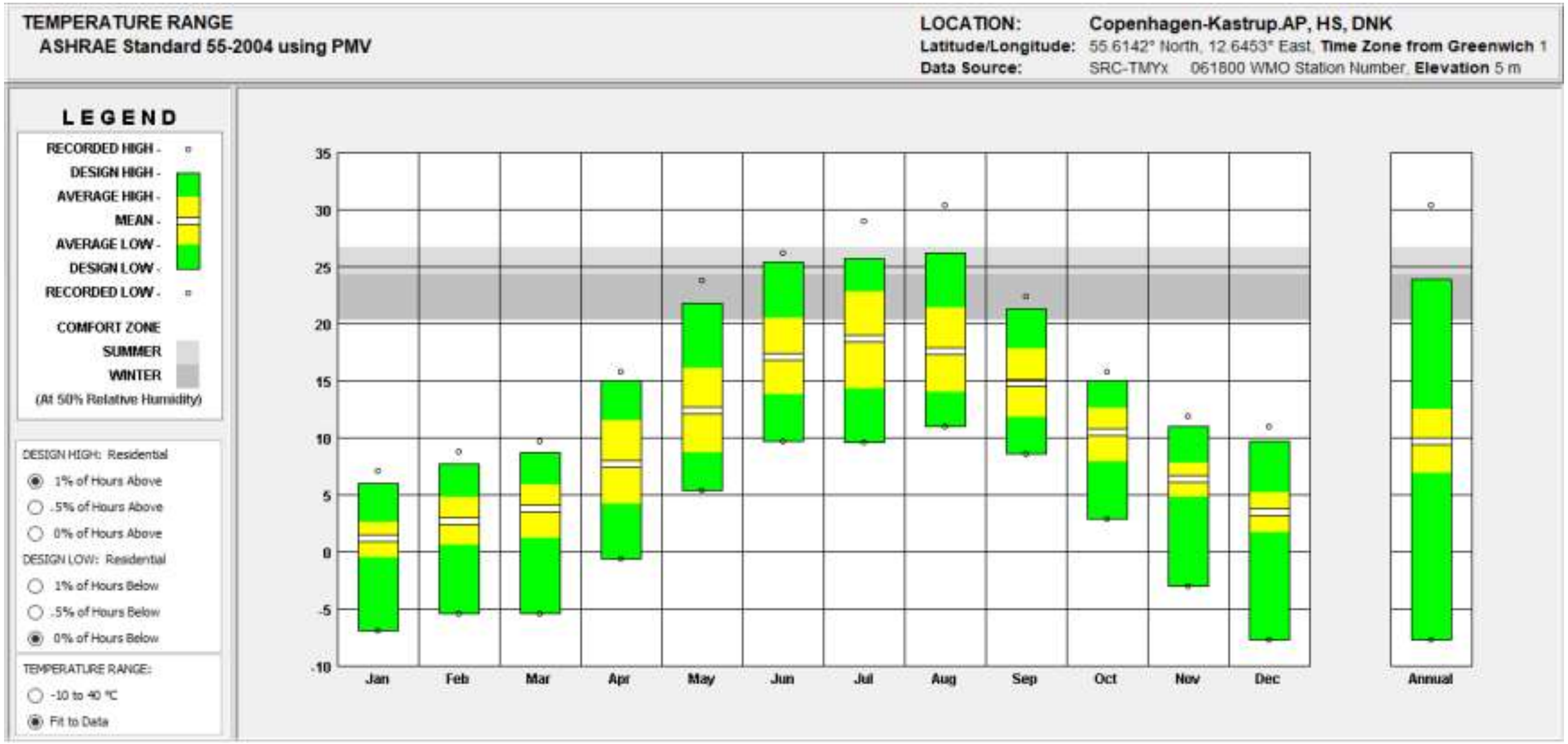

Figure 155: Temperature range diagram- Copenhagen

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

RELATIVE HUMIDITY

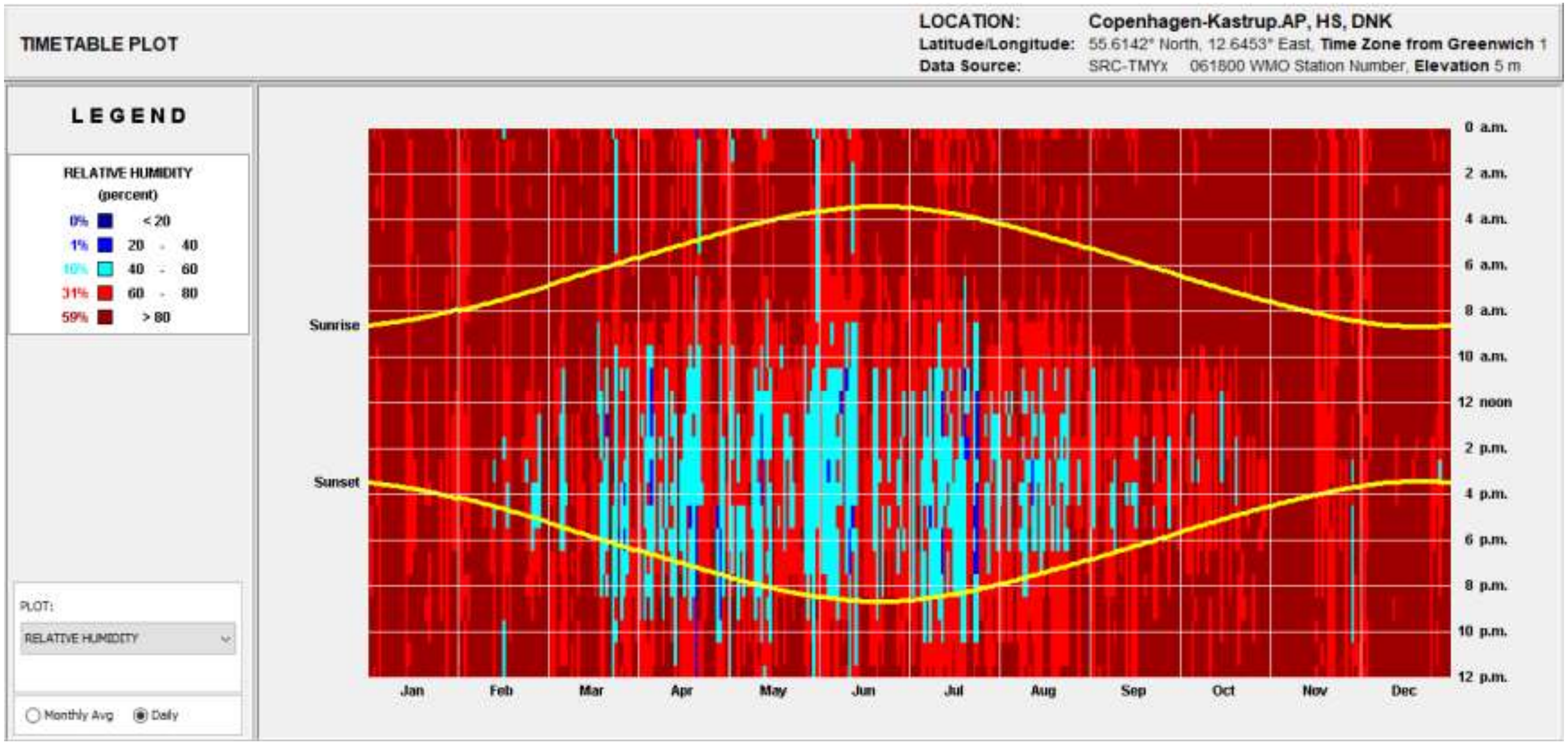

Figure 156: Relative humidity diagram- Copenhagen

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

SKY COVER

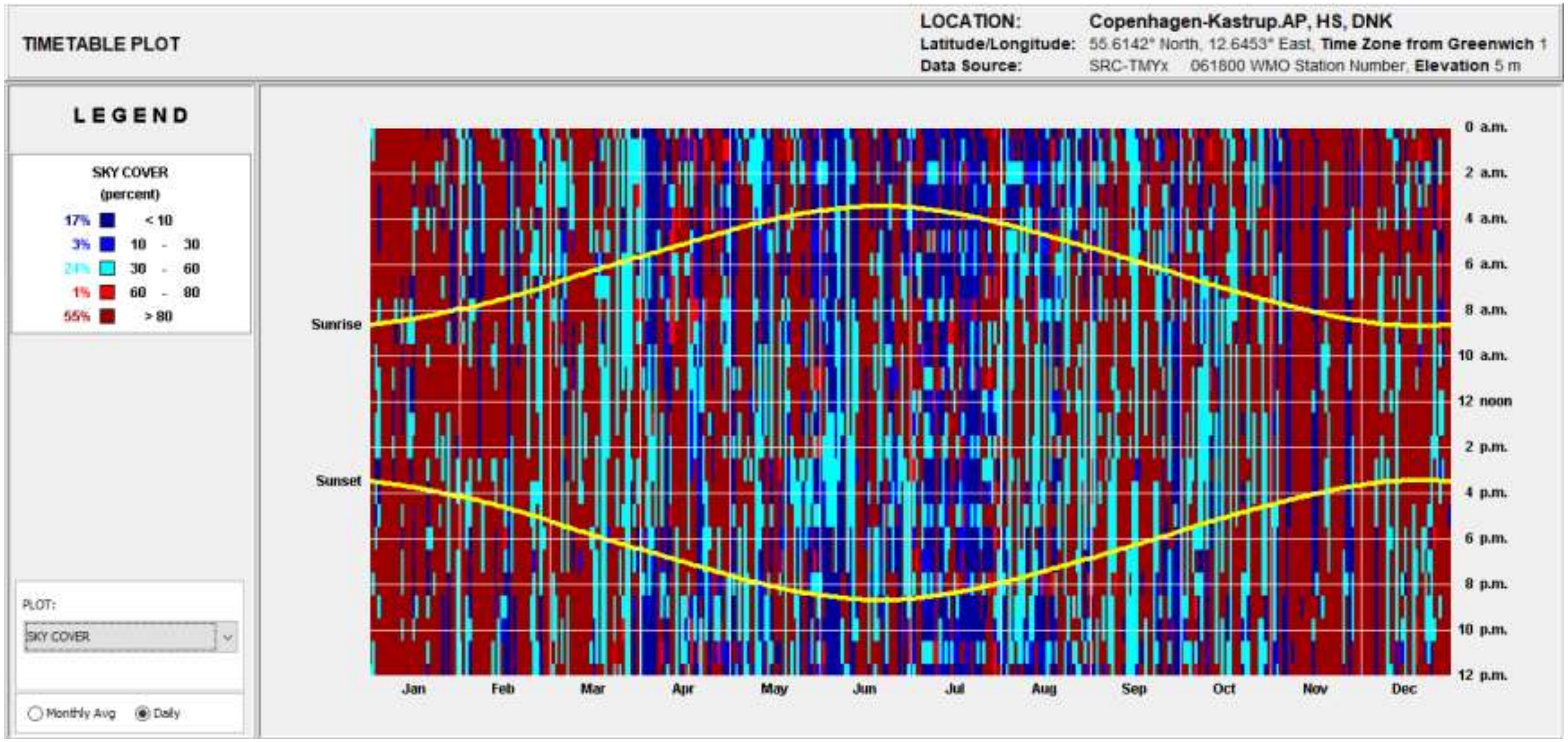

Figure 157: Sky cover diagram- Copenhagen

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

WIND ANALYSIS

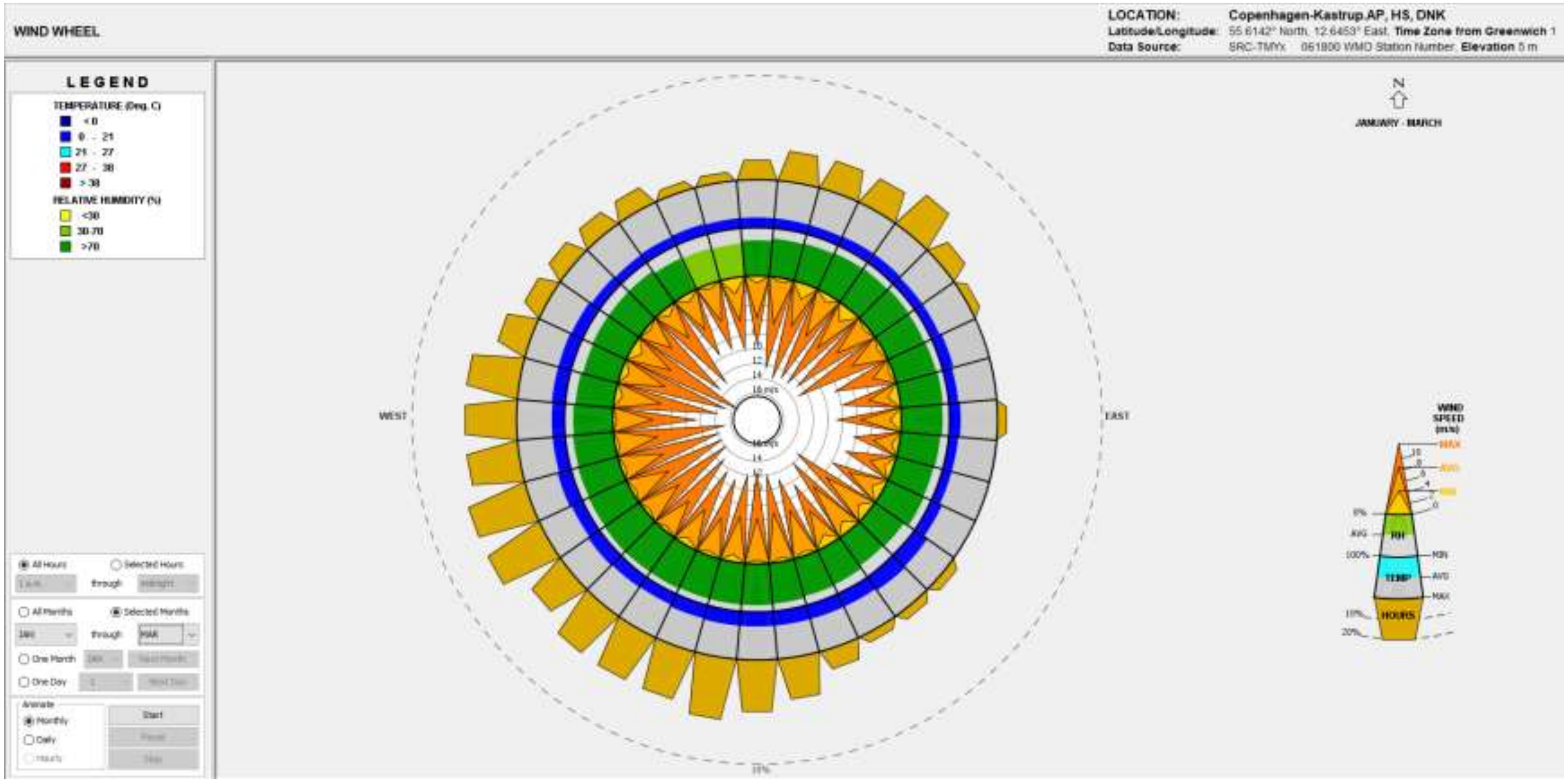

Figure 158: Wind wheel_JAN-MAR- Copenhagen

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

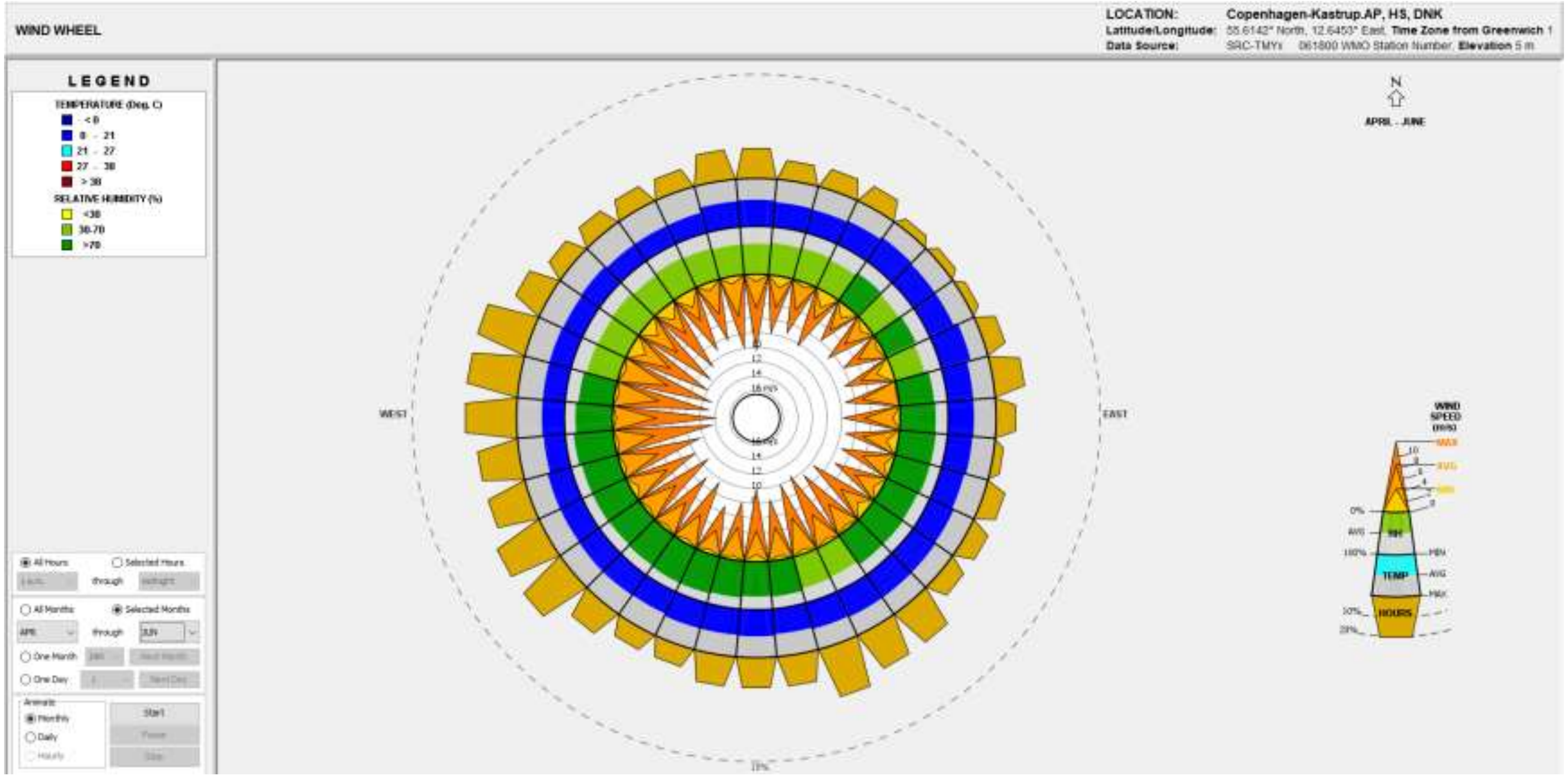

Figure 159: Wind wheel_APR-JUN- Copenhagen

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

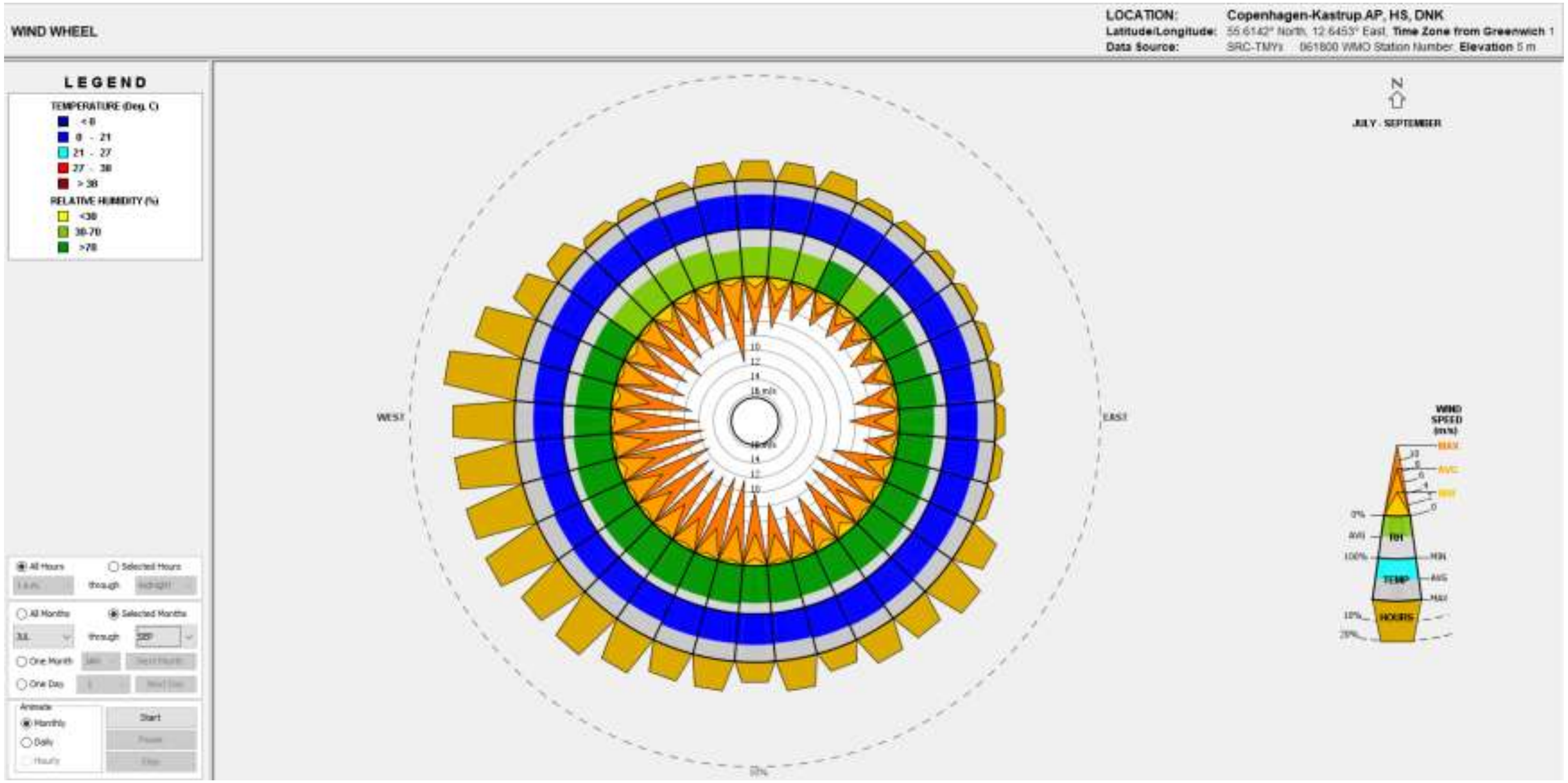

Figure 160: Wind wheel_JUL-SEP- Copenhagen

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

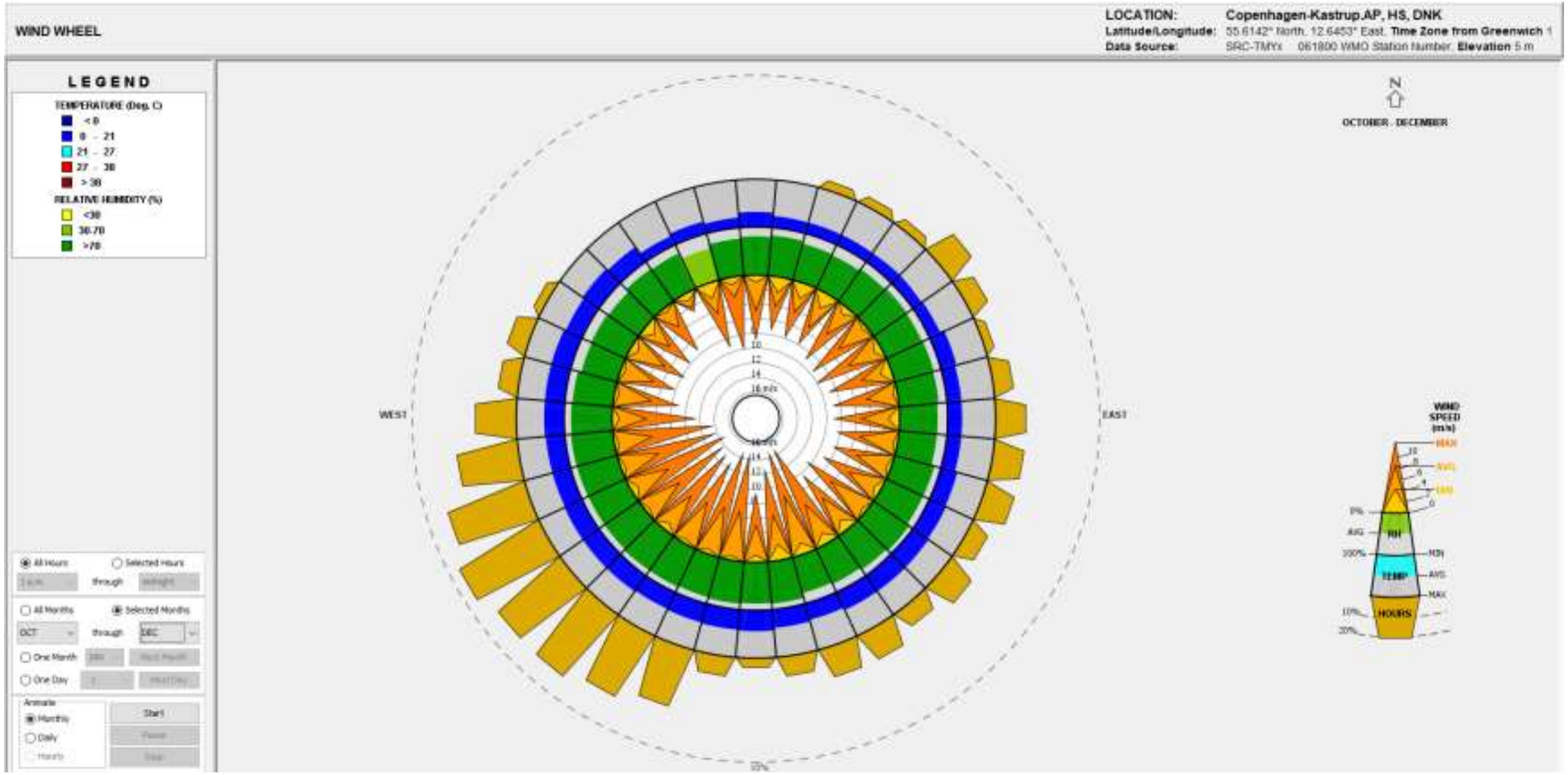

Figure 161: Wind wheel_OCT-DEC- Copenhagen

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

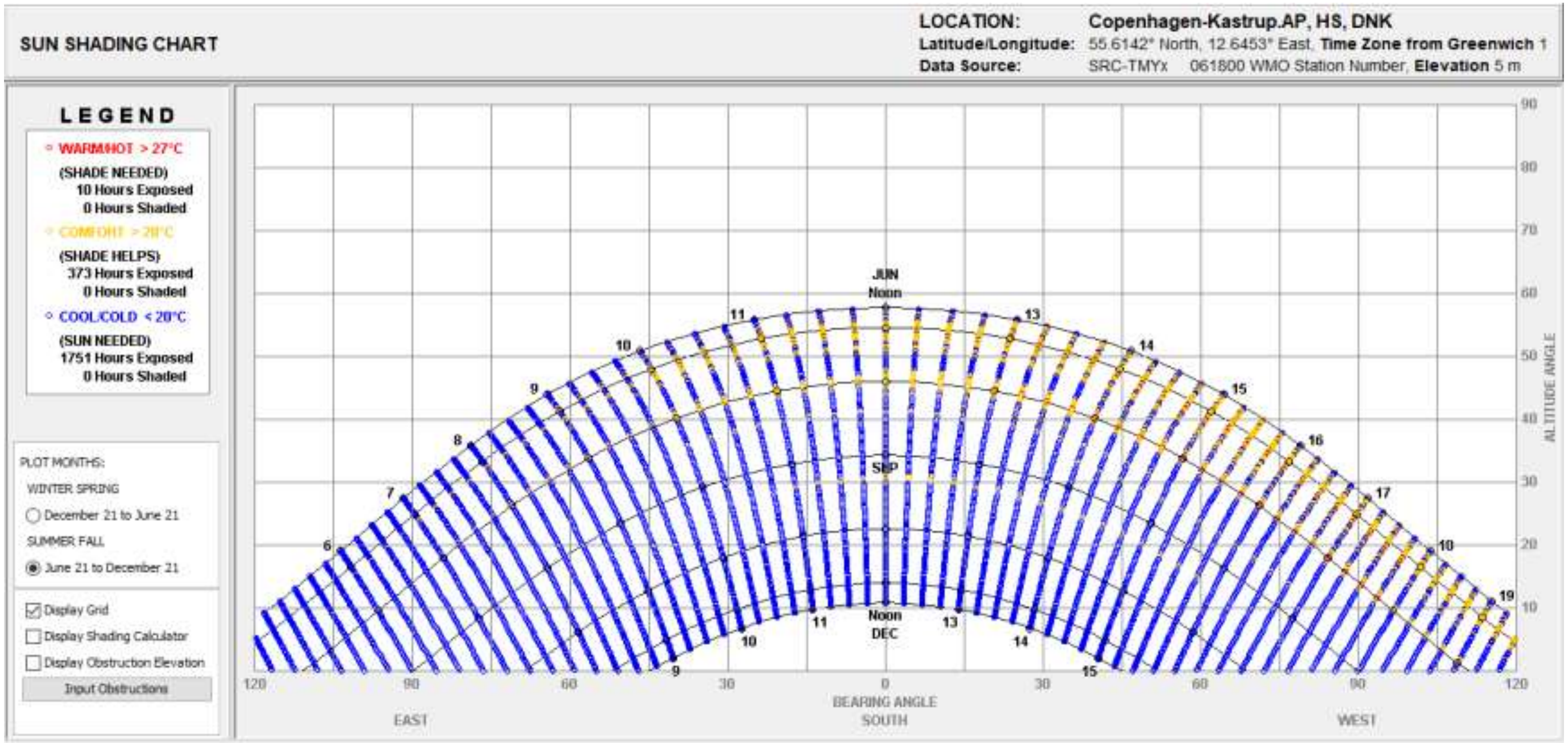

Figure 162: Summer fall chart- Copenhagen

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

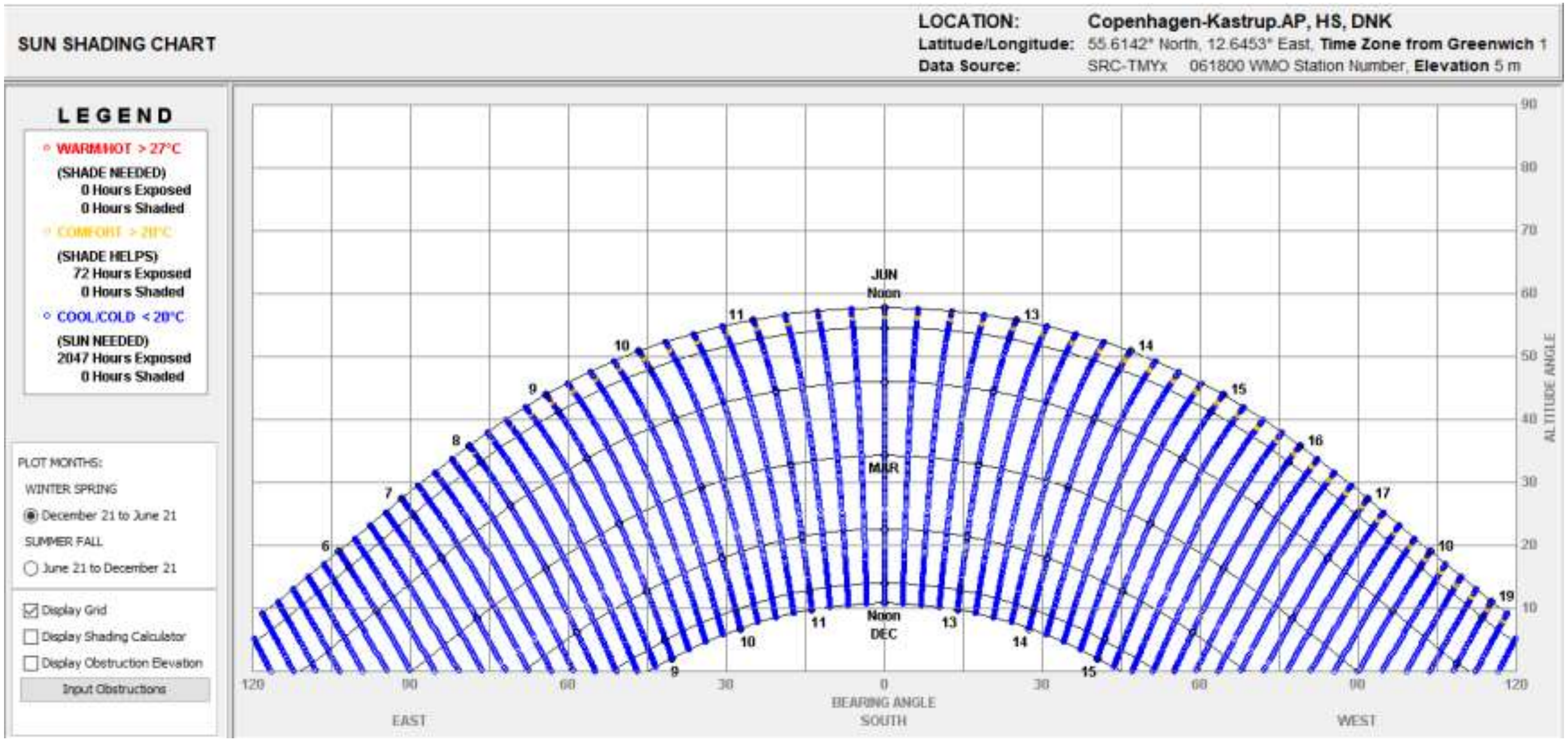

Figure 163: Winter spring chart- Copenhagen

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

BIOCLIMATIC CHART – GIOVONNI DIAGRAM

Through winter months, it would never be comfortable inside the buildings, unless some design strategies were implemented.

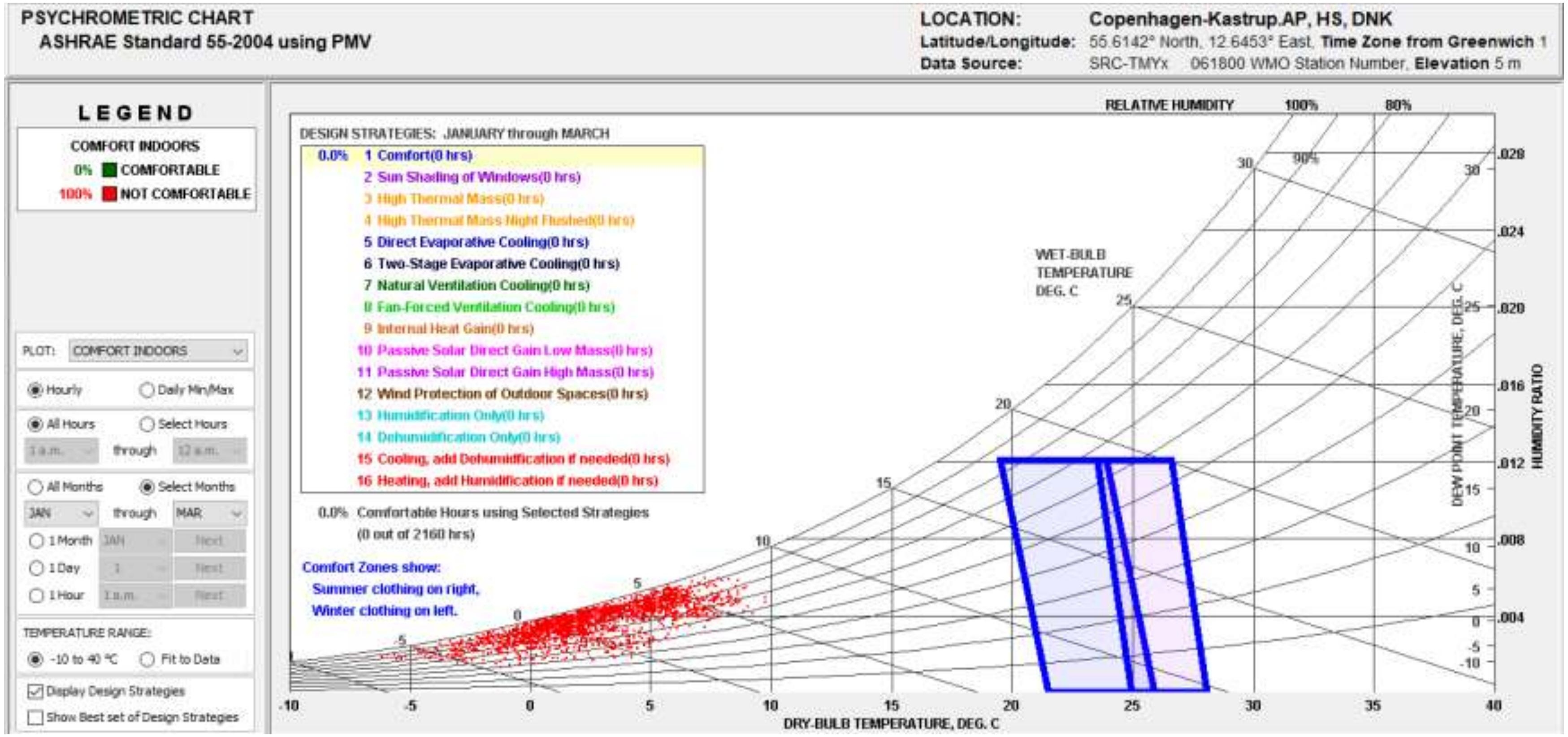

Figure 164: Psychometric chart without any strategy JAN-MAR- Copenhagen

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

In this case, there would be a brief frame of time (5%) during the spring months, when it would be comfortable inside the buildings without implementing any design strategy.

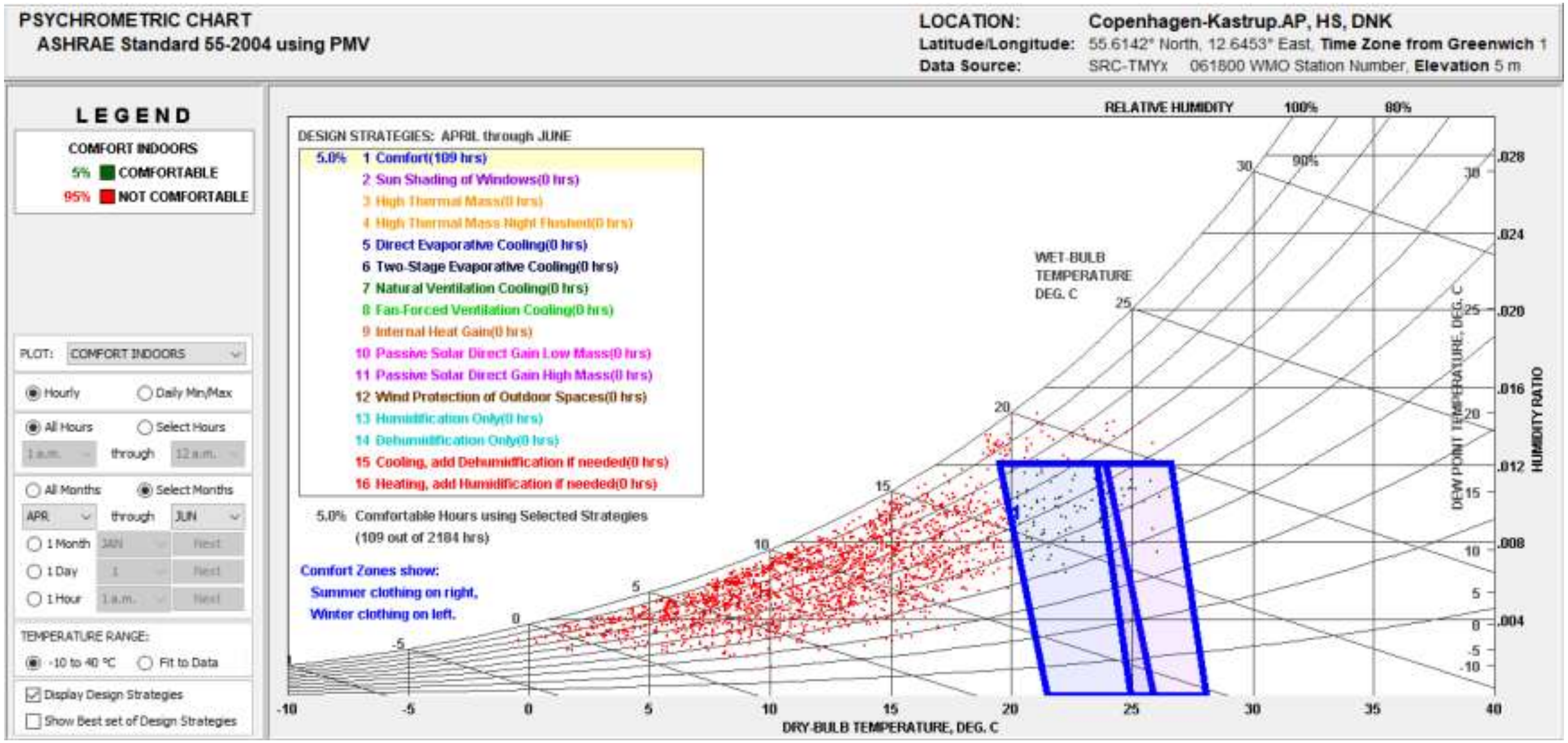

Figure 165: Psychometric chart without any strategy APR-JUN- Copenhagen

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 864374.

Through summer months, it would be a lapse of comfortable time inside the buildings (17%) without implementing any design strategy.

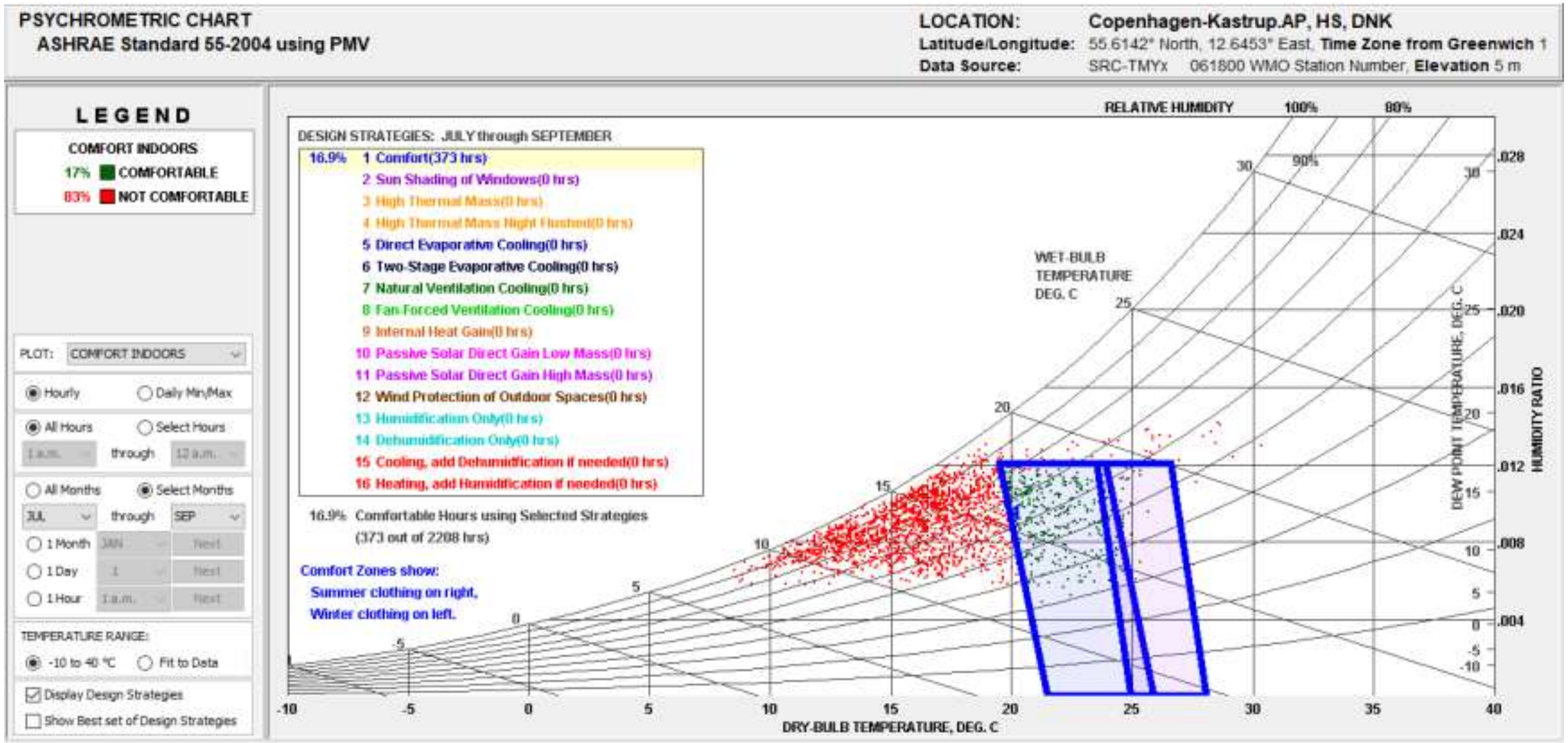

Figure 166: Psychometric chart without any strategy JUL-SEP

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

Lastly, during autumn months, it would never be a time when it would be comfortable inside the buildings without implementing any design strategy.

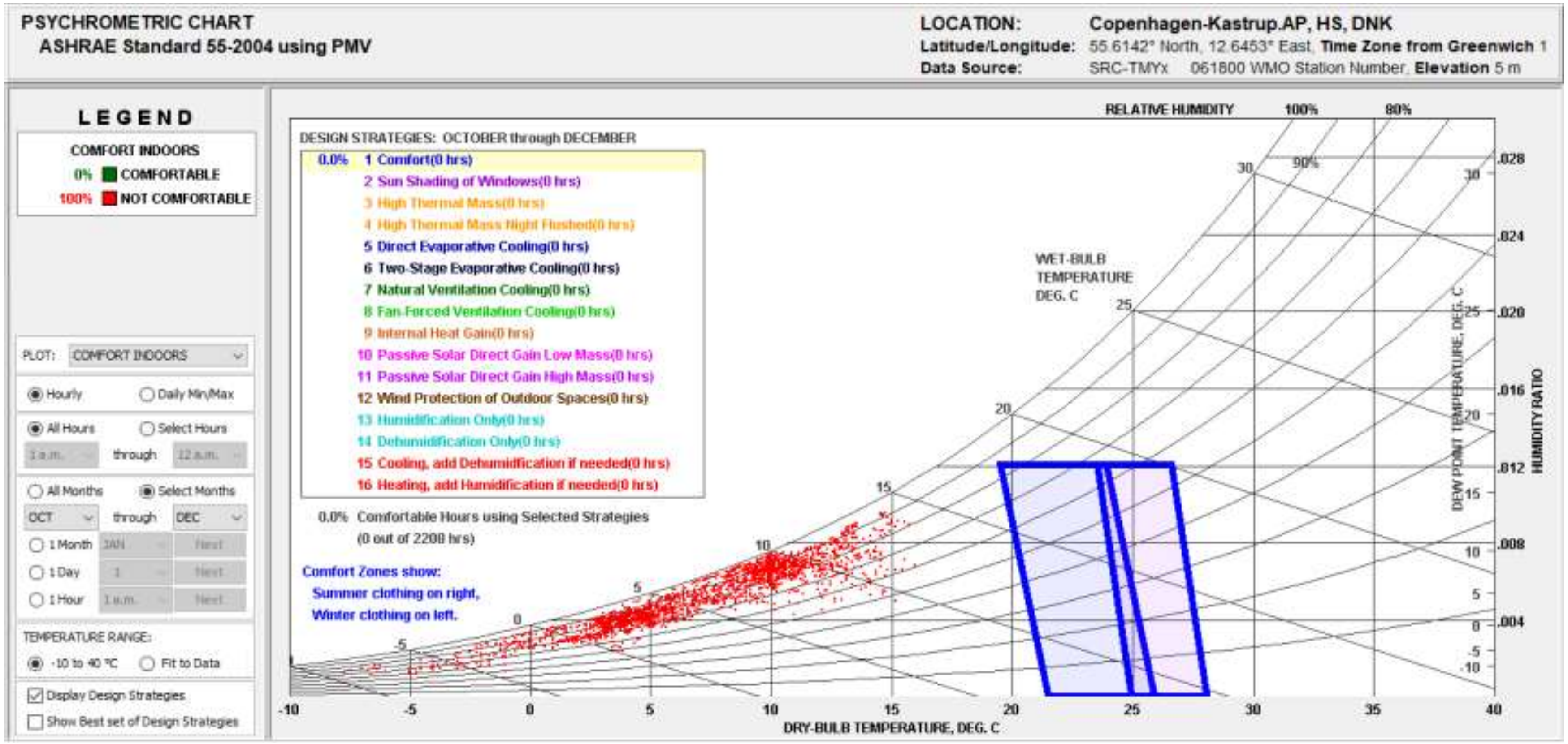

Figure 167: Psychometric chart without any strategy OCT-DEC- Copenhagen

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

ANNEX 3.4. Bioclimatic architecture case studies

SunZEB, in Helsinki (Finland) (mySMARTLife, 2022), (MySmartlife, 2020)

This building is one of the interventions included in MySmartLife project, being the first SunZEB building finished in 2020. It is located in the former fish harbor of Kalasatama, which has begun to transform into a neighborhood for smart urban development, where several interventions of this European project were implemented.

This building incorporate smart controllers in every apartment as well as integrated renewable energy sources, waste heat recovery, and smart home solutions. Additionally, several building of the area, including SunZEB, are part of a district heating system that supplies thermal energy for both building heating and residential hot water heating. On the roofs of certain buildings, PV panels have also been installed with a capacity of 28.72 kWp. In this way, the buildings' thermal needs have been met by district heating, and some of the electricity needs of the building where the solar panels are located have been met by them.

By utilizing heat pumps in the building's cooling system to recycle excess heat into the Helsinki's district heating system and store excess solar energy and other waste energies throughout the summer, it maximizes the usage of renewable energy. It also take advances of the low-lying sun to heat and maximized natural light for the apartments, during winter

Indicator	2020		2021	
Reduction in annual energy consumption	Thermal	5 %	Thermal	1 %
	Electrical	-1 %	Electrical	-5 %
	Total	4 %	Total	0 %
Reduction in primary energy consumption	Thermal	5 %	Thermal	1 %
	Electrical	-1 %	Electrical	-5 %
	Total	3 %	Total	-1 %
Reduction in greenhouse gas emissions	Thermal	6 %	Thermal	2 %
	Electrical	-122 %	Electrical	-83 %
	Total	-6 %	Total	-7 %

Table 31. Archived impacts (Kalasatama). Source: (MySmartlife, 2020, pág. 121)

The Edge, in Amsterdam (The Netherlands) (The Edge, s.f.)

The Edge building is located in Amsterdam's financial district and accommodates a Deloitte´s office, designed by PLP Architecture. This highly efficient building produces more energy than it consumes, through a number of techniques, which include high levels of thermal and acoustic insulation, renewable energy production, and reuse of water.

The buildings´ orientation is based on the path of the sun and shaped to best utilize natural light and heat; so that the atrium open up to the north allowing sunlight into the building´s inside. The entrance atrium façade is covered by a curtain wall which also takes into account natural ventilation to prevent overheat, in coordination with a heat recovery ventilation system. In this sense, the excess ventilation air from the offices is reused to cool the atrium area, after passing through a heat exchanger to utilize any warmth.

The other façades are load bearing walls with are small openings, to produce shading and support for the ventilation openable panels. As well, the south façade is cover with PV panels whose orientation maximize the energy production and preventing unwanted heating. Apart

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from the PV panels in the south façade, there are also a PV installation in the south facing roof area of the building and the energy grid is connected to the PV panels located in some University of Amsterdam´s buildings.

The heating/cooling installation is power through geothermal energy with heat pumps, which run on self-generated PV energy. The PV energy production also the electric vehicles from the employees and electronic devices.

The overall measures manage to reduce its energy consumption by 70% when compared to a typical office building. For this purposed, there are lighting sensor which continuously measure the occupancy, movement, lighting levels, humidity and temperature, so the energy use is adjusted automatically.

Regarding water reused, rainwater collected on the roof is reused to water the green areas of the building and flush toilets.

Finally, it has been taken into account the biodiversity of the area, as the green areas surrounding the building separate it from the nearby highway, allowing animals and insects to safely pass through.

Figure 168The Edge. Souce: (The Edge, s.f.)

Kantoor in Nijkerk, (The Netherlands) (maasarchitecten, s.f.)

Kantoor building hold a Vreugdenhil´s office, designed by Maas Architecten. It is located between Arkemheenweg, the A28 and Schakelsweg in Nijkerk.

This building has a low energy demand, due to the isolation materials used in its construction, the partial structural glazing that maximized natural light use in the interior and the smart

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control system that covers all the installation. It also incorporates 170 PV panels on the roof that partially covers the electricity demand and a thermal heat energy storage to provide some flexibility. Finally, it reuses the rain water collected from the roof to flush toilets.

Figure 169 Kantoor. Source: (maasarchitecten, s.f.)

Twin City Tower, in Bratislava (Slovak Republic) (sieberttalas, s.f.)

The Twin City Tower is close to Bratislava´s historical city centre, in an emerging business district, located in an old industrial zone. This building is a project from the Slovak development group HB Reavis, design SIEBERT + TALAŠ architects (2010-2018). In order to increase its sustainability and lower its energy consumption, the following bioclimatic measures have been incorporated.

The building´s façade is a curtain wall with integrated photovoltaic cells; which covers part of the buildings electricity needs, while maximizing natural light into the offices inside the building. Although the amount of energy produced by the façade varies through the year along with the amount of daylight reflect on it, the solar glass modules reduce the building´s HVAC demand by 19%, with a peak energy output of 25 kW. This would also allow a reduction in the cost of the energy.

The cladding of the façade was designed to provide natural ventilation and incorporates a system of baffle plates that, when activated by tenants, divert air from the edge of the panels into the void and into the office spaces.

Finally, the building incorporates a green roof to help improve relicience and increase moderately carbon sequestration, apart from including some vegetation in the building and the plantation of grown trees in the surrounding area. It is expected to reduce the CO_2 emission compare to the average buildings by 378 Tons of CO_2.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

Figure 170 Twin City Tower. Source: (sieberttalas, s.f.)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.

ANNEX 4- PRESELECTED DISTRICTS

From the PED template, the different areas are evaluated. The results are shown in the following table for all the cities. In the majority of these areas, the most significant factors contributing to the outcomes were of technological and governmental nature, aligning with pre-existing plans in some instances. It is crucial to emphasize that this methodology holds validity solely within the context of these specific cities. Our intention is not to compare the different PEDs among the cities, as each city possesses distinct impacts and prioritization weights, reflective of their individual preferences, thus resulting in varying MCDA values.

	BRATISLAVA		BUDAPEST		COPENHAGEN		KRAKOW		MATOSINHOS			RIGA	
	PED 1	PED 2	PED 1	PED 2	PED 1	PED 2	PED 1	PED 3	PED 1	PED 2	PED 3	PED 1	PED 2
Spatial and Land use factors	0.15	0.29	0.28	0.00	0.08	0.00	0.58	0.79	0.95	1.00	1.00	0.34	0.80
Technological factors	0.64	0.78	0.25	0.21	0.92	0.88	1.00	0.92	0.00	0.11	0.11	0.92	0.73
Social factors	0.43	0.43	0.18	0.05	0.86	1.00	0.05	0.00	0.62	0.49	0.49	0.22	0.00
Economic factors	0.11	0.11	1.00	0.22	0.27	0.08	0.23	0.38	0.15	0.46	0.71	0.30	0.00
TOTAL	0.57	0.76	0.50	0.00	0.93	0.83	0.97	1.00	0.35	0.54	0.64	0.91	0.68

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864374.