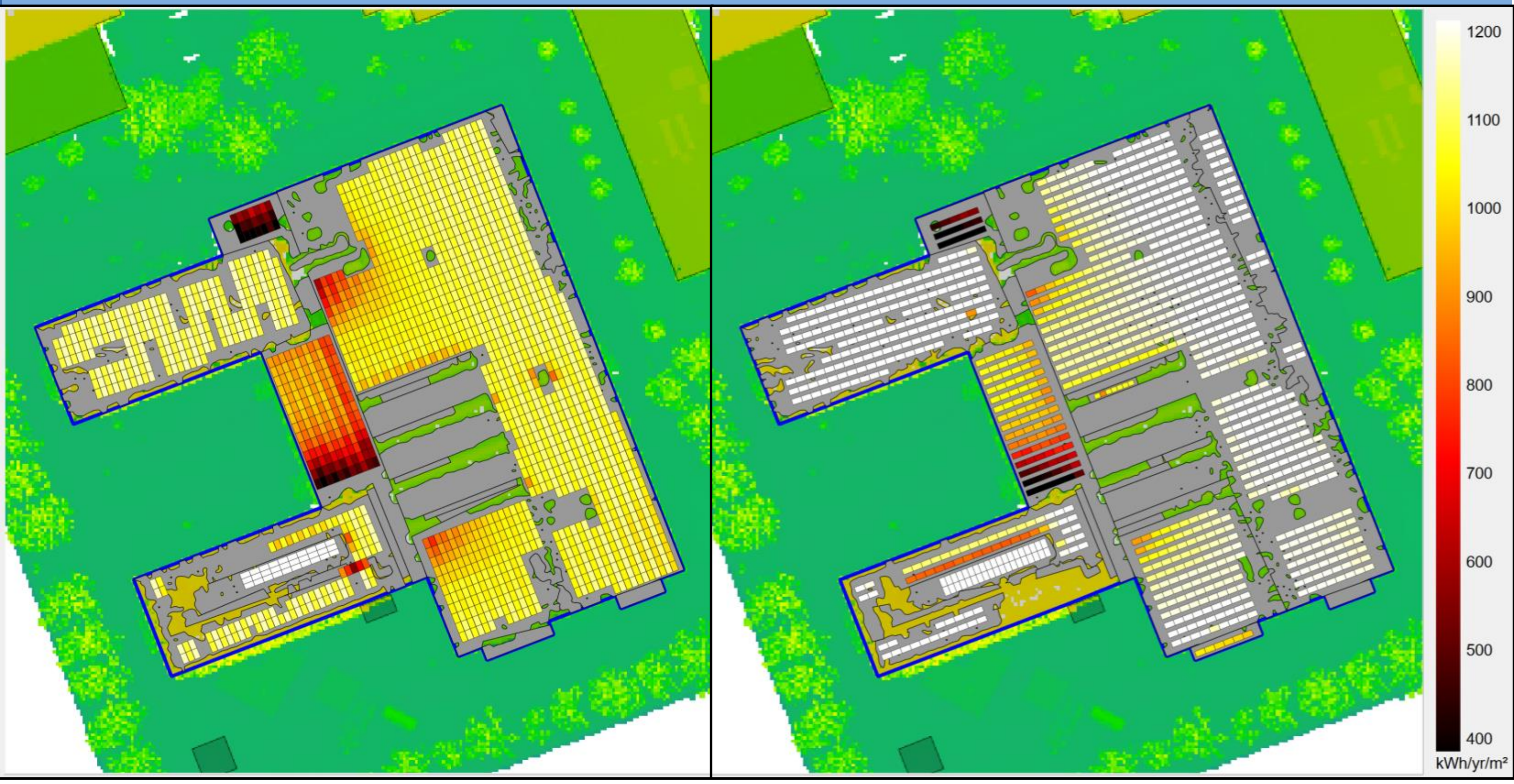
simply positive

D4.2 Report on urban policy suggestions regarding automated choice of installation modes and expansion to various panels dimensions

June 2024



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Dissemination Level

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V2	Draft report	TUD	June 2024
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Disclaimer

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Executive Summary

The report outlines a comprehensive approach to urban planning through geo-referenced multi-layer mapping centered on Amsterdam's focus district. This mapping integrates various data, including photovoltaic (PV) potential, roof usage, protected areas, water management, and voltage grid fluctuations. By intersecting this information, a realistic assessment of PV potential for the entire city and its applicability to other focus districts is achieved. Furthermore, the report proposes the automation of decision-making processes across different installation modes of PV modules. These modes optimize energy usage and minimize aesthetic interference by considering landscape orientation, aesthetic compactness, visibility from street view, and energetic output of photovoltaic-thermal (PVT) modules. The recommendations aim to guide urban policy towards sustainable energy integration while accommodating diverse panel dimensions and installation scenarios. Additionally, an application is created to assist decision makers in generating an image for residents.

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List of Abbreviations and Acronyms

APE	Avoided Primary Energy
ATES	Aquifer Thermal Energy Storage
BAG	NL: Basisregistratie Adressen en Gebouwen
DHW	Domestic Hot Water
HP	Heat Pump
LiDAR	Light Detection and Ranging
PV	Photovoltaic
PVT	Photovoltaic-thermal
SCF	Sun Coverage Factor
SH	Space Heating
STC	Standard Test Conditions
ST	Solar Thermal
SVF	Sky View Factor

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1. Introduction

1.1. Purpose of the document

The purpose of the document is to propose a comprehensive urban planning approach centered on Amsterdam's focus district, utilizing multi-layer mapping and data integration to assess PV potential and automate decision-making processes for PV module installations. Decision makers will be able to switch between different layouts, orientations and can change the settings of the potential PV system in an application. The recommendations aim to guide urban policy towards sustainable energy integration while accommodating different panel dimensions and installation scenarios, ultimately encouraging efficient energy usage with minimal aesthetic interference.

1.2. Relation to other project activities

In previous years a study was carried out to estimate the rooftop PV potential energy yield in Amsterdam with the PVW and AMS institute. The project led to the realistic quantification of solar PV potential on Amsterdam rooftops and a comparison with the status of PV installations. In the developed modeling framework, height data of the terrain is used to digitally build the urban fabric, recognize rooftops with respect to cadaster data, automatically place PV modules on rooftops, and accurately compute the PV systems yield up to the AC-side for every building. All this is accomplished with a pace of 2.4 buildings/second. These numbers are already used by the municipality of Amsterdam, that is supporting the Simply Positive project, to engage citizens and plan in time PV installations with accelerated permit certifications.

1.3. Structure of the document

The remaining of the document is structured as follows; chapter 2 provides the methodology used to gather data on existing PV systems and the model for calculating rooftop PV potential. Chapter 3 focuses on mapping and analyzing the semi-annual progress of PV installations in Amsterdam. Chapter 4 discusses the outcomes of automated decision-making processes, specifically addressing the calculated PV energy yield potential considering various limiting factors. It also details the energetic output of PVT collectors. In chapter 5, urban policy suggestions are presented to enhance the integration of PV systems within urban landscapes. Chapter 6 outlines implementation strategies for these suggested policies. Lastly, chapter 7 ends with the conclusions.

2. Methodology

2.1. Data collection

LiDAR Height Data

The new version of the *Algemeen Hoogtebestand Nederland* height data (AHN4) for the years 2020 and 2021 is used and is accessible through the AHN viewer [1]. This dataset comprises a Light Detection and Ranging (LiDAR) point cloud with an average resolution of 25 cm, which was processed into a digital surface model with a grid size of 50 cm for analysis. These raster data are organized into tiles measuring 2.5 by 1.25 km, necessitating district-wise processing within Amsterdam.

BAG Cadaster Building Data

The *Basisregistratie Adressen en Gebouwen* (BAG) data, retrieved from the Cadaster on June 6th, 2023, encompasses 545,288 addresses corresponding to 194,380 buildings citywide. Each building's footprint is defined as a 2D polygon using X and Y coordinates [2].

Climate Data

Hourly meteorological data collected from weather stations in and around Amsterdam determine typical weather patterns over an average year. Historical weather data spanning multiple years are utilized to generate a dataset of 8760 hours, incorporating parameters important for computing time-dependent solar irradiance on PV and solar thermal (ST) modules.

Table 1 - Parameters of the archetype PV module utilized in this study.

Parameter	Value
PV module length (m)	1.669
PV module width (m)	0.996
Efficiency at STC (%)	19.6
Open circuit voltage (V)	41.08
Number of cells in series	120
Ideality factor (-)	1.2
Temperature coefficient (%/°C)	-0.027
Ground albedo (-)	0.2
Reflective index (-)	0.1
Top emissivity (-)	0.2
Back emissivity (-)	0.89

Module Data

Standard rectangular PV modules, along with their dimensions and mounting height, constitute key input parameters for deployment analysis. Additionally, module characteristics such as efficiency under standard test conditions (STC), open circuit voltage, short circuit current, and other relevant factors derived from datasheets contribute to calculating energy yield. Table 1 presents a summary of the parameters for the PV module panel utilized in this study. Water-based solar thermal (ST) with glazing while unglazed photovoltaic-thermal (PVT) collectors are used with an area of approximately 2 m^2. Both thermal and electrical efficiencies of the collectors at zero reduced temperature (function of operating conditions) are provided in the later part of the document.

2.2. Mapping and Geo-referencing

Input Data

In the current approach, LiDAR data serves as the foundation for assessing PV deployment potential. We start with LiDAR point clouds classified as buildings to identify planar surfaces suitable for PV array installation. Our selection criteria benefits non-curved surfaces exceeding 10 m^2. For flat rooftops, modules are oriented southward with a tilt angle of 13 degrees or east-west with a 10-degree tilt. On sloped rooftops, both portrait and landscape orientations are considered. Furthermore, hourly meteorological data, along with PV module characteristics, inform our analysis to estimate annual PV energy yield. Figure 1 illustrates our modeling framework, which integrates LiDAR data processing with a skyline-based approach to assess PV deployment viability.

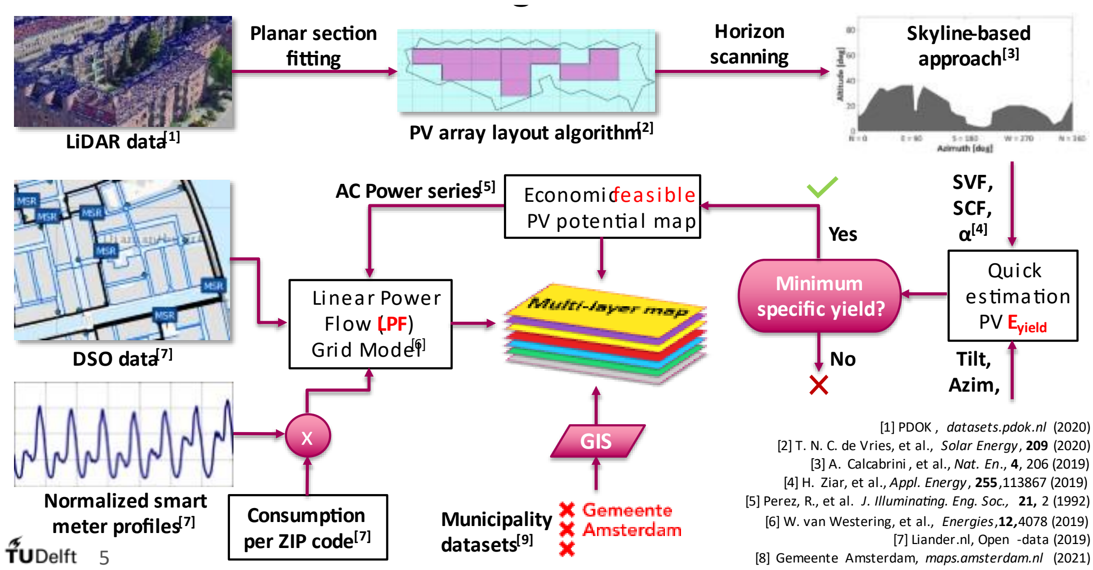


Figure 1 - Modeling framework for the assessment of PV energy yield.

Surface Detection and Ignoring Out-of-Plane Geometry

To ensure precise identification of suitable PV installation sites, even in complex urban environments, we accurately detect flat surfaces disregarding out-of-plane points with a threshold of 25 cm.

Skyline-based Model

We utilize parameters such as sky-view factor (SVF), sun-coverage factor (SCF), ground albedo, and module tilt and azimuth to estimate annual PV energy yield. Modules failing to meet a performance threshold of 650 kWh/kWp are considered unsuitable for installation. The resulting AC power output feeds into a linear power flow model, facilitating voltage analysis for grid networks.

2.3. Multi-layer mapping

Integration of Spatial Data Layers

Incorporating water management areas as a foundational layer, our multi-layer mapping approach integrates information on various building types, including existing PV installations,

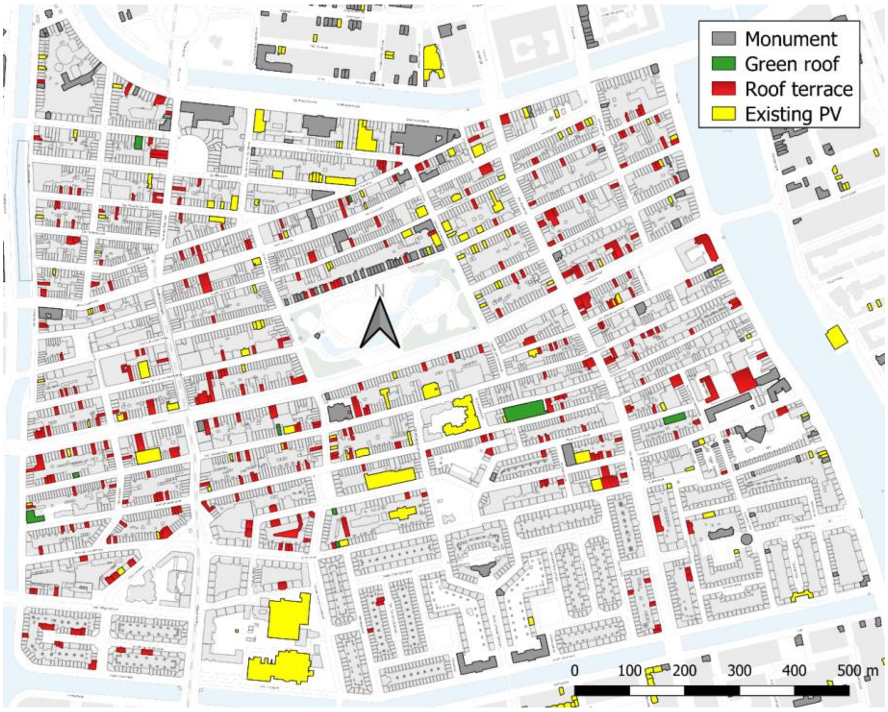


Figure 2 - Multi-layer map for the district in Amsterdam.

roof terraces, green roofs, and historic buildings as depicted in Figure 2. By overlaying these datasets, we achieve a comprehensive understanding of urban landscapes, considering both structural and environmental factors.

Layered Analysis for Optimal Site Selection

Utilizing spatial data layers on building types and water management areas, our analysis identifies suitable locations for PV deployment within the urban fabric. This requires examining (i) how common existing PV installations are, (ii) what is the potential for rooftop expansions through roof terraces, and (iii) the possibility for integrating PV modules on green roofs. Additionally, considerations for historic buildings require detailed evaluation to balance preservation efforts with renewable energy goals.

Visualization of Spatial Relationships

Multi-layer mapping enables the visualization of spatial relationships between water management areas, building types, and proposed PV deployment sites. Through interactive mapping tools, stakeholders gain insights into the distribution of existing and potential PV installations relative to water management zones, facilitating informed decision-making in urban planning and renewable energy initiatives.

Enhanced Decision Support

By integrating numerous spatial datasets, our multi-layer mapping approach offers enhanced decision support for urban policymakers and stakeholders. Insights derived from this analysis inform strategic interventions to maximize solar energy utilization while mitigating environmental impacts, particularly in water-sensitive areas. Moreover, considerations for historic buildings ensure alignment with heritage conservation objectives, fostering sustainable development practices within protected urban landscapes.

2.4. Installation mode definitions

Classification of Installation Modes

Describing installation modes for PV systems, we consider various factors such as roof type, orientation, and available space. Installation modes are categorized as follows:

- Standard Rooftop Installation:
  This mode involves the placement of PV modules on conventional flat or sloped rooftops, optimizing orientation for maximum solar exposure.
- Roof Terrace Integration:
  Incorporating roof terraces into PV deployment strategies, uses existing or planned rooftop recreational areas to accommodate solar panels, maximizing space utilization.
- Green Roof Integration:
  Integrating green roofs with PV installations promotes dual benefits of renewable energy generation and ecological sustainability, supporting biodiversity and mitigating urban heat island effects.
- Historic Building Adaptation:
  This mode emphasizes preservation while integrating PV systems in a manner sensitive to architectural aesthetics and heritage considerations.

Adaptive Strategies for Diverse Urban Contexts

Flexibility is important in adapting installation modes to diverse urban contexts. By considering local regulations, architectural typologies, and community preferences, installation strategies are used to maximize solar potential while considering the unique characteristics of each site. Through stakeholder engagement and iterative design processes, we ensure that installation modes align with broader urban policy goals and address specific challenges posed by water management areas and protected heritage sites.

2.5. Energy optimization criteria

Maximizing Energy Yield

Energy optimization criteria focus on maximizing the energy yield of PV systems while considering site-specific constraints and objectives. Key optimization parameters include:

- Solar Irradiance:
  Maximizing exposure to solar irradiance by orienting PV modules to capture sunlight throughout the day, accounting for shading effects from nearby structures or vegetation.
- Roof Geometry:
  Optimizing the layout and tilt angle of PV modules to match the geometry of rooftops, minimizing energy losses due to suboptimal orientation.
- Efficiency and Performance:
  Selecting PV modules with high efficiency ratings and performance characteristics modified to local climatic conditions, ensuring optimal energy conversion and yield.
- Operational Considerations:
  Incorporating operational factors such as maintenance requirements, system reliability, and grid integration capabilities to enhance long-term energy performance.

Sustainability and Resilience

Beyond energy optimization, criteria also encompass broader sustainability objectives, including:

- Environmental Impact:
  Minimizing environmental footprint through sustainable allocation practices and responsible end-of-life management of PV systems.
- Climate Adaptation:
  Building resilience against climate change impacts by promoting distributed renewable energy generation, reducing reliance on centralized power sources, and enhancing community energy resilience.
- Social Equity:
  Ensuring balanced access to the benefits of solar energy, particularly in underserved communities, through inclusive planning processes and targeted deployment strategies.
- Economic Viability:
  Balancing upfront investment costs with long-term energy savings and societal benefits, supporting economic viability and reasonable distribution of renewable energy resources.

3. Mapping and Analysis

3.1. Focus district of Amsterdam

Amsterdam, the capital city of the Netherlands illustrated in Figure 3, has a population of 921,402 within its urban area. The city is pushing forward with solar power use through advanced urban strategies. By carefully studying rooftops and using automated decisions for installation, Amsterdam is making the most of solar energy while smoothly incorporating solar

Figure 3 - Aerial view of the city of Amsterdam.

infrastructure into the city. With goals to reach a capacity of 550 MW by 2030, the city shows its commitment to sustainability. The project gives stakeholders valuable insights based on data, helping Amsterdam move towards a cleaner future and inspiring other cities worldwide. Amsterdam's focus on specific districts leads to smart urban policies and advanced mapping methods for optimal solar panel placement, ensuring energy efficiency and minimal visual impact, which supports seamless integration into the cityscape.

3.2. PV potential mapping

In this section, the PV potential mapping utilizing a skyline-based model approach is investigated. The methodology employed for calculating the annual energy yield of modules installed on the roofs of Amsterdam buildings is detailed. Subsequently, the results of the total annual energy yield are presented in Figure 4 with the installed capacity data from 2020 and 2022. This mapping not only offers insights into the current state of solar energy utilization but also provides a foundation for formulating urban policy suggestions concerning the automated selection of installation modes and the expansion of various panels dimensions.

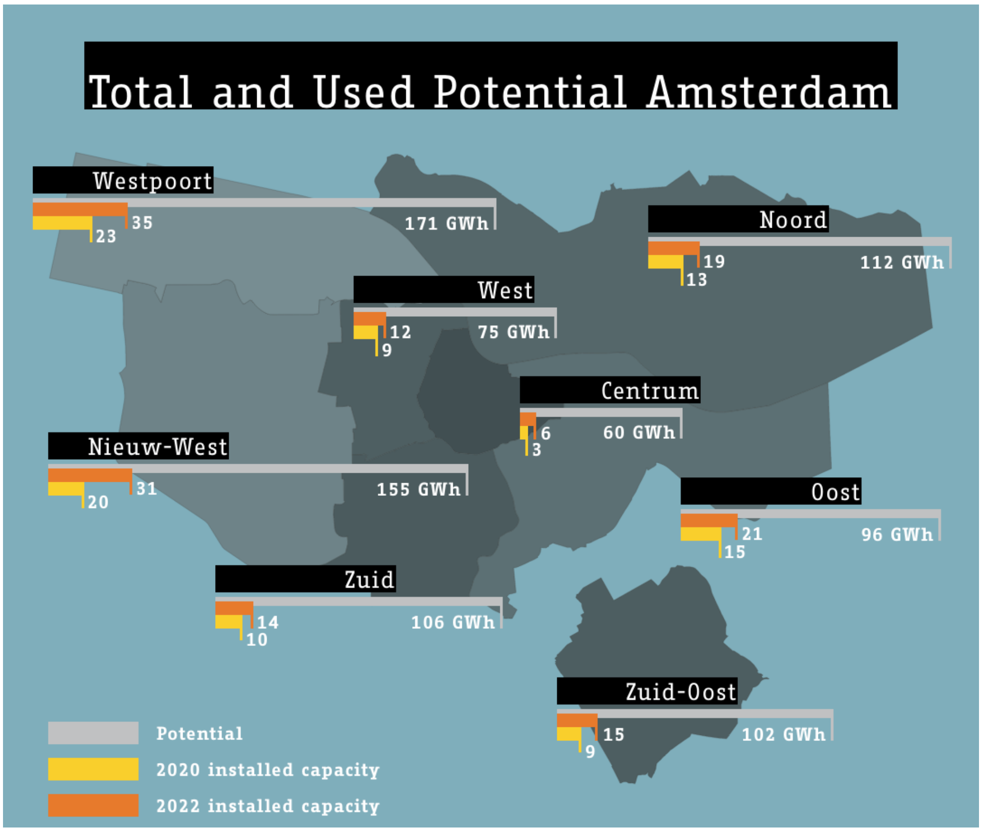


Figure 4 - Total and used PV potential of the districts in Amsterdam.

3.3. Applicability to focus districts

By looking at the data from 2020 and 2022, we can understand how much solar power these districts in Amsterdam can generate. Our aim is to help other focus districts to make smart decisions about where to put solar panels and how to make them work best. Our findings are not just useful for Amsterdam; they can help other districts become more sustainable and energy-efficient too. By sharing what we have learned, we can empower more communities to include clean energy solutions.

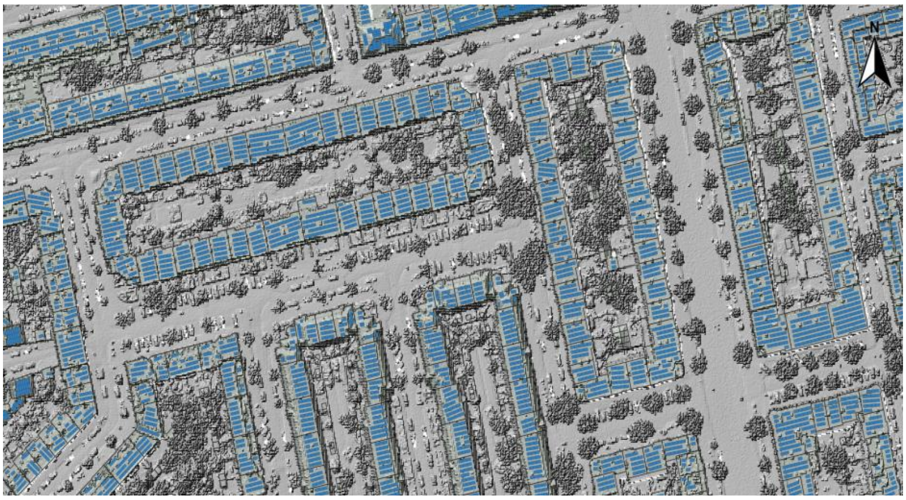
4. Automation of decision-making

4.1. Installation modes

The automated decision-making processes for installation modes of PV systems is explored that is in line with urban policy objectives. These modes are classified into four categories as described in section 2.4. Flexibility is key, adapting these modes to diverse urban contexts by considering local regulations, architectural styles, and community preferences. Stakeholder engagement ensures alignment with urban policy goals while addressing site-specific challenges. Automation simplifies decision-making to manage urban complexities efficiently.

4.2. Landscape vs. Portrait vs. East-West

In this section, we investigated the comparison between landscape, portrait, and east-west installation modes for PV modules, with a focus on optimizing energy utilization and minimizing aesthetic impact. The east-west layout has a higher yield due to the increased number of panels as presented in Figure 5b. Although the south-facing orientation depicted in Figure 5a traditionally delivers better performance, its yield may be compromised due to fewer panels.

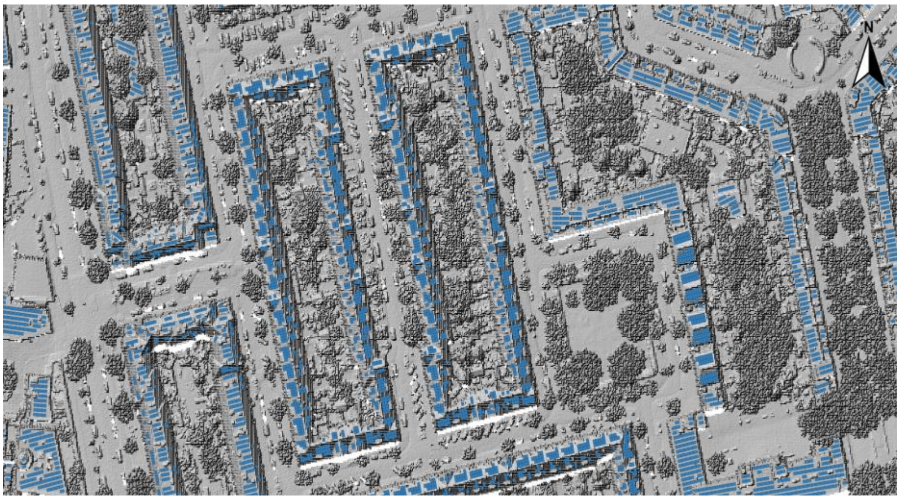


(a)

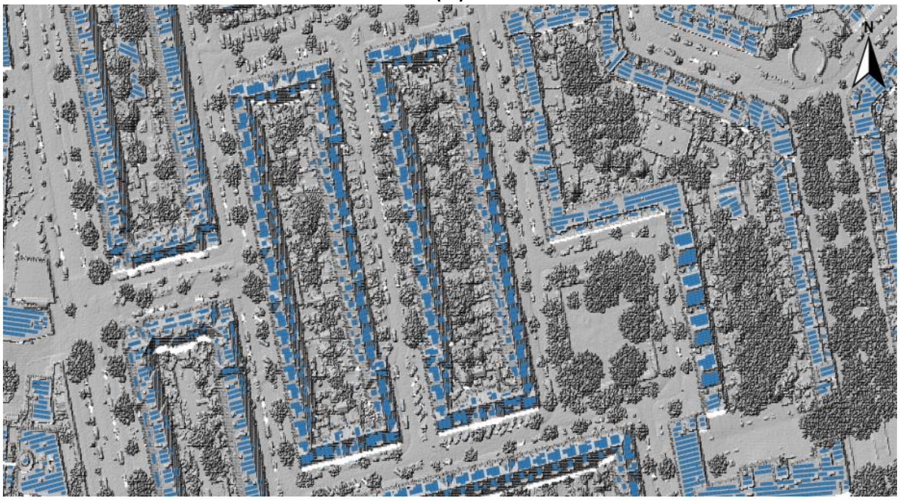
(b)

Figure 5 - Layout for the focus district in Amsterdam: (a) south facing layout for flat surfaces and (b) east-west layout for flat surfaces.

Additionally, the landscape orientation presented in Figure 6b is noted for its efficient panel placement, while portrait orientation illustrated in Figure 6a offers better panel positioning. Through automation, these considerations can be integrated to make informed decisions that balance energy efficiency and visual appeal.



(a)



(b)

Figure 6 - Orientation for the focus district in Amsterdam: (a) portrait orientation for slopped surfaces and (b) landscape orientation for slopped surfaces.

4.3. Aesthetic compactness

The focus is to ensure the aesthetic appeal of PV installations by emphasizing compactness. Aesthetic considerations play a vital role in urban environments, where visual balance is important. Compact designs minimize visual intrusion while maximizing energy generation potential. Through automation, decisions regarding the layout and arrangement of PV modules can be optimized to maintain the aesthetic integrity of urban spaces.

4.4. Modules visibility from street view

Addressing the visibility of PV modules from street view is essential to uphold the visual quality of urban landscapes. This part examines methods to reduce the visibility of modules while maintaining their functionality. Strategies include strategic placement, screening, or integration with architectural elements to minimize their impact on the streetscape. By automating assessments of module visibility, urban planners can ensure that PV installations contribute positively to the overall visual character of the built environment. In this project, on demand, previously computed PV modules (and related energy yield) can be removed from the original ensemble if they are visible from the public domain.

4.5. Energetic output of PVT modules

PVT systems, combining PV and thermal energy, are a promising sustainable energy solution. They utilize mediums like air and water, offering diverse applications such as space heating/cooling, hot water production, and more [3]. As cities tackle rising energy demands

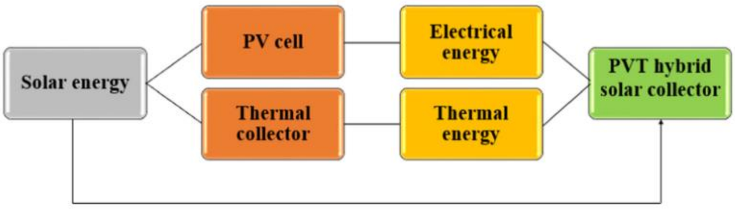


Figure 7 - Concept of hybrid solar PVT collector [4].

and environmental issues, policymakers are increasingly adopting solar power with PVT systems offering a dual solution as depicted in Figure 7 by generating electricity and heat from sunlight efficiently. Figure 8 highlights the performance advantages of PVT collectors over traditional solar technologies such as standard PV and solar thermal (ST) modules,

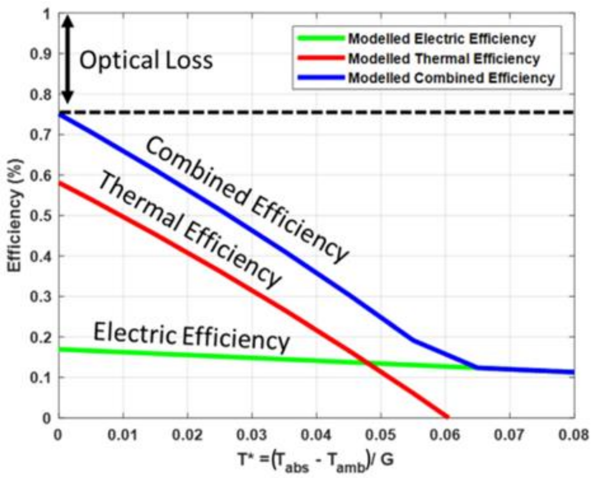


Figure 8 - Performance analysis of a PVT collector: highlighting electric efficiency (green), thermal efficiency (red), and combined efficiency (blue) [5].

emphasizing their combined electrical and thermal characteristics. This dual functionality allows the electrical output to be utilized for electrical loads, while the thermal energy can support space heating (SH), domestic hot water (DHW), and even cooling. These features make PVT collectors a compelling option for urban energy policies aimed at enhancing sustainability and energy efficiency.

In Figure 9, the avoided primary energy (APE) in Amsterdam is analyzed, considering both electrical and thermal energy. Results indicate that, per square meter, PVT panels offer the highest APE, closely followed by water-based ST modules. PVT applications are divided based on temperature levels. For example, air-based thermal collectors have lower APE and lower outlet temperature, making them more suitable for floor heating. In contrast, water-based collectors achieve higher outlet temperatures due to the superior heat transfer properties of water as a working medium. This makes them ideal for applications such as space heating through radiators and hot water production. Additionally, these collectors exhibit significantly higher APE.

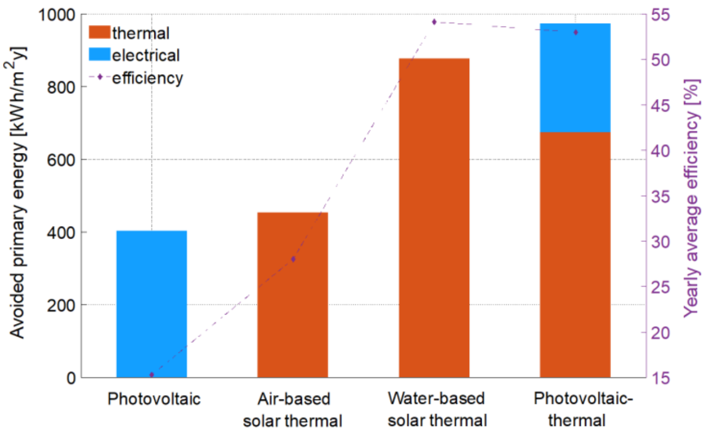


Figure 9 - Average annual efficiency and avoided primary energy comparison of a PVT collector with only PV and solar thermal (both air and water) collectors considering Dutch climate.

However, efficient storage methods for excess heat in water-based ST or PVT systems are currently lacking. Without storage, excess heat generated during periods of high solar irradiance and low demand is wasted, impacting system efficiency, as illustrated in Figure 10.

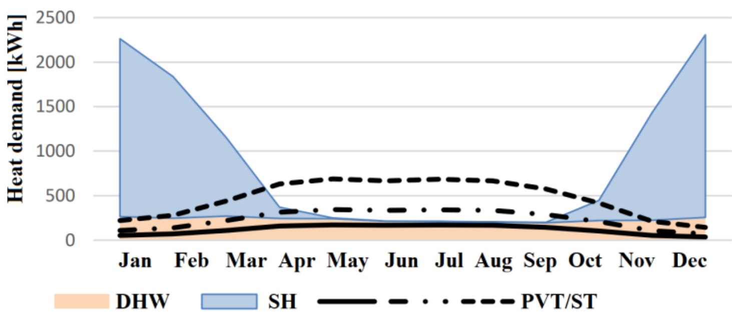


Figure 10 - Heat demand for a building in Amsterdam throughout the year for domestic heat water (DHW, orange) and space heating (SH, blue). The black lines are collectors with different areas [6].

Effective heat storage solutions are crucial to enhance the performance and economic viability of PVT or ST systems. Seasonal storage options can significantly improve efficiency, reduce energy wastage, and enhance the economic feasibility of these systems. By capturing and storing excess heat, these collectors can ensure a more reliable and continuous energy supply, essential for meeting the increasing demand for renewable energy. Seasonal storage solutions like low-temperature Aquifer Thermal Energy Storage (ATES), as shown in Figure 11, offer notable advantages. They store excess summer heat underground for heating purposes during winter and reserve cold for cooling during summer, providing a sustainable climate control solution. However, they may not inherently offer the required temperature range. To address this limitation, integrating additional components such as a heat pump (HP) becomes necessary. PVT systems integrated with thermal storage and HP have significant potential to meet the energy demands of urban environments while minimizing environmental impact.

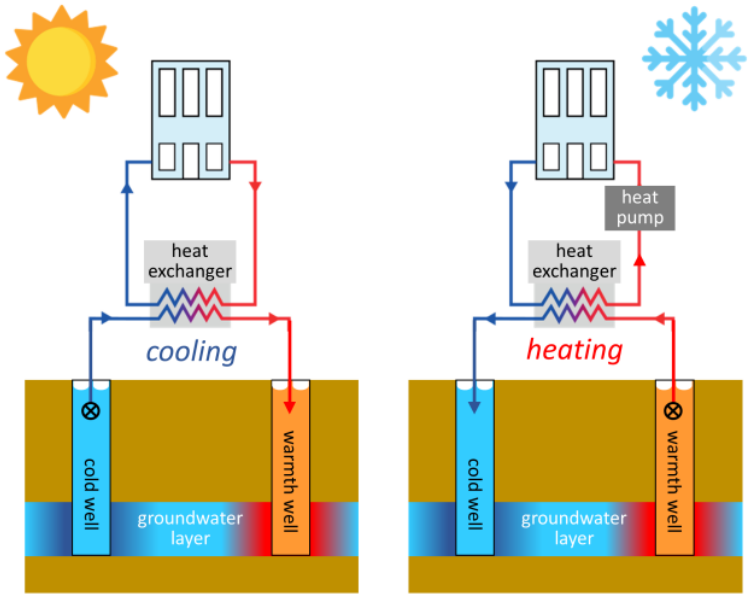


Figure 11 - Basic working principle of an ATES system [7].

The integration of PVT modules can enhance existing insulation strategies in buildings with varying insulation levels. In poorly insulated buildings, PVT systems provide electricity generation and thermal energy capture, reducing the need for additional heating in colder climates. Conversely, in well-insulated buildings, emphasis may be on optimizing electricity generation to meet overall energy demands. Considering the construction year is important; older buildings often have higher heat demand due to outdated standards, while newer constructions are typically more energy efficient. PVT systems can be integrated into retrofitting projects for older buildings to improve energy performance, decreasing reliance on traditional heating and promoting sustainability. Additionally, building heat demand varies based on occupancy, usage, and location. By analyzing these factors alongside insulation and construction year, urban planners can deploy PVT modules to match specific heat demand profiles effectively, optimizing energy utilization in urban areas.

The surface area of a PVT collector is a crucial parameter directly affecting system efficiency and performance, as illustrated in Figure 12, where both PV and thermal efficiency decrease as area increases for both SH and DHW applications.

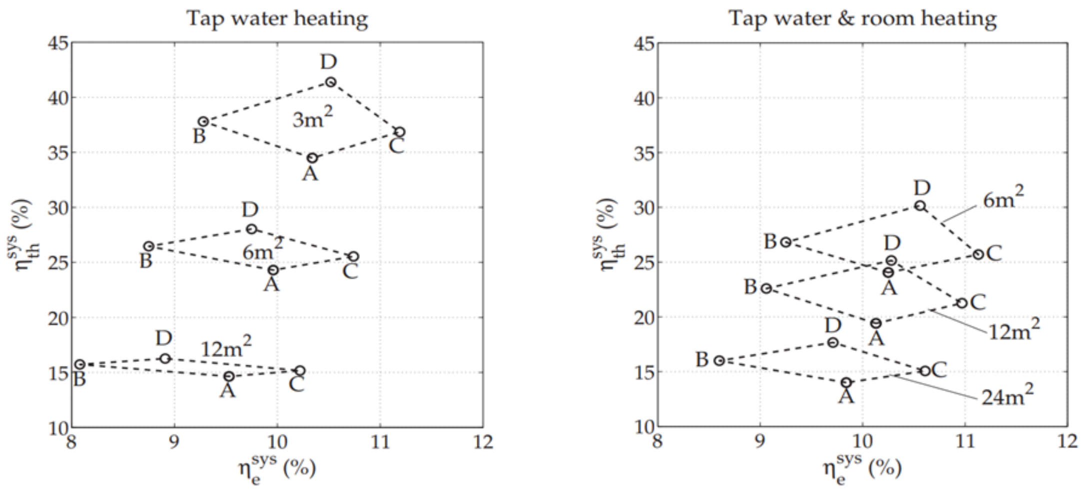


Figure 12 - The annual electrical system efficiency versus the annual thermal system efficiency for PVT systems with c-Si cells and coating configurations A, B, C and D [8].

The goal is to explore installation modes and expand PVT systems and ST modules to accommodate different panel dimensions, improving their effectiveness and scalability in urban environments. However, several factors hinder the widespread adoption of PVT systems in urban areas, including:

- Complex installation requirements
- High installation costs
- Need for diverse expertise
- Limited flexibility in panel dimensions
- Challenges in integrating storage solutions and HP's

Addressing these challenges requires a comprehensive approach, including policy frameworks that promote automation in installation processes and accommodate different panel types to optimize system performance. This report explores the potential benefits of implementing automated selection mechanisms for PVT system installation modes, streamlining deployment while ensuring compatibility with urban infrastructure. Additionally, strategies are examined for expanding PVT systems to incorporate panels of various types and dimensions, enabling greater customization and integration within diverse urban environments.

In the comprehensive system integrating solar collectors with ATES and HP, the following operational modes can be considered to cover heating demand:

(i) Solar heating mode (Mode I): Direct utilization of collectors to supply heat to the building.

(ii) HP heating mode (Mode II): Integration of collectors with HP for heating purposes.

(iii) HP storage mode (Mode III): Combination of HP with ATES for heating.

Additionally, there can be a few more modes that can be used for heating as well as for covering cooling demand:

(i) Underground storage mode: Utilization of only ATES to directly supply heat to the building.
(ii) Combined heating and cooling mode: Utilization of all components for both heating and cooling requirements.
(iii) Cooling mode: Utilization of HP and ATES for providing cooling during summer months.
(iv) PV only mode: Utilization cold fluid from ATES and passing through collectors to balance the system and cool down the collectors and using PV module electricity to run HP rather sending it back to grid due to negative prices.

These operational modes not only contribute to efficient energy utilization but also present adaptable solutions for various urban environments. As we investigate ways to automatically choose and vary the size of panels, it is crucial to understand these different methods well to suggest smart urban policies.

Figure 13 illustrates the space heating demand for an 80 m² house, depicted in blue, alongside the heat production by a single PVT system of approximately 2 m², shown in orange. The figure highlights that PVTs predominantly generate heat during the summer months (in purple), whereas the heating demand is highest during the winter months (in red). This disparity

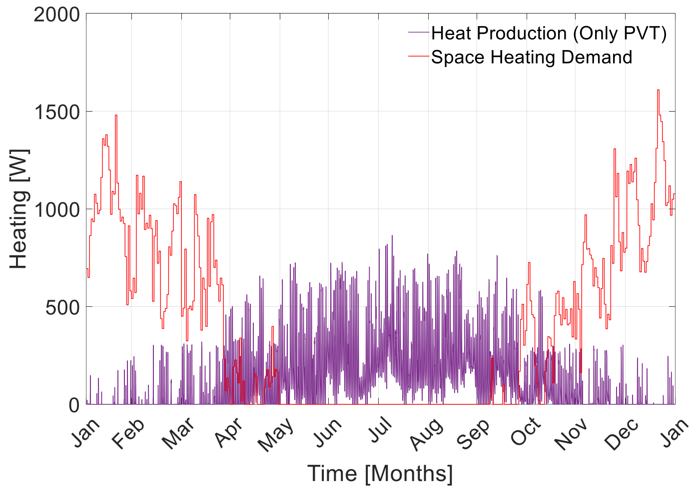


Figure 13 - Heat production of a PVT collector of approximately 2 m² and SH demand for 80 m² house.

indicates an opportunity for seasonal energy storage. The excess heat generated during the summer can be captured and stored for later use, effectively shifting the surplus energy to the winter months when the heating demand is high. This approach can significantly enhance the efficiency and sustainability of energy systems, ensuring that the heat produced in the less demanding summer months is not wasted but rather utilized during the peak demand in winter.

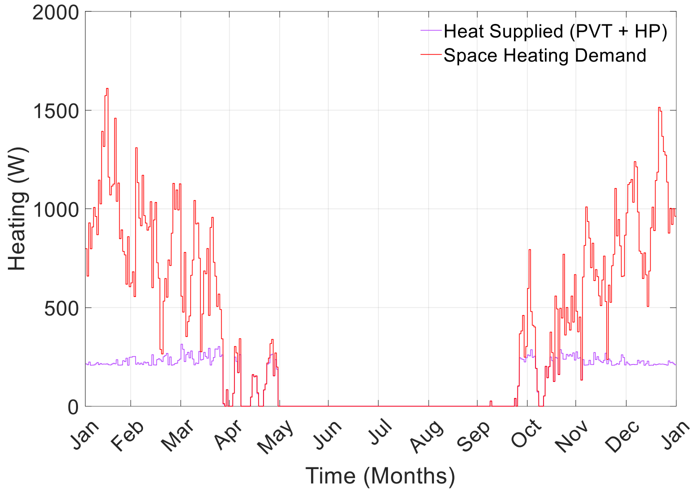


Figure 14 - Heat production of a PVT collector of approximately 2 m² combined with HP and SH demand for 80 m² house.

In Figure 14, an HP is integrated with a single PVT collector, and the results are displayed only for the winter months when heating is needed. It is observed that a PVT combined with a HP can supply a portion of the required heat (in light purple) during winter. By adding additional modules, it is possible to meet the heating demand entirely. However, to minimize the number of solar collectors needed, given the limited roof space, seasonal storage is essential.

Next, we explore the suitability and optimal combinations of different solar collectors. In the presented Figure 15, it is evident that as the apartment area increases, fewer PVTs combined with PV modules are required compared to using only PVTs or ST collectors combined with PV

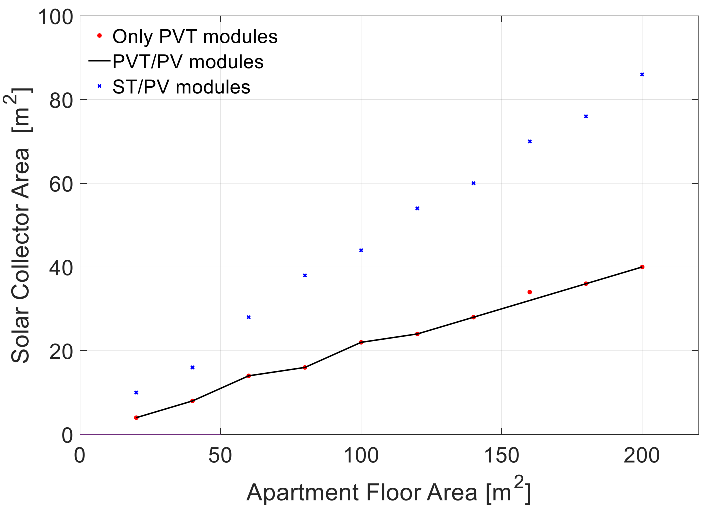


Figure 15 - Required solar collectors for various house areas using different combinations.

modules. This is because HPs require substantial power for heating, and PV-only modules can effectively supply this power. Meanwhile, PVTs provide both heating and electricity, making this combination a better solution in terms of performance and energy calculations.

Effective insulation plays a pivotal role in mitigating heating demands within structures, thereby leading to significant reductions in both the number of required building modules and the extent of roof coverage needed. This dual benefit not only translates to cost savings for developers and homeowners but also aligns with broader sustainability goals by curbing energy consumption and reducing environmental impact. Consider a real example of a four-story building in the center of Amsterdam, located at Beursstraat 25. Built in 1700, the building has a roof area of 142 m². With the current insulation, the total SH demand is approximately 61,500 kWh. However, with improved insulation, the SH demand can be reduced to approximately 18,700 kWh. The DHW demand remains the same at about 10,800 kWh, as depicted in Figure 16 (right) and has no effect of insulation.

Under current insulation conditions, covering the SH demand would require 42 to 93% of the roof space with various combinations of solar collectors. After renovation, the SH demand

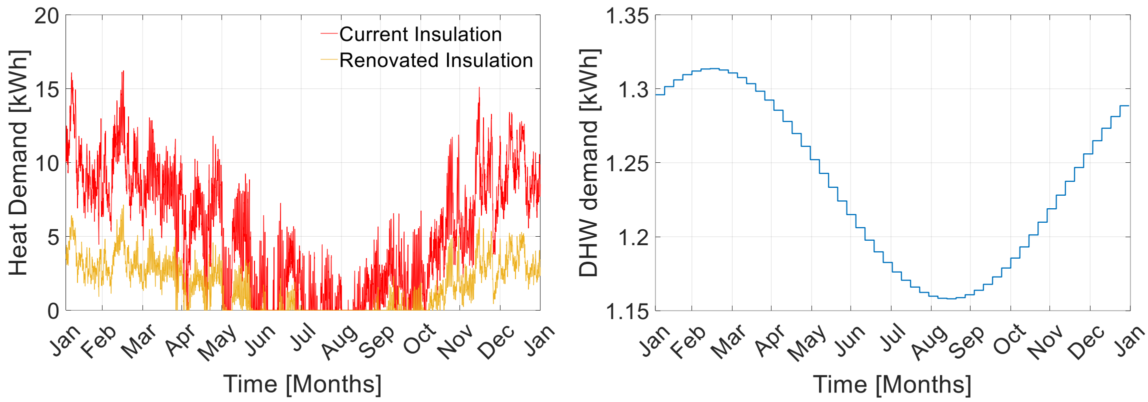


Figure 16 - SH demand with current and new insulation (left) as well as DHW load (right) throughout the year for Beursstraat 25.

decreases significantly, and the required roof coverage drops to 14 to 30% depending on the combination. As previously mentioned, combining PVTs with PVs or only PVTs is the most efficient solution. With the new insulation, only 10 PVT modules are needed to meet the SH demand (1 PV and 9 PVTs) requiring a total area of 30 m² (each module is approximately 2 m²). Additionally, to meet the DHW demand, which is required year-round, an extra 17% of the roof area is necessary. This translates to 24 m² or 12 PV and PVT modules in total to cover the DHW demand. In this scenario, Mode I covers only 7% of the SH demand, Mode II covers 70%, and Mode III covers 23% of the demand.

Table 2 - Solar collectors required to cover SH and DHW demand for renovated buildings in Amsterdam.

Building address	**Floors**	**Roof area (m^2)**	**SH demand (kWh)**	**DHW demand (kWh)**	**PVTs required for SH**	**PVs/PVTs required for DHW**
Beursstraat 25	4	142	18,700	10,800	10	12
Warmoesstraat 96	3	163	11,500	13,200	7	15

Beursstraat 21	5	158	25,200	29,000	14	33
Beursstraat 5	4	134	28,500	32,800	16	37
Oudebrugsteeg 3	4	69	18, 600	6,800	10	8

Comparable results can be derived for various buildings across Amsterdam by conducting a comparative analysis of different heating demands and available roof areas as given in Table 2. This comparison accounts for buildings with varying heating demands and roof sizes, with a focus on new insulation for SH, while maintaining the constant heat demand for DHW.

4.6. A comparison between PV and PVT

A new tool has been developed in python language to primarily handle a wider variety of input data formats and allow for more advanced calculations. In this example the solar irradiation for the solar modules on the building groups in the Focus District of the center of Amsterdam

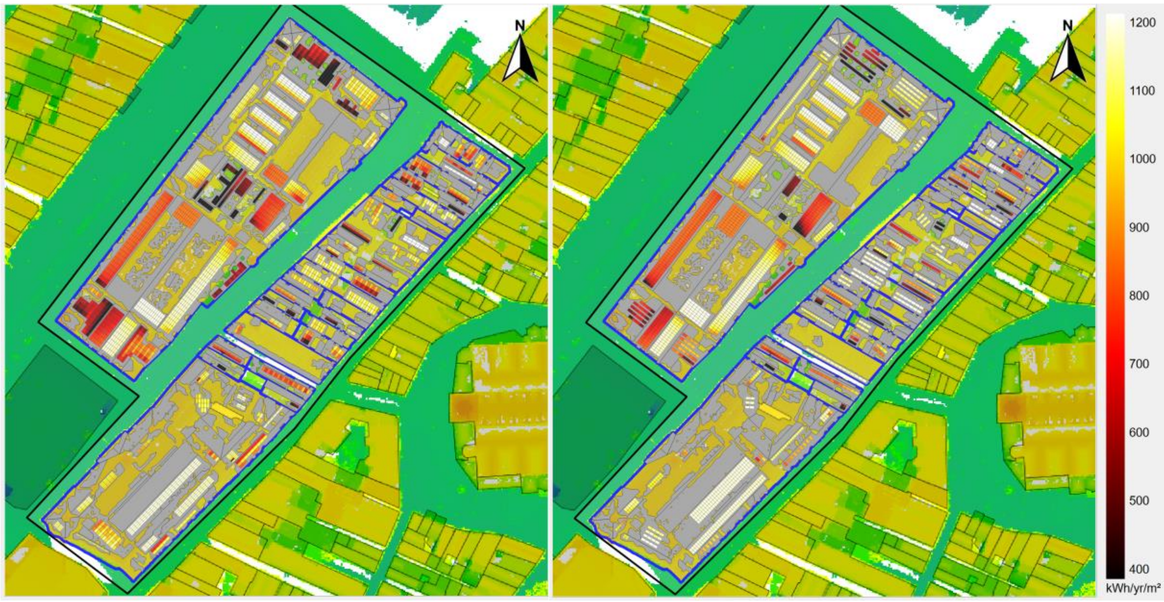


Figure 17 - Solar irradiation for solar modules for building groups in the focus district of the center of Amsterdam with east west-landscape (left) and south facing-portrait (right).

is shown in Figure 17 with layout and orientation. The images show (left) a combination of east-west facing layout for zero-tilt surfaces and landscape orientation for sloped surfaces and (right) south-facing layout for zero-tilt and portrait orientation for sloped surfaces. The grey shapes show the detected suitable roof surfaces for modules. It can be seen that the detected surfaces do not cover all of the rooftop, due to the more complex roof structures in the city center. The solar irradiation for modules on the AMS institute building is shown on the cover page of this report. The grey shapes show the detected suitable roof surfaces for modules, which almost completely covers the maximum possible roof area.

Using the hourly irradiance and meteorological data, we can calculate the electrical yield of PVs, thermal yield of glazed STs and the electrical and thermal energy yield of unglazed PVTs for every module. The results are shown in Table 3 for the city center and AMS institute. The results are for south-facing and portrait combined and it can be observed that PVTs performance is much better per m^2 as compared to the combined use of standalone PV and conventional ST module. Not only per m^2, also the electrical output for PVTs is higher due to the use of heat extraction medium. The use of glazing on top of the ST module increases the thermal output but in case of PVT. If glazing is used, the electrical efficiency decreases, which results in lower PVT electrical output.

Table 3 - Solar collectors electrical and thermal yield for multiple locations.

Location	**No. of panels (2 m^2 per module)**	**Installed capacity (kW)**	**PV electrical yield (MWh/yr)**	**ST thermal yield (MWh/yr)**	**PVT electrical yield (MWh/yr)**	**PVT thermal yield (MWh/yr)**
AMS institute	1147	379	434	1641	452	890
City centre	2095	691	702	2713	750	1451

5. Urban policy suggestions

5.1. Policy framework for PV installation

This section presents a robust policy framework designed to govern the installation of PV systems within urban settings. It offers comprehensive guidelines and regulations pertaining to the placement, sizing, and upkeep of PV modules, aimed at optimizing energy generation while blending with the urban landscape.

5.2. Integration with urban planning

The report explores strategies for seamlessly integrating PV installations into existing urban planning models. It explains methods for incorporating PV potential assessments into broader city-wide planning initiatives, underscoring the importance of aligning energy objectives with wide urban development goals.

5.3. Regulatory considerations

This part underscores critical regulatory aspects crucial for facilitating the widespread adoption of PV technology. It delves into the complexity of permitting procedures, urban development guidelines, and building codes necessary to accelerate PV installation processes while ensuring compliance with relevant local regulations.

5.4. Support

This part outlines various supportive measures aimed at promoting PV adoption within urban landscapes. This encompasses an array of initiatives such as financial incentives, technical assistance programs, and collaborative ventures between public and private sectors, all geared towards mitigating barriers and stimulating investment in solar energy infrastructure.

5.5. Stakeholder engagement

The significance of active stakeholder involvement throughout the decision-making progression has to do with strategies for fostering meaningful collaboration among governmental bodies, community organizations, and private enterprises to ensure that PV initiatives match with the diverse needs and priorities of all stakeholders.

This report aims to provide practical policy recommendations tailored to the unique needs of urban settings to facilitate the widespread adoption of PVT systems as a sustainable energy solution. Collaboration among policymakers, industry stakeholders, and urban planners is essential to unlock the full potential of PVT technology and drive the transition towards a cleaner, more resilient urban energy landscape. To facilitate the widespread adoption of PVT systems in urban areas, policymakers should consider the following recommendations:

- Implement policies incentivizing the use of automation technologies in PVT system installation processes.
- Develop guidelines for accommodating diverse panel sizes and configurations in urban environments.
- Provide financial incentives or tax credits for businesses and homeowners adopting PVT systems.
- Collaborate with industry stakeholders to establish standards for automated installation equipment and panel compatibility.
- Offer technical assistance and training programs to support the adoption of PVT systems among installers and contractors.

6. Implementation strategies

The focus districts can follow in the footsteps of Ramplaan neighborhood [9] by adopting a similar collaborative approach between residents and local government, supported by financial incentives and subsidies. By investing in sustainable technologies like solar collectors integrated with HP's and ATES, districts can significantly reduce their reliance on fossil fuels for heating and electricity. This transition not only mitigates carbon emissions but also empowers communities to take control of their energy needs. Implementing communal networks for distributing surplus energy, along with underground storage systems for seasonal variation.

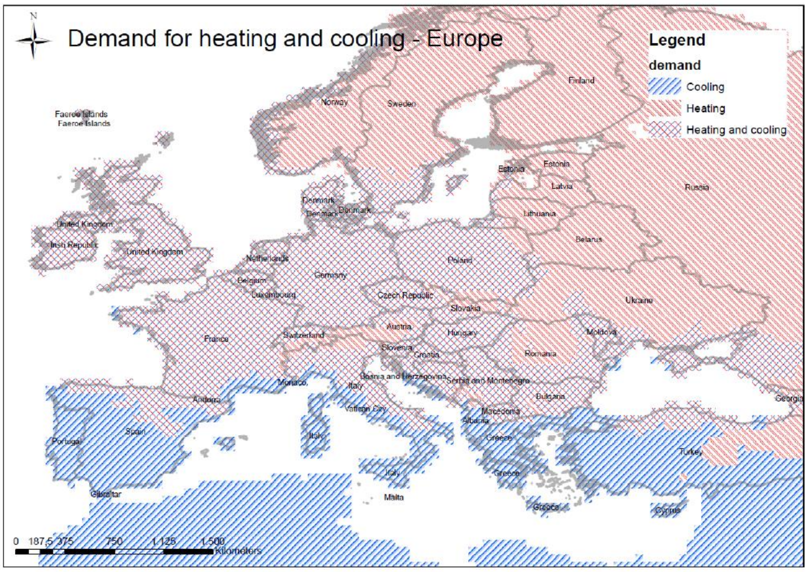


Figure 18 - Demand for heating and cooling, Europe [9].

In Figure 18, the depiction of heating and cooling demand reveals distinct patterns. Northern Europe demonstrates a greater need for heating, whereas southern Europe experiences extended summers and requires more cooling. Likewise, Figure 19 illustrates the suitability of ATES systems across Europe. The data indicates that the Netherlands is highly suitable to these systems, whereas southern Europe shows lower suitability for ATES implementation.

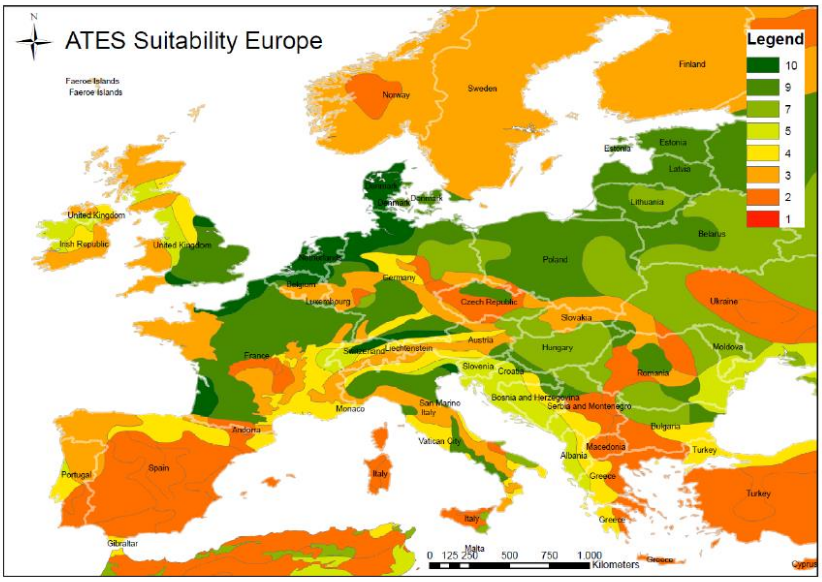


Figure 19 - ATES suitability throughout Europe [9].

6.1. Comparison with real study cases

In the Ramplaan neighborhood, as illustrated in Figure 20, collaboration between residents and the municipality of Haarlem, supported by a 4-million-euro government subsidy, is underway to establish a more sustainable and cost-effective method for heating homes through solar PVT systems integrated with HP's and boilers to facilitate hot water production and heating, termed as solar heating network. This is to decouple the dependency on large

Figure 20 - Aerial view of the Ramplaan neighborhood with solar heating network [10].

corporations for heat provision. Ramplaan residents are taking initiative by harnessing their own heat resources and distributing it amongst themselves via a communal network, thereby assuming control over their energy requirements. The residents team up with companies and the local government to make their system work by sharing ideas and responsibilities. The companies help by providing advice and installing equipment like solar panels and HP's. The municipality also plays a big role by providing support and even financial help, making sure the project runs smoothly and benefits everyone involved. The Ramplaan project includes PVT, warm-cold storage, and HPs. It operates in three modes:

- Mode I: HPs draw heat from the *zeer lage temperatuur* (ZLT) or very low temperature network during winter.
- Mode II: HPs utilize heat from PVTs on roofs during transitional seasons.
- Mode III: PVT produces heat for storage and usage during summer.

This initiative aligns with Haarlem's broader agenda to transition towards eco-friendliness and ultimately phase out natural gas dependency by 2040 using wind, water or geothermal heat. Through collective effort and the adoption of renewable energy sources, Ramplaan exemplifies a significant contribution to the global fight against climate change. Inspired by a successful project in Ramplaan neighborhood in Haarlem, a similar approach can be used for the multiple buildings in Amsterdam to make its districts energy positive by utilizing solar collectors with HP's and ATES considering multiple modes.

We compared our results with the real system installed in Ramplaan neighborhood. Three modes are also taken into consideration in this study, which include:

- Mode I: Direct heating from solar collectors.
- Mode II: Heating with solar collectors and HP.
- Mode III: Heating with ATES and HP.

For SH, the net heat demand was 11,000 kWh for one of the buildings in Ramplaan neighborhood, and 9 PVT panels are required to cover 100% of the demand with a collector area of 2 m² each. In the case of Warmoesstraat 96 in Amsterdam, the obtained results are quite close, as depicted in Table 4, where the number of PVTs required is 7 in total. However, if one utilizes PV and conventional ST modules separately, the number of modules increases to 14 in total. This shows, again, the benefits of PVTs as they produce both heat and electricity simultaneously using same area.

Table 4 - Number of solar collectors required by Warmoesstraat 96 for SH.

Building address	Net heat demand (kWh)	Roof area (m^2)	PVTs (approx. $2m^2$)
Warmoesstraat 96	11,450	163	7

It is worth noting that the neighborhood predominantly focuses on the utilization of boilers or domestic storage tanks for DHW coverage. However, our analysis for Amsterdam city extends beyond conventional methods by considering the integration of solar collectors, HPs, and seasonal storage for DHW provision.

6.2. Collaboration with local authorities

To replicate the success of the Ramplaan neighborhood initiative in the city of Amsterdam or other focus districts, the municipality could take several concrete steps:

- Assessment and Planning:
  Conduct a thorough assessment of the district's energy needs, existing infrastructure, and potential for solar energy generation by developing a comprehensive plan.
- Stakeholder Engagement:
  Engage with residents, businesses, and community organizations to gather support for the initiative. Encourage participation and collaboration in the planning and implementation process.
- Financial Support:
  Seek government subsidies or grants, similar to the 4-million-euro subsidy in Haarlem.
- Regulatory Framework:
  Establish supportive policies and regulations to incentivize the adoption of renewable energy technologies. This could include feed-in tariffs and tax incentives.
- Infrastructure Development:

Invest in the necessary infrastructure to support the district energy-positive model, including upgrading existing heating systems, installing solar collectors on rooftops, and implementing ATES systems for thermal energy storage.

- Raising awareness:
  Provide education and outreach programs to raise awareness about the benefits of renewable energy and district energy systems, especially PVT systems combined with HP and ATES. Additionally, educate property owners about the benefits and possibilities of using different solar panel dimensions, emphasizing customization and optimization for individual needs.
- Monitoring and Evaluation:
  Implement a monitoring and evaluation system to track the performance and impact of the district energy-positive initiative. Use data to identify areas for improvement and adjust strategies as needed to maximize carbon reduction.

By taking these concrete steps, the city of Amsterdam can effectively replicate the success of the Ramplaan neighborhood initiative and work towards making the district energy-positive while reducing dependency on natural gas and combating climate change.

7. Conclusions

- The report underscores the advantages of east-west layout for higher energy yield despite traditional preferences for south-facing orientation. Automation offers a balanced approach, optimizing both energy efficiency and aesthetic appeal in PV module installations.
- By implementing supportive policies, cities can enhance the efficiency, safety, and adaptability of solar installations, contributing to a more sustainable urban future.
- PVT collectors generate both electricity and heat, maximizing solar energy utilization. This dual output makes PVT systems highly efficient for urban installations.
- Glazed collectors provide superior thermal performance; however, if a higher electrical yield is required, unglazed collectors are more suitable.
- Integrating seasonal storage and heat pumps with PVT collectors enhances energy output and reliability. This combination ensures consistent energy supply, addressing seasonal variations and increasing overall system efficiency.
- Prioritizing good insulation reduces heating demand, minimizing both module requirements and roof coverage, leading to cost savings and environmental sustainability.

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simply positive