MASTER

Energy transition
a decision support tool towards hourly energy self-sufficient greenfield developments

Loenders, Sven H.M.

Award date:
2023

Energy transition: a decision support tool towards hourly energy self-sufficient greenfield developments

Graduation thesis combined master program – 60 ECTS
7CC40 – Graduation project CME
7Z45M0 - Graduation project USRE

Loenders, S.H.M. – 1256467

Graduation committee CME:
Prof. Dr. Ir. B. (Bauke) de Vries (Chair)
Dr. Q. (Qi) Han (1st supervisor)
Ir. S.J.E. (Stephan) Maussen (2nd supervisor)

Graduation committee USRE:
Prof. Dr. T.A. (Theo) Arentze (Chair)
Ir. S.J.E. (Stephan) Maussen (1st supervisor)
Prof. Dr. Ir. B. (Bauke) de Vries (2nd supervisor)

Company guidance:
Ir. R. (Remko) de Leeuw (Arcadis)

Department of the Built Environment
Eindhoven, June 23rd, 2023

This page is intentionally left blank

Colophon

General

Title	**Energy transition: a decision support tool towards hourly energy self-sufficient greenfield developments**
Document	Master thesis
Version	Final version
Date	June 23, 2023
Place	Eindhoven

Author

Name	S.H.M. (Sven) Loenders
Student-ID	1256467
Email	s.h.m.loenders@student.tue.nl / sven.loenders@gmail.com

Institute

University	Eindhoven University of Technology
Faculty	Department of the Built Environment
Program 1	Construction Management and Engineering
Program 2	Architecture, Building and Planning (track: USRE)

Graduation committee Construction Management and Engineering

Chairman	Prof. Dr. Ir. B. (Bauke) de Vries
First supervisor	Dr. Q. (Qi) Han
Second supervisor	Ir. S.J.E. (Stephan) Maussen

Graduation committee Architecture, Building and Planning (USRE)

Chairman	Prof. Dr. T.A. (Theo) Arentze
First supervisor	Ir. S.J.E. (Stephan) Maussen
Second supervisor	Prof. Dr. Ir. B. (Bauke) de Vries

Graduation company

Company	Arcadis Nederland B.V.
Supervisor	Ir. R. (Remko) de Leeuw

Preface

Dear reader,

This master thesis is written to obtain my master's degree in Construction Management and Engineering as well as the master's track Urban Systems and Real estate and therefore brings my university career at the Eindhoven University of Technology to an end.

In the past academic year, I was able to propose the research and executed it as well, which I have done with great enthusiasm. My personal interest in the energy transition in relation to the built environment has been reflected throughout my university career, among others within the VIRTUe student team, and therefore I am pleased I could integrate this personal interest and rather important topic into my master thesis.

I would like to thank my supervisors of both university committees for their guidance, time and contribution, which did result in the thesis I present proudly right now. I would like to give special thanks to my first supervisors, Qi Han and Stephan Maussen for their support.

Additionally, I would like to thank all experts who did contribute to this thesis as well as my colleagues at Arcadis, not only for their knowledge and expertise but also for their enthusiasm and motivation at the different offices, which made it feel like a warm and welcoming place. Special thanks upon this to Remko de Leeuw, being my Arcadis supervisor.

Lastly, I would like to thank my loved ones for listening, their support and their distractions which have certainly contributed to an enjoyable and pleasant time!

I proudly share this thesis with all who are interested, and I hope you enjoy reading this thesis,

Sven Loenders
Melick, June 2023

Table of Contents

Summary

The awareness towards energy consumption, sustainability and energy transition is increasing, however, the share of the built environment in energy consumption is large. The energy consumption, still mainly via fossil sources, does contribute largely to the Dutch greenhouse-emitted gasses. In the Netherlands, in 2020, already 32.7% of the Dutch emission could be devoted to only the energy consumption and demand for heating and cooling.

However, times have changed, and the increasing awareness does result in more sustainable solutions and technologies which can reduce the impact of the built environment on the emission, although, not solved overnight, but will take up years. Electrification is a way to improve emissions. However, in the context of the Netherlands which is deemed in this research, this encounters the problem of grid congestion. The Dutch electricity grid is congested in large parts of the country. This not only slows down the electrification it impacts sustainability, the energy transition but also the development of new buildings. Especially dwellings are in high demand in the Netherlands. Furthermore, electrification should not be seen as the holy grail solution for the energy transition and the emissions, electrification does require necessary conditions (e.g. installations and thermal resistance) on the buildings to where it is applied to.

The research conducted did focus on the sustainability and energy transition of residential dwellings in greenfield development, a segment where pioneering with sustainability and energy-neutral can be applied from the initiative and design phase onwards. The need for the development of a tool has been identified from the problem context and literature onwards. There are already many tools available within the field of energy modelling and energy systems, however, all with a very specific aim in either moment of application or level of detail. Argued that there are no tools available able to model energy demand, energy supply and energy neutrality on an area level, with a sophisticated level of detail in both output and input, which matches the area development phase where this level of detail can still be adjusted to affect the energy demand, supply and also the level of energy-neutrality, which deems the scope of this research: how to develop a decision support tool towards hourly energy self-sufficient greenfield developments covering energy demand, production and storage.

Therefore, a spreadsheet tool has been developed which allows the modelling of energy performances of residential greenfield developments. The tool is able to model this development on an hourly resolution for a full year, which contributes to the identification of the mismatch of energy demand and supply over different time periods, e.g. daily, monthly and annually. This hour resolution adds more detail to the energy match and mismatch in comparison to common approaches looking at the annual match of energy demand and supply defining energy neutrality or self-sufficiency. The tool is developed along a design research cycle, in which the research questions have been targeted towards the identification of variables of different components integrated into the tool. The tool is composed of 3 components, which interact with each other: energy demand, energy supply and energy storage. The identification of variables for the different components has been executed by thorough literature studies and the involvement of experts from different companies and institutes. The energy demand component is mainly shaped by physic-law calculations and methods which define a gross demand for heat load and cool load upon the entered building characteristics and types in the area, transferred to a net load by a selectable

system/technology. The supply component calculates estimates of hourly renewable energy potential according to inserted setups of photovoltaic panels, thermal collectors or wind energy collectors. Both components rely on composed long-term weather data sets from multiple strategic locations in the Netherlands including temperature, wind speeds and solar radiation. A full match between the demand and supply is desired, although unfortunately a utopia. Upon the tool user's choice, two types of scalable energy storages, battery storage or thermal storage, can be added to the simulation. The addition of a storage can subdue the mismatch to a certain extent or ideally to 100%.

The design research cycle is reflected in the use of the tool as well. The tool is intended to test a base scenario according to initial insights and assumptions of an area development or first design values. Depending on the performances of this base scenario simulation, as the tool will present in a dashboard, changes to the dwellings and area parameters can be evaluated by a new simulation run in the tool. Improvements can be tested iteratively in this way. The tool should therefore be seen as a 'test and try' approach, supportive of design decisions along the initiation and design process of a residential greenfield development.

Some features on the results dashboard in the tool are the total energy demand and supply (of that area, or per building id) and the level of self-sufficiency, expressed as the number of hours in a year the area can fulfil in its own energy needs. Also, the external energy demand and grid feed-in are indicated as summed values as well as plotted over time. The fill levels of the energy storages are also shown on the dashboard if present in the specific simulation.

The operation of the tool has been demonstrated at the final stage with 2 case studies. Both case studies are residential greenfield developments, although they do differ in their project stage. Case 1 approaches the adaption of a land-use plan, in case 2 the design stage is mostly completed and prepared for execution. Both cases do perform between 40 – 60% of energy self-sufficiency on their base scenario parameter values. Different suggestive design changes were tested based on adjusted parameters. In most cases, this led to improvements in energy self-sufficiency, demand reduction or supply increase or a mix of these. Realizing a 100% energy self-sufficiency scenario 'at all costs' turned out to be achievable in energy quantity terms, however, did indicate substantial oversizing of energy storage systems and energy supply systems.
The developed tool is therefore capable to bridge the gap between science and practice in the field of area development and energy transition (energy planning) and in that way did where it was intended for. Insights into the energy performances of greenfield developments were gained and potential optimisations along the buildings and the area being simulated have been evaluated in the planning and (early) design phases of development projects. Broad-based implementation of the tool is therefore expected to result in future area development with energy-optimized architectural designs, which consume less energy and perform better on energy efficiency. In an ideal situation, this results in a fully energy self-sufficient or even energy-positive development. In turn, this contributes to a more emission-free, cleaner and hopefully better world.
What should be added to this, is that the current tool is a first version and does certainly leave room for improvements in the future or features to be added, extension of the tool capacity to handle more dwellings types within a single simulation and the addition of technologies becoming market-ready in the future.

Samenvatting

Het bewustzijn ten aanzien van energieverbruik, duurzaamheid en energietransitie neemt toe. Het aandeel van de gebouwde omgeving in het energiegebruik is groot, dat overigens nog steeds voornamelijk door fossiele bronnen wordt opgewekt. In 2020, kon 32.7% van de Nederlandse uitstoot aan broeikasgassen worden toegeschreven aan alleen al de energievraag naar verwarming en koeling

De tijden zijn echter veranderd en het toenemende bewustzijn leidt tot duurzamere oplossingen en technologieën die de impact van de gebouwde omgeving op de uitstoot kunnen verminderen. Elektrificatie is een manier om de uitstoot te verbeteren. In de context van Nederland, waar dit onderzoek over gaat, stuit dit echter op het probleem van congestie van het elektriciteitsnet. Het Nederlandse elektriciteitsnet is in grote delen van het land overbelast. Dit vertraagt niet alleen de elektrificatie, maar heeft ook gevolgen voor de duurzaamheid, de energietransitie en de ontwikkeling van nieuwe gebouwen. Vooral naar woningen is veel vraag in Nederland. Verder moet elektrificatie niet worden gezien als de allesomvattende oplossing voor de energietransitie en de emissies, elektrificatie vereist wel de nodige voorwaarden (bijv. installaties en warmteweerstand) aan de gebouwen waar het op wordt toegepast.

Het uitgevoerde onderzoek richt zich op de duurzaamheid en energietransitie van woningen in greenfield ontwikkeling, een segment waar pionieren met duurzaamheid en energieneutraal kan worden toegepast vanaf de initiatief- en ontwerpfase. Vanuit de probleemcontext en de literatuur is de behoefte naar de ontwikkeling van een instrument vastgesteld. Er zijn echter al veel instrumenten beschikbaar op het gebied van energiemodellering en energiesystemen, echter allemaal met een zeer specifiek doel, moment van toepassing of detailniveau. Er zijn geen instrumenten beschikbaar die de energievraag, het energieaanbod en de energieneutraliteit op gebiedsniveau kunnen modelleren, tot op een zeker detailniveau in zowel output als input, dat aansluit bij de fase waarin de gebiedsontwikkeling verkeerd, en waar dit detailniveau nog kan worden aangepast om de energievraag, het energieaanbod en ook het niveau van energieneutraliteit te beïnvloeden, wat het toepassingsgebied van dit onderzoek duidt: hoe kan een beslissingsondersteunende tool worden ontwikkeld voor energie zelfvoorzienende greenfieldontwikkelingen die betrekking hebben op energievraag, -productie en -opslag.

Daarom is een spreadsheet-tool ontwikkeld waarmee residentiële greenfield ontwikkelingen kunnen worden gemodelleerd. De tool kan dit gebied modelleren op uurbasis voor een volledig jaar, wat bijdraagt tot de identificatie van de mismatch tussen energievraag en -aanbod in verschillende tijdsspanne; dagelijks, maandelijks en jaarlijks. Het instrument is ontwikkeld volgens een ontwerp-onderzoeks-cyclus, waarbij de onderzoeksvragen gericht zijn op de identificatie van variabelen die in de verschillende componenten van de tool aanwezig zijn. De tool bestaat uit drie componenten die met elkaar samenhangen: energievraag, energieaanbod en energieopslag. De identificatie van variabelen voor de verschillende componenten is uitgevoerd door literatuurstudies en de betrokkenheid van deskundigen van verschillende bedrijven en instituten. De energievraagcomponent wordt voornamelijk gevormd door natuurkundige berekeningen en methoden die een bruto warmtelast en koellast definiëren op basis van de ingevoerde gebouwkenmerken en -types in het gebied, omzetbaar naar een netto last op basis van de geïnstalleerde installatietechniek. De opbrengst

component berekent het potentieel aan hernieuwbare energie per uur volgens ingevoerde opstellingen van zonnepanelen, thermische collectoren of windturbines. Beide componenten zijn gebaseerd op samengestelde langjarig weerdatasets van meerdere strategische locaties in Nederland, van temperatuur, windsnelheden en zonnestraling. Een volledige match tussen vraag en aanbod in een gebied is gewenst, maar helaas een utopie. Naar keuze van de gebruiker van de tool kunnen twee soorten aanpasbare energieopslagen, batterijopslag of warmteopslag, aan de simulatie worden toegevoegd, die de mismatch tot op zekere hoogte of idealiter voor 100% kunnen ondervangen.

De onderzoek cyclus van het ontwerp wordt ook weerspiegeld in het gebruik van het instrument. De tool is bedoeld om in eerste instantie het basisscenario door te rekenen, volgens de eerste inzichten en aannames van een gebiedsontwikkeling, of eerste ontwerpen. Afhankelijk van de prestaties van dit basisscenario, die aan de hand van een dashboard in de tool kunnen worden afgelezen, kunnen wijzigingen aan de woningen en het gebied worden gemaakt die vervolgens met een nieuwe run in de tool getest kunnen worden op verbetering. De tool dient dus als "try en test" instrument, ter ondersteuning van ontwerpbeslissingen tijdens het initiatief en/of ontwerpproces van een greenfield woonwijk. Enkele kenmerken van het dashboard zijn de totale energievraag en -aanbod (van dat gebied, of per ID) en het niveau van zelfvoorziening, dat is het aantal uren per jaar dat het gebied in staat is om in zijn eigen energiebehoeften te voorzien. Ook de externe energievraag en de terug levering aan het net worden weergegeven als opgetelde waarden en als grafiek, hetgeen ook geldt voor de energieopslag, indien aanwezig in de gebied/plan.

De werking van de laatste versie van de tool is geanalyseerd aan de hand van twee casestudies. Beide casestudies zijn nieuwe woonwijken, maar verschillen in hun projectfase. Case 1 bevindt zich in de bestemmingsplan fase, case 2 is uitgewerkt en klaar voor uitvoering. In beide gevallen ligt de zelfvoorzieningsgraad van het basisscenario tussen 40 en 60%. Verschillende mogelijke ontwerpwijzigingen werden getest door middel van aangepaste parameters, die in de meeste gevallen leidden tot verbeteringen in de energiezelfvoorziening, vermindering van de vraag of verhoging van het aanbod. Het realiseren van een 100% energiezelfvoorzieningsscenario, tegen elke prijs, blijkt haalbaar qua energiehoeveelheid, maar betekend wel dat er een enorme over dimensionering nodig voor de energieopslagsystemen en de opwek installaties.

De ontwikkelde tool is dus in staat om de kloof tussen wetenschap en praktijk op het gebied van gebiedsontwikkeling en energietransitie (energieplanning) te overbruggen en doet op die manier waar hij voor bedoeld is, namelijk inzicht krijgen in de energieprestaties van een nieuwe gebiedsontwikkeling en potentiële optimalisaties evalueren, reeds te gebruiken in de initiatief- en (vroege) ontwerpfasen. Een brede toepassing van het instrument zal daarom naar verwachting leiden tot toekomstige gebiedsontwikkeling met energie-geoptimaliseerde architectonische ontwerpen, die minder energie verbruiken en beter presteren op het gebied van energie-efficiëntie, of idealiter volledig zelfvoorzienend of zelfs energienegatief zijn. Dit draagt dan weer bij tot een emissievrijere, schonere en hopelijk betere wereld. Hieraan moet worden toegevoegd dat de huidige tool een eerste versie is en zeker ruimte laat voor verbeteringen in de toekomst of het toevoegen van functionaliteiten, zoals het kunnen simuleren van meer dan 5 gebouwen typen per simulatie of uitbreiding van de tool met technologieën die in de toekomst op de markt komen.

Abstract

Awareness regarding the impact of the built environment on greenhouse emissions is increasing. Electrification is one of the options to reduce emissions in this sector. However, this causes problems for congested grids when electrification is widely practised in the Netherlands. Due to this, the interest in energy self-sufficient areas and microgrids increases, in order to be able to still enable the energy transition and keep on going new developments. Along the design research cycle, a tool has been developed from a scientific point of view, being able to analyse residential greenfield developments (communal) upon its energy performance in an initiative or (early) design stage by parameters, for an entire year with an hourly resolution. The self-sufficiency of the simulated area is one of the performance indicators, which can be improved by reducing the energy demand of the buildings in the plan area by their parameters, increasing the energy supply or adding communal energy storage facilities. Planning and design can be renamed to energy-oriented design and energy planning, as the tool is intended to seek an energy-optimal scenario by changing building design and area layout. The tool is composed of a mix of theory (literature) and knowledge of experts. Within the research, the tool has been applied in two case studies, where tested parameter adjustments, after a base scenario simulation, did indicate a substantial increase in energy self-sufficiency, by reducing the demand with among others shade control, increasing the renewable energy supply by small wind energy collectors and the installation of a battery storage (short cycle) and a thermal energy storage (long cycle). The developed tool enables the design of future residential area developments with energy-optimized architectural designs, which consume less energy and perform better on energy efficiency. Ideally, these developments are fully energy self-sufficient or even energy positive.

Keywords: Energy oriented design, Area development, Energy transition, Energy modelling, Energy storage

Glossary

Abbreviation	Definition
EST	Energy Storage Technologies
DHW	Domestic Hot Water
SH	Space Heating
SC	Space Cooling
PV	Photovoltaic
TES	Thermal Energy Storage
K	Kelvin
J	Joule
Kg	Kilogram
Wh	Watt-hour
kWh	Kilowatt-hour
MWh	Megawatt-hour
SM	Statistical Method
EM	Engineering Method
COP	Coefficient of Performance
VLU	Full-Load Hour
ASHP	Air Source Heat Pump
GSHP	Ground Source Heat Pump
WSHP	Water Source Heat Pump

List of Figures

List of Tables

1. Introduction

The awareness towards energy consumption, sustainability and energy transition is raised by multiple facets within the built environment. A short introduction will be given upon these facets deeming the incentives of this thesis research. Further, this chapter will introduce the research question and the corresponding sub-questions, as well as the research design and relevance. The chapter will be concluded with a reading guide.

1.1 Problem definition

The need for transitions and changing habits toward climate issues and sustainability is not new. Although the increase in sustainability is picking up, there is still a long way to go in order to fulfil agreements like the Paris Agreement, in which 195 countries including the Netherlands agreed upon the fact to put everything into operation to reduce further global heating up to a maximum of 2 degree Celsius (aiming at 1.5℃). This has been translated into a framework for the Netherlands specifically by the policymakers. The main target here is the reduction of greenhouse gasses, of which carbon dioxide is the most important one, coming down to a reduction of 49% by 2030 and up to 95% by 2050 compared to Dutch emissions by 1990. (Centraal Bureau voor de Statistiek, 2022b; Ministerie van Economische Zaken en Klimaat, 2021).

The built environment and its use are responsible for a majority of the emitted greenhouse gasses in the Netherlands by the use of fossil energy for heating and cooling (32.7% of the Dutch emissions in 2020) and for the electricity demand (21.8% equivalent) (Centraal Bureau voor de Statistiek, n.d.). Reducing the emissions can be done among others by increasing the potential and efficiency of generated renewable energy from already-installed or new-to-install sources (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2022a). (IPCC, n.d.; Ministerie van Economische Zaken en Klimaat, 2021).

This illustrates an alternative energy solution. Although to reduce the problem size it is important to see the wider palette of solutions, where the buildings' energy efficiency is an important aspect to reduce the amount of demanded energy. High energy performance standards are easy to apply in new developments. In the case of existing buildings, it becomes more difficult to improve energy efficiency levels up to current standards if that is even within reach. Nevertheless, a building fulfilling the most recent energy performance standards still demands energy, which emphasises the need for renewable energy production (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2022a).

An additional constraint will occur when electrification in housing and industry will enhance. More electricity will be demanded from the grid, however, these grids have reached their capacity locally (Rijksoverheid & Studiegroep Duurzame groei, 2016). This means that power connections can barely be extended or added to the grid, which further restricts the energy transition, as a 'blacked-out' grid will also restrict feed-in from collected solar energy at plants or dwellings (Abbenhuis, Jetten, & RTL Z, 2022; NOS, Stigter, & Nijpels, 2022). Next to transition and sustainability restrictions, grid congestion also restricts the extension of the Dutch housing stock. The housing stock is currently under supply pressures as well, as it cannot cope with the demand for housing. A solution for the housing market shortage is extending the number of dwellings in the Netherlands through greenfield developments (Clashen & Lever, 2022). Greenfield developments are developments deemed as undeveloped land, most often at the edge of a settlement, initiated for the development of a specific type of land use and real estate or the mix of multiple including the required infrastructure (Reed & Sims, 2015). Greenfield area development is built up from scratch, where policies and intentions can frame the criteria for that specific area to be developed. (Polman & McDonalds, 2022).

However, as illustrated, difficulties will occur when new power-grid connections will be needed for these stock-extending developments, as more power from the national and regional grid will be demanded. This will likely occur when large-scale sustainability renovations will take place, where natural gas is banned from dwellings and additional electric power consumption can be expected (e.g. cooking and heating) (Clashen & Lever, 2022; Polman & McDonalds, 2022). Furthermore, the uncertainties in the global energy market have an impact on the costs of energy, which gives another dimension to the energy problem.

A solution to the addressed goals and challenges within the Netherlands might be found in (local) renewable energy production. National legislation aims at a rapid increase in renewable energy production, among others by solar energy and wind energy (McKinsey&Company, Roelofsen, de Pee, & Speelman, 2016; Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2022a). Nevertheless, this solar and wind energy, renewable sources, does not guarantee energy certainty as people are used to. The produced energy by these sources is highly related to solar irradiance as well as wind intensity. As a consequence, it is likely possible that at certain moments, not enough electrical energy will be produced and available to meet the demands, and vice versa. From the demand side, there are more determining factors, the demand for energy depends on the time of the day, day of the week and season as well (American Enterprise Institute & Zycher, 2019). Therefore, wind and solar energy on their own cannot fulfil the national energy demand in their current application and grid interaction.

The fact that renewable energy is not upfront available, efficiently, at the desired time, in the desired quantity as also the fact that not all renewable produced energy in good weather conditions days can be used, could potentially be solved by buffering of produced renewable energy by (production peak) storage. Summarizing, more than ever the planning of space becomes relevant and the fact that the energy transition can be identified as a spatial challenge as well.

1.2 Research questions

This research aims to contribute to the next steps in the energy transition challenge and implementation process within the built environment and area development. Therefore, an instrument to model, year-round, energy demand, production and energy storage of a development area, is being designed and developed within this research. The intention is to build this tool from a general perspective to be widely applicable. In the study, data evaluation and research into parameters and methods defining this energy demand, supply and storage will be executed. The data and methods will form the backbone of the tool. The compiled research questions and sub-questions are progressively in line with the expected components and development process of the tool, in which the collected answers result in the next tool development step.
The main research question is formulated as:

"How to develop a decision support tool towards hourly energy self-sufficient greenfield developments covering energy demand, production and storage?"

Coherent the next sub-questions are researched:

1. Which variables define the energy demand in a greenfield development?
2. Which variables define the energy production in a greenfield development?
3. What could be the potential of (neighbourhood) energy storage in communal self-sufficiency, what are the available technologies or opportunities?
4. How to integrate energy demand, production and storage for a decision support tool towards hourly energy self-sufficient greenfield developments?

1.3 Objectives

The objective of this thesis is to develop a simulation tool which should enhance the sustainability and energy transition of the built environment by self-sufficiency and consumption of renewable electrical energy in greenfield developments. The tool can also be used as a decision support tool in order to have better insights into the availability of renewable energy and growing demand within such development area and the need to transform into a (partial) self-sufficient area.

Modelling the energy demand and potential production of energy in a planned greenfield development will bring insights to developers and other involved parties on how new neighbourhoods can be developed without or minor grid dependence. Which measures and technologies should be changed or added to the development in order to get such greenfield development (almost) self-sufficient. Think also of the capacity of energy storage and the infrastructure associated with this. Energy storage can deal with grid capacity problems and therefore still allows sustainability transitions and extensions of the built environment, its application on a communal level could become a key aspect in balancing energy demand and supply profiles of specific area developments. Tackling the spatial challenge, the tool will evaluate building and area performance according to entered parameters, and optimisations to these parameters can be implemented after tool evaluation. A summarizing description of the tool objective could be formulated as *energy-oriented design for greenfield area developments*.

1.4 Research outline

The proposed research will be a tool development. Figure 1 indicates schematically how the research will be tackled. This will be further explained in the next sections. It is expected that the variables of the model and calculation methods can be composed by a combined input from literature, expert interviews and stakeholder involvement.

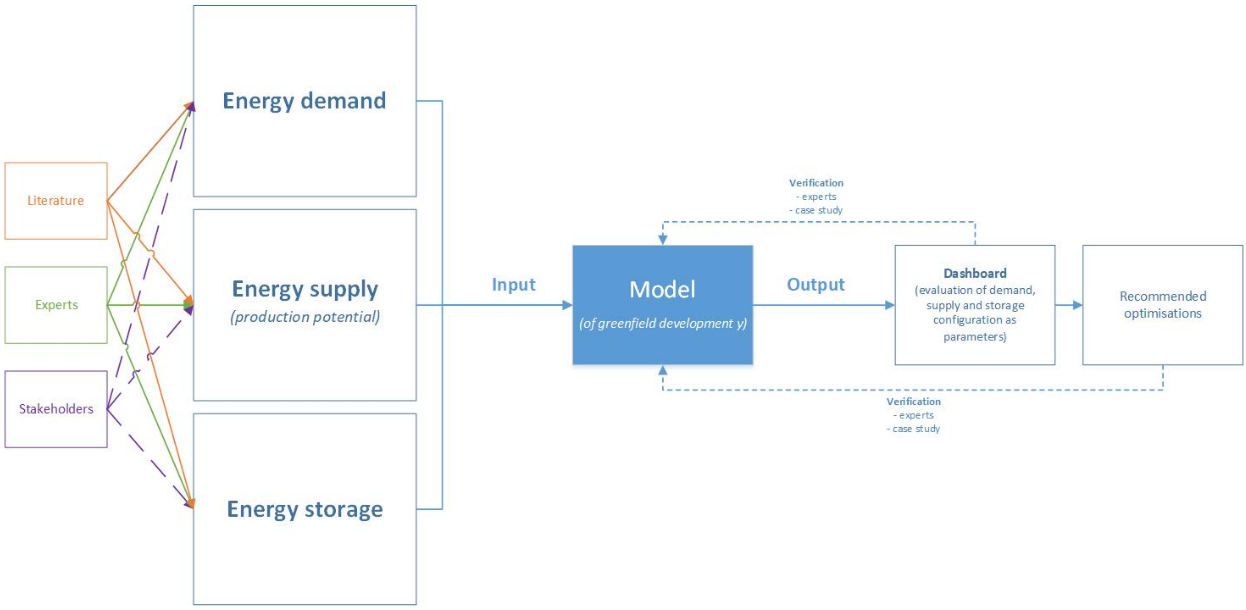


Figure 1 - Overview of the research structure

1.4.1 Literature
The model needs input from different perspectives and multiple sources. Some of the variables for the model will require literature contribution. Therefore, a literature study will be performed for both the demand and supply side in a greenfield development. The goal of this literature research is to identify variables which can be incorporated on a literature base which are strongly linked to an energy demand or supply potential, for example, the performance of a heat pump system in the Dutch climate, or the average domestic power consumption for a defined number of persons per household.

Additionally, knowledge regarding energy storage should be retrieved. This should be focussed on currently available technologies, as also technologies in development taking into account the implementation time of communal energy neighbourhoods and developments. State-of-the-art literature as well as experts in the field of energy storage will be consulted here.

1.4.2 Expert interviews
In addition to the literature, interviewing experts is deemed an important factor in retrieving and validating variables. Therefore, experts in energy transition, real estate (development), sustainability and technologies will be consulted to retrieve knowledge where literature is not capable to do so. Furthermore, the knowledge and experience of experts can also be used to validate found assumptions and statements in the literature regarding variables of energy demand, supply and storage in real estate development. The expert interviews will be performed in unstructured and semi-structured interviews. These types of interviews come about as feedback is requested at the moment, especially within the tool development phase short, quick and iterative polling is needed with experts.

1.4.3 Stakeholders
The development of real estate, in a traditional qualification, is already a complex process with a large range of stakeholders with different interests and competencies. The development of a self-sufficient development project will face the complexity of interests and competencies of stakeholders as well and might even be at a higher rate. The involvement of stakeholders in the tool development is considered relevant as the collaboration of stakeholders is in the end needed to enable actual self-sufficient greenfield development, as well as these stakeholders, will have knowledge and preconditions valuable to incorporate in the model to create the best possible approximation of a real self-sufficient real estate development. The (local) authorities are foreseen as an important stakeholder for example.

1.5 Social, practical and scientific contribution

The contribution of this research on the social aspect should be mainly found in the contribution to the energy transition and so to the inhibition of climate change, a contribution to the next steps of a better future and climate. Additionally, the social contribution specifically in the Netherlands is the fact that by implementing the tool successfully, the housing market can be extended by avoiding grid extension obstructions and additional supply for housing can be constructed to relieve the overheated Dutch housing market.

Deeming the scientific relevance, some shortcomings in literature and studies regarding energy storage and urban/spatial development have been mentioned in section 1.2 and will be further elaborated upon in chapter 2. This study, including the tool as being the product of, tries to bridge these shortcomings by making a comprehensive simulation model. The model is an additional instrument for real estate developers, public parties and other similar or involved parties in the development of real estate. The model simulates energy demand and supply in an off-grid area in which the combination with energy storage opportunities is a key aspect to ensure (a high level of) self-sufficiency. Especially, the long-term perspective is missing according to consulted literature, which is meant the long-term storage of energy. Therefore, the tool has a year-round simulation horizon of the energy in such greenfield development. The tool also tries to bridge the gap between spatial development, the energy transition and climate change, a practical aspect, which has been addressed by several papers as a missed opportunity to enhance the energy transition. Especially the aspects and characteristics linked to area development provide opportunities to integrate renewable energy and sustainability up to their maximum potential. The fact that the tool is linked to real building and area parameters and the early applicability in the design and plan process for energy evaluation (and re-evaluation after changes) makes it directly usable in practice.

1.6 Reading guide

This thesis is structured as follows. The following-up chapter 2 will provide a thorough look at the energy transition in general and in the context of the Netherlands. It will further discuss what already has been researched on energy modelling and related topics to this, with a specific focus on what variables have been identified in previous research and recommendations for future studies. In Chapter 3 will be elaborate on the methodology of this research. The fourth chapter will extensively discuss the development process of the tool. Chapter 5 will show the applicability of the developed tool in a case study, which will be followed by an evaluation and discussion of the tool and the research in Chapter 6. The research will be concluded in Chapter 7 by answering the research questions, highlighting the relevance and stating the limitations of this research and the recommendations for further research and tool development steps.

2. Literature study

This chapter will synthesize the available literature on the topic of energy demand, supply and storage modelling and the parameters necessary to model this. Furthermore, it will recap the incentive for this research and how already executed research in this field of energy transition in the built environment and energy modelling did contribute to the framing of this research.

2.1 The energy transition in the built environment context

Buildings are responsible for large shares of energy use, up to 40% of European energy consumption and relatively 36% of Europe's total CO_2 emission (both building-related energy usage and user-related energy consumption) (Bouw, Noorman, Wiekens, & Faaij, 2021; Pront-van Bommel, 2012; Zhao & Magoulès, 2012) (McKenna, Merkel, & Fichtner, 2017) (Belussi et al., 2019). The European Council did setup targets to reduce the share of energy use and CO2 emission by the built environment within the European Union, to a reduction of 80 to 95% reduction of emissions by 2050 compared to 1990 values (Bartolini, Carducci, Muñoz, & Comodi, 2020; Schlachtberger, Brown, Schramm, & Greiner, 2017). In order to meet these targets, transitions and changes on multiple fronts are needed, among which a shift towards (more) renewable energy sources and the reduction of energy consumption by efficiency measures, involving the action of European directives, national policy and the local, municipal role (Bartolini et al., 2020; Bouw et al., 2021; Hansen, Breyer, & Lund, 2019; Schlachtberger et al., 2017)**.** Summarized as the energy transition (Planbureau voor de Leefomgeving & Ros, 2015).

The need for this energy transition and the change of habits towards issues and sustainability is not new either. However, the urgency and the increase of sustainability needs to be picking up, especially aiming towards agreements like the Paris Agreement, in which 195 countries including the Netherlands agree upon the fact, to put everything into action to reduce further global heating, by emission, to a maximum of 2 degree Celsius (aiming at 1.5°C) (Hansen et al., 2019). The European directives in this (as referred to before), are redirected into a national framework by the Dutch governmental bodies, targeting at a CO_2 emission reduction of 49% by 2030 and up to 95% by 2050, relative to 1990 emissions (Centraal Bureau voor de Statistiek, 2022a; Ministerie van Economische Zaken en Klimaat, 2021). Zhao & Magoulès (2012) and Bouw et al., (2021) did point out the large share of the built environment to the total CO_2 emission. The Dutch framework does mean a reduction of 20.2 Mton of CO2 for the generation of electricity as consumed in the Netherlands, and 3.4 Mton of reduction for the built environment sector (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2022b; Ministerie van Economische Zaken en Klimaat, 2021)

The Dutch Ministry of Internal Affairs (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2022a) and IPCC (IPCC, n.d.) do state the same words as Bartolini et al. (2020), Bouw et al. (2021), Hansen et al. (2019) and Schlachtberger et al. (2017), that the reduction can be achieved by the transition from fossil energy sources to the deployment of potential renewable energy sources in an efficient way (energy supply), as well as improve the performances on energy demand by increase buildings' energy efficiency levels. A link between these two can be made as well, because buildings performing well on energy efficiency, still demand energy, which still urges the need for renewable energy supply. (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2022a).

Having framed the occasions of the energy transition and a glance at the energy transition, the transition should be deemed. Electrification is a key concept of the transition, where other sources of energy get banned and replaced by electrification; electric cooking, heat pumps and electric vehicles (Bouw et al., 2021; Hansen et al., 2019; Hoffman et al., n.d.; Papaefthymiou & Dragoon, 2016; Schuttenhelm, Brouwers, Zeman, & IEA, n.d.). In short, increasing the demand for electric energy, gradually, reducing the demand for other (fossil) energy sources. This has an impact on the electricity grid, which is being stressed due to the increasing demand for electricity (electrification) and the increasing supply of renewable electric energy; congestion (Bosseboeuf et al., 2015; Bouw et al., 2021; Hansen et al., 2019; Hoffman et al., n.d.; Koirala, van Oost, & van der Windt, 2018; Schuttenhelm, Slootweg, ten Brinck, Zeman, & Brouwers, 2022; van Weezel, van de Weijer, & Visser, 2022).

Other trends are pointed out which do have an impact on the energy transition in positive and negative contribution. Identified is, that in the Netherlands, on a national level grid congestion occurs by the aforementioned causes (Abbenhuis et al., 2022; Berenschot, 2022; Borsboom, Mossallam, & Van Der Linden, 2022; Clashen & Lever, 2022; J. Gerdes, S. Marbus, 2014; Polman & McDonalds, 2022; Schuttenhelm et al., 2022). Next to sustainability, another additional cause of grid congestion was identified, namely the increase in grid connections by (residential) developments (Clashen & Lever, 2022; Polman & McDonalds, 2022; Programma Aardgasvrije Wijken, 2020). Recently, the evolution in energy costs due to undisclosed reasons has boosted sustainability. Combined with the declining prices of solar technology, investments do become more feasible and financially attractive when expanding to higher energy costs (Hansen et al., 2019; Luthander, Widén, Munkhammar, & Lingfors, 2016; Vereniging Eigen Huis, n.d.; Vieira, Moura, & de Almeida, 2017). This cycle then again ends at the congested grid, as an additional investment does lead to more produced renewable energy, which cannot be fed into the grid due to capacity issues.

The increasing share of renewable energy is underlined by the Central Statistical Office, indicating a steady incline in renewable energy supply throughout the last years (Centraal Bureau voor de Statistiek, 2021, 2022a). The Central Statistical Office also separately indicates the individual sources of the generated renewable energy, within the Netherlands solar energy and wind energy are the dominant renewable energy supply sources (Centraal Bureau voor de Statistiek, 2022a). Schill states that this also holds for many other countries as '*the potentials of dispatchable renewable - such as hydro power, geothermal, or bioenergy - are limited. The renewable energy transition is thus often driven by wind power and solar photovoltaics (PVs)'* (Schill, 2020).

However, solar and wind energy are characterised by their fluctuation in supply, they are strongly weather-dependent (Bartolini et al., 2020; Belussi et al., 2019; Hoffman et al., n.d.; Schill, 2020; Schlachtberger et al., 2017; Siraganyan, Mauree, Perera, & Scartezzini, 2017). This dependence presents *'a challenge to the balancing of production and demand in the electricity system'* (Schlachtberger et al., 2017). The combination of solar energy and wind energy tackles the problem to a little extent, as the amount of solar energy peaks in the spring and summer, and wind energy indicates a little higher distribution in the autumn and winter period. Renewable energy supply is therefore characterised by peak loads, exactly the reason why the increasing penetration of renewable energy sources does stress the grid. These peak loads can be identified on short-cycle and long-term cycles, referring to a mismatch between energy demand and renewable energy supply in the day-night cycle or over-seasonal (Belussi et al., 2019; Vieira et al., 2017).

Solutions for all the identified grid- and demand problems related to the energy transition, entities of the renewable supply and sustainability of buildings and processes, and to keep the momentum for increasing renewable energy generation without restricting new developments, can be found in demand matching and the storage of energy (self-consumption). Siranganyan et al. did put context to the term; '*energy storage has different aims as bridging seasonal differences and imbalances, levelling daily load cycle, peak shaving and improving grid stability, power quality and reliability of supply'* (Siraganyan et al., 2017). The storage of energy (energy storage) is inevitable when targeting at high penetration of renewable energy ambitions (various agreements) or energy self-sufficient areas. (Bartolini et al., 2020; Belussi et al., 2019; Bouw et al., 2021; Dunn, Kamath, & Tarascon, 2011; Guerra et al., 2020; Gür, 2018; Hoffman et al., n.d.; Luo, Wang, Dooner, & Clarke, 2015; Luthander et al., 2016; Papaefthymiou & Dragoon, 2016; Rijksdienst voor Ondernemend Nederland, 2009; Sager-Klauß, 2016; Schill, 2020; Schlachtberger et al., 2017; Vieira et al., 2017).

Why energy storage is meaningful, has been proved. However, how it should be integrated has not been distinguished, except the fact that has been stated it can improve grid stability (Papaefthymiou & Dragoon, 2016; Siraganyan et al., 2017; Vieira et al., 2017). A general distinction in literature is made between the application on an individual level, per dwelling or household, or on a communal level. Research insights do indicate that central storage or neighbourhood storage is the most promising application. It is proven more effective with regard to cost savings and utilization, as the storage enables peak shaving with buffering for periods of a supply deficit, but also balances the mismatch among multiple households, demanders and suppliers with different demand and supply profiles, and therefore a higher ratio of self-consumption. (Bartolini et al., 2020; Luthander et al., 2016; Proka, 2017; Roberts, Bruce, & MacGill, 2019; Vieira et al., 2017; Walker & Kwon, 2021). The central/communal approach of energy storage will therefore be further considered within this research.

2.2 Spatial development and the energy transition

Validated is the more effective implementation of energy storage in relation to the self-sufficiency of renewable energy and grid stability, when energy storage is applied in a communal or central approach (area, neighbourhood or district) in comparison to individual implementation (Bartolini et al., 2020; Koirala et al., 2018; Luthander et al., 2016; Roberts et al., 2019; Vieira et al., 2017; Walker & Kwon, 2021). In this context, the integration of the energy transition into urban development and spatial planning becomes more interesting as well (Allegrini et al., 2015; De Pascali & Bagaini, 2019; ISSO, n.d.-c; Jablonska, Ruijg, & Willems, 2011; Koirala et al., 2018). De Pascali and Bagaini do use the term '*energy planning'* in their paper explained as '*the relationship between energy and physical-functional organisation has outlined the relevance of including energy-related planning and strategies in the spatial planning'* (De Pascali & Bagaini, 2019).

By this, the energy transition, in an area approach, does become a spatial challenge (Architecture Workroom Brussels & LABO ruimte, n.d.; Programma Aardgasvrije Wijken, 2020; Torabi Moghadam, Lombardi, & Mutani, 2017). Added to this is the statement that the energy transition is not the only challenge (in the Netherlands) debated with spatial impact (Verdaas, 2020). The expansion of the Dutch housing stock, as deemed before, the circular economy, biodiversity, climate adaptation and change mobility modes, are addressed as these spatial impacting challenges. Therefore it is claimed that area development and energy transition will meet each other in spatial integration, where area development is characterised by acting from a perspective (Programma Aardgasvrije Wijken, 2020; Verdaas, 2020). Also, the research group titled LABO Ruimte underlines the complexity of the challenge within area development nowadays and points out the lack of recognition in public and politics (Architecture Workroom Brussels & LABO ruimte, n.d.). The climate and energy challenges are recognized as a spatial task as well, '*by integrating energy solutions in areas, they contribute to the energy transition',* deemed by multiple case studies in north-European countries (Heurkens, 2018).

Widely argued is the agreement of the area level as the appropriate level to implement the energy transition into spatial development (Architecture Workroom Brussels & LABO ruimte, n.d.; De Pascali & Bagaini, 2019; Heurkens, 2018; Stoeglehner & Abart-Heriszt, 2022). Considering the transformation of individual dwellings is too small, the potential is diminished (Architecture Workroom Brussels & LABO ruimte, n.d.). However, national and municipal sustainability policy is mostly formulated on the city level, area developments do have the potential, and opportunity to implement these policies, being a way to divide the energy transition challenge into manageable tasks (Architecture Workroom Brussels & LABO ruimte, n.d.; Heurkens, 2018; Petersen & Heurkens, 2018).

In spatial planning, a logical distinction between existing and new urban systems can be made. The energy transition is relevant in both cases, however, the level of complexity does differ. In existing urban systems, without large-scale renovation, the implementation of a central energy system would require large changes to buildings, infrastructure and public space. Knowledge, actually the lack off and the deficit of examples forms a bottleneck in the transition of existing urban systems. Also, for new urban structure developments (greenfield nor brownfield) there is a lack of valid approaches, to start with. Revealed is the strength of spatial planning and the possibility for shaping the energy transition, energy planning, however, argued that an incremental approach with an empirical base is needed to realize integrated spatial and energy planning. Tackling the deficit of tools and executing analysis could narrow the gap between policy intentions and actions to come to rational choices in energy planning and implementation (Heurkens, 2018; ISSO, n.d.-c; Jablonska et al., 2011).

Seen the complexity of the execution of energy planning in existing urban contexts, the aforementioned reasons for grid congestion, the trends and other spatial challenges, the research will focus on application in new urban contexts, so greenfield development, in order to gain knowledge and develop an incremental, empirical approach instrument.

The nature of greenfield developments does indicate why the implementation of spatial planning in hand with energy planning is less complex compared to brownfield developments or changes to existing urban structures. Within greenfield frameworks, called zoning plans or spatial plans, requirements for buildings and infrastructure can be laid down. Integrating energy planning from the first initiatives in a greenfield development enables maximizing the renewable energy potential of that area. Argued is the principle of *Trias Energetica*. Sustainable buildings will not exist without a connection to a sustainable area (ISSO, n.d.-c; Jablonska et al., 2011). The conversion and storage of energy at an area level are required to have an energy-neutral built environment (Allegrini et al., 2015; De Pascali & Bagaini, 2019; Heurkens, 2018; ISSO, n.d.-c; Jablonska et al., 2011; Koirala, Koliou, Friege, Hakvoort, & Herder, 2016; Koirala et al., 2018; Petersen & Heurkens, 2018).

The T*rias Energetic* is visualised in figure 2 (van Vlimmeren, 2021), however, adapted by ISSO (n.d. -c) and Jablonska et al. (2011) into an alternated version of 5 steps in the context of energy-neutral area development, in which all 5 steps are equally relevant and should be included in an energy concept (figure 4). Recognized is also the need for an altered version of the *Trias Energetica* in the context of energy neutrality (van Vlimmeren, 2021). Fossil fuels are no longer recognized as a 'backup' option as being the third step in the *Trias Energetica.* This is replaced by capturing energy storage and the conversion of different types of energy, figure 3.

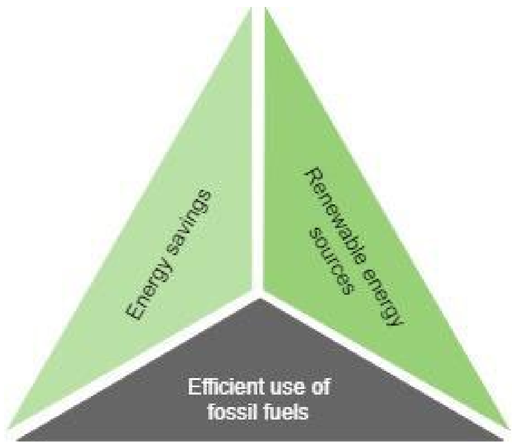


Figure 2 - Trias Energetica (van Vlimmeren, 2021)

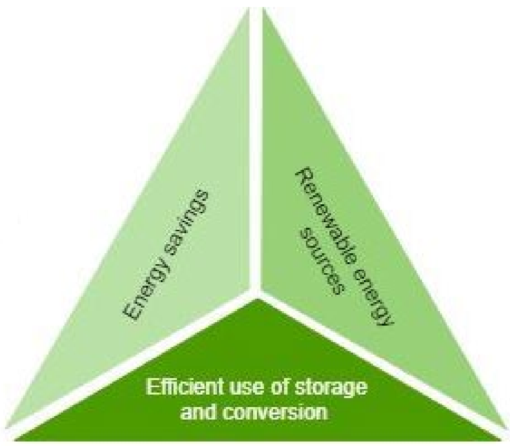


Figure 3 - Altered Trias Energetica (van Vlimmeren, 2021)

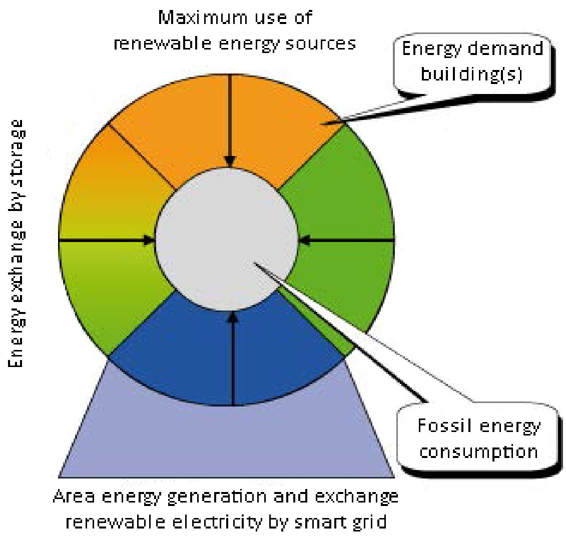


Figure 4 - Adapted Trias Energetica for energy-neutral built environments (ISSO, n.d.-c; Jablonska et al., 2011)

The steps in Figure 4 are additionally explained in the correct order below:
(ISSO, n.d.-c; Jablonska et al., 2011)

1. Reduce energy demand;
2. Optimum use of renewable sources;
3. Energy exchange in energy hubs and via smart grids;
4. Storage of energy within different cycles, day, week, season to match demand and supply of energy;
5. Efficient application of imported energy and fuels to cover mismatch of renewable energy supply in case of emergency.

Consequently, it is underlined that the development of energy-neutral areas can be approached by an altered *Trias Energetica* vision, with a fundamental and systematic design sequence, stepwise. The exchange of energy on a local level, as addressed in the renewed *trias energetica*, results from the fact that it is impossible to generate all energy demanded, on one's own site. Therefore, matching and exchanging energy demand and supply on a local level led to the creation of local grids, frequently referred to as microgrids or smart grids.
The design of sustainable spatial plans and developments, along the T*rias Energetica*, does support the earlier statement that sustainable buildings cannot be isolated from their context, *'buildings must be assessed as elements in urban energy systems, since neither the building nor the system can be fully understood isolated'* (Allegrini et al., 2015).

Recommendations read to calculate energy performances to test energy concepts before implemented in specific development locations with the actual area characteristics (Ferrari, Zagarella, Caputo, & Bonomolo, 2019; Giuseppina & D'Amico, 2019; Huang, Yu, Peng, & Zhao, 2015; Hygh, DeCarolis, Hill, & Ranji Ranjithan, 2012; ISSO, n.d.-c; Jablonska et al., 2011). In this way, microgrids can be designed in an optimal way, considering the interaction between stakeholders and experts in different project phases. For example, consider the orientation of dwellings and roofs to capture radiation in an optimal way, building shapes and building physics measures to reduce the energy demand, and when optimized, the shift to technical installations to exploit the potential of ambient renewable sources increases the freedom of design (Catalina, Virgone, & Blanco, 2008; Hygh et al., 2012; ISSO, n.d.-c, 2020; Jablonska et al., 2011; Schuttenhelm et al., n.d., 2022).

2.3 Energy modelling

A lot of research has been conducted on the computation of energy simulation models, the prediction of energy demand, renewable energy potential as well as the topic of Photovoltaic modelling for autonomous regions and more recently the research area of energy storage increases interest.
Especially in the studies with regard to energy simulation models, a large discrepancy in their scope and application can be distinguished. Common differentiation can be seen in the application of models in only electricity or heat as being considered energy, or the order of magnitude being the building level or national level. The application of models on building energy will be highlighted first, followed by the literature on urban energy modelling and last a section on energy storage, renewable energy analysis and autonomy.

Building energy consumption modelling

Multiple energy simulation models focusing on the building levels are discussed and evaluated in numerous papers (Belussi et al., 2019; Coakley, Raftery, & Keane, 2014; Crawley, Hand, Kummert, & Griffith, 2008). These types of models are abbreviate as BES models, Building Energy Simulation (Coakley et al., 2014). Emphasized is the role of these models in the design and optimization of buildings. In which design is dominantly referred to in the case of new construction and optimisation refers to retrofitting and upgrading existing buildings and real estate portfolios (Coakley et al., 2014).
Over 20 tools are being evaluated by Coakley et al. and Crawley et al., all categorized as BES models. Evaluated is the approach of tools, in which a distinction is made between law-driven tools and data-driven tools (Coakley et al., 2014; Crawley et al., 2008).

- Law-driven tools use in base laws and correlations of physics, e.g., gravity, heat/mass transfer. (Coakley et al., 2014)
- Data-driven tools do use historic data(sets) for mainly the prediction of energy consumption from a statistical approach, often regression analysis. (Coakley et al., 2014). The data-driven approach is a common way in scientific research in energy modelling and will be evaluated thoroughly later on.

A selection of the tools being evaluated by Coakley et al. (2014) and Crawley et al. (2008) are DOE-2, EnergyPlus, TRYNSYS, ESP-r, Ecotect, eQuest, Ener-win, BSim and TRACE (Coakley et al., 2014; Crawley et al., 2008). The majority of the evaluated tools do run a year-round simulation, with an hourly resolution, a common way to go according to research. Some tools are only applicable to specific contexts, DOE-2 and Ener-win are American tools, in the first instance calibrated for application there due to their integrated datasets. Developed tools within the segment of BES, being evaluated, dominantly do have a law-driven entity, hence all distinctive in their approach, extensiveness, field of application or tailored to specific tasks. In general, the thermal, visual and acoustic performances are being evaluated in the whole building simulation. Frequently, energy costs and other advanced features are incorporated as well. However, the evaluation of building energy performances with these tools is underlined as complex according to the extensive and detailed level of information needed beforehand. Consequently, this results in a rather detailed performance analysis as well.

In the review of Belussi et al. (2019), the focus is specifically on the performance of Zero Energy Buildings (ZEBs). Next to the variables considered in the previously mentioned building energy simulation models, like walls-, windows-, glass- entities, building type and location, Belussi et al. (2019) does underline that Zero energy buildings cannot be evaluated without considering the end-user contribution within the energy consumption. Variables suggested according to their review do contain climate, morphology (including wall and window aspects), thermal loss, solar gain and internal comfort level. Internal comfort is deemed an important aspect of the end-user contribution towards space heating energy consumption. Building energy consumption is commonly subdivided into space heating and cooling demand, domestic hot water, lighting and consumption by appliances. (Belussi et al., 2019; Coakley et al., 2014; Crawley et al., 2008).

Data-driven building energy consumption is often analysed by means of regression, seen in the extensive range of scientific research on this topic. (Asadi, Amiri, & Mottahedi, 2014; Catalina, Iordache, & Caracaleanu, 2013; Fumo & Rafe Biswas, 2015; Giuseppina & D'Amico, 2019; D. Majcen, Itard, & Visscher, 2013; Daša Majcen, Itard, & Visscher, 2015; Shimoda, Fujii, Morikawa, & Mizuno, 2004; van den Brom, 2020; van der Bent, van den Brom, Visscher, Meijer, & Mouter, 2021a). Underlined in these papers is the relevance of building energy consumption modelling as being '*a key tool to reduce energy consumption and emissions'* (Asadi et al., 2014). Also, the fact that energy modelling is complex due to the (inter)relationship of various parameters of buildings and (direct) context is widely recognized. Asadi et al. (2014) do argue the relevance of early design stage energy performance evaluation, as design decisions are made early in the design process, and the introduction of energy planning, especially for new buildings, can improve design, increase energy performance and reduce computation time (Giuseppina & D'Amico, 2019).

From the literature, regression studies on building energy consumption can be targeted to commercial buildings and or residential buildings. The principle of regression does not differ among these studies, however, the variables for prediction might do. Asadi et al. (2014) and Giuseppina and D'Amico (2019) both present a regression study on non-residential building energy performances. They emphasize the integration of generic building energy performance analysis in energy design stages, as building parameters still can be altered, although do not aim at the replacement of detailed energy performance models, like EnergyPlus, ESP-r or TRYNSYS, as discussed before.

Regression analysis techniques are widely applied in papers for residential energy modelling with different goals (Fumo & Rafe Biswas, 2015; Ioannou & Itard, 2015; D. Majcen, 2016; D. Majcen et al., 2013; Daša Majcen et al., 2015; van den Brom, 2020; van der Bent et al., 2021a). Among these goals are the prediction of energy demand and consumption based on residential dwelling entities, the potential energy savings by building renovation and energy label discrepancies. These discrepancies are identified in existing building stocks, where theoretical energy consumptions do differ from actual values. Three empirical models for the estimation of actual energy consumption are indicated: a linear regression, a non-linear regression and a machine learning model (GBM) (van der Bent et al., 2021a).

Concluding the papers on regression studies, a set of general validated parameters can be formulated, indicating explanatory contribution in energy consumption by residences, summarized in table 1.

Table 1 - Identified variables from regression literature.

Type of building (linked indicator to following parameters)	(van der Bent et al., 2021a), (D. Majcen, 2016), (Asadi et al., 2014), (Giuseppina & D'Amico, 2019), (Daša Majcen et al., 2015) (van den Brom, 2020)
Window and door quality - U-value	(van der Bent et al., 2021a) (D. Majcen, 2016) (Asadi et al., 2014), (Giuseppina & D'Amico, 2019), (van den Brom, 2020)
Insulation quality – R-value (floor, façade, roof)	(van der Bent et al., 2021a) (D. Majcen, 2016) (Asadi et al., 2014) (Giuseppina & D'Amico, 2019) (van den Brom, 2020)
Building characteristic surfaces	(van der Bent et al., 2021a) (D. Majcen, 2016) (Asadi et al., 2014) (Giuseppina & D'Amico, 2019) (Daša Majcen et al., 2015) (van den Brom, 2020)
Year of construction	(van der Bent et al., 2021a) (D. Majcen, 2016) (Daša Majcen et al., 2015) (van den Brom, 2020)
Construction type/mass	(van der Bent et al., 2021a) (D. Majcen, 2016) (Asadi et al., 2014) (Giuseppina & D'Amico, 2019)
Ventilation	(van der Bent et al., 2021a) (D. Majcen, 2016) (Daša Majcen et al., 2015) (van den Brom, 2020)
Indoor temperature	(van der Bent et al., 2021a) (D. Majcen, 2016) (Asadi et al., 2014) (van den Brom, 2020)
Internal heat gains	(van der Bent et al., 2021a) (D. Majcen, 2016) (Asadi et al., 2014) (Giuseppina & D'Amico, 2019) (van den Brom, 2020)
(heated) floor area	(van der Bent et al., 2021a) (D. Majcen, 2016) (Asadi et al., 2014) (Giuseppina & D'Amico, 2019) (van den Brom, 2020)
Heating system and efficiency	(van der Bent et al., 2021a) (D. Majcen, 2016) (Asadi et al., 2014) (Giuseppina & D'Amico, 2019) (Daša Majcen et al., 2015) (van den Brom, 2020)
(hot) Tap water system	(van der Bent et al., 2021a) (D. Majcen, 2016) (Daša Majcen et al., 2015) (van den Brom, 2020)
Number of occupants	(van der Bent et al., 2021a) (D. Majcen, 2016) (Asadi et al., 2014) (Giuseppina & D'Amico, 2019) (Daša Majcen et al., 2015) (van den Brom, 2020)
Photovoltaic panels	(van der Bent et al., 2021a) (D. Majcen, 2016) (van den Brom, 2020)
Solar heat panels	(van der Bent et al., 2021a) (D. Majcen, 2016)
Cooling technology	(van der Bent et al., 2021a) (D. Majcen, 2016) (Asadi et al., 2014) (Giuseppina & D'Amico, 2019) (van den Brom, 2020)
Airflow rates	(D. Majcen, 2016)
Energy label	(D. Majcen, 2016), (Daša Majcen et al., 2015)
Weather impact	(D. Majcen, 2016) (Asadi et al., 2014) (Daša Majcen et al., 2015) (van den Brom, 2020)
Daylight control	(Asadi et al., 2014)
Building orientation	(Giuseppina & D'Amico, 2019) (van den Brom, 2020)

Table 1 gives a first indication of relevant variables to be included in the model that will be developed in this thesis and will be complemented by other literature.

Evaluation of the existing housing stock and changes to this is deemed possible along a regression method. Likely the evaluation of current new construction as well. However, as regressions are composed of recent or historic available data, the evaluation of future building characteristics and values due to tightened sustainability policy along shaped regression formulas will not work out. A law-driven modelling approach (Coakley et al., 2014) seems more suitable, also referred to as white-box modelling; where a theoretical structure is used to calculate an outcome, e.g. NTA8800 or laws of physics, developing transparent models with an understandable behaviour (van der Bent et al., 2021a). The doctoral thesis by van der Brom (2020), illustrates the possibilities of a combination of a statistical, traditional building energy model with building properties and data-driven models (van den Brom, 2020).

So, available building simulation tools require a high level of technical knowledge and software experience to precisely model, even simple buildings. However, the required details and information for these tools are available from later design stages onward. Despite this, '*a notable portion of a building's life-cycle impacts is determined by decisions made in the early design stages. Choosing proper building characteristics at this step has the potential to substantially decrease a building's life cycle impact* (Asadi et al., 2014). It is therefore key to develop a tool for effective decision support for energy simulation in early design stages. (Asadi et al., 2014; Giuseppina & D'Amico, 2019).

Urban energy modelling

In addition to whole building energy simulation tools, the bigger picture, an urban area, is often considered a more suitable approach to improve sustainability and energy performances and enhance the energy transition (Allegrini et al., 2015; Architecture Workroom Brussels & LABO ruimte, n.d.; De Pascali & Bagaini, 2019; ISSO, n.d.-c; Jablonska et al., 2011; Koirala et al., 2018; Programma Aardgasvrije Wijken, 2020). As building energy simulation tools are available, there are area energy simulation tools available as well. Allegrini et al. (2015) argue that it is no longer sufficient to simulate the use of building energy separately from the context, microclimate and energy system, in which it is situated (Allegrini et al., 2015). A wide range of available approaches and tools for urban energy modelling is evaluated and reviewed in numerous papers (Allegrini et al., 2015; Bouw et al., 2021; Ferrari et al., 2019; Hansen et al., 2019; Hong, Chen, Luo, Luo, & Lee, 2020; Malhotra et al., 2022; Ram, Swain, Vallabhaneni, & Kumar, 2021; Tozzi & Jo, 2017; Vreenegoor, Hensen, & Vries, 2008) Bouw et al. (2021) do distinguish tools available from the scientific community (e.g. EnergyPLAN, HOMER, RETScreen, etc.) and the professional practice (WarmteTransitieAtlas, Vesta Mais, Energy Transition Model, Gebiedsmodel, etc.) and do evaluate them on 10 criteria. What can be concluded from the 13 evaluated models is the most frequently used time horizon of one year, and hourly resolution. Nevertheless, the tools all have their own point of interest, ranging from financial evaluation, and minimizing emissions to high renewable share and area autonomy. A similar conclusion is drawn by Hansen et al. (2019) in their evaluation of over 180 papers regarding 100% renewable energy modelling, the vast majority did emphasize technical feasibility and economic viability. *'State-of-the art in 100% Renewable Energy modelling applies a full hourly methodology, capturing various forms of flexibility in achieving optimized energy system solutions'* (Hansen et al., 2019). Three similar subgroups, with slightly different definitions, have been identified to review urban energy tools (Allegrini et al., 2015; Tozzi & Jo, 2017):

- District energy tools; include heat networks, multi-energy systems and low-temperature networks (Allegrini et al., 2015), more detailed level results, and models which take more inputs into account (Tozzi & Jo, 2017).
- Multi-scale renewable energy tools; includes solar, wind and bioenergy and seasonal storage (Allegrini et al., 2015), basic renewable energy modelling tools, and easy to use (Tozzi & Jo, 2017).
- Regional/Urban (micro)climate tools; related to the energy demand for heating, cooling and lighting, as strongly dependent on the local (micro)climate (Allegrini et al., 2015), including higher scale projects tools that can be applied at a specific context (Tozzi & Jo, 2017).

Within these two papers over 35 tools have been reviewed considering a broad range of criteria, suiting one of the subgroups presented above. The tools all have the intention to inform the user, although all in a different context linked to the scope of the tool. The aim of having a single integral tool capable of presenting both information on planning, design and operation remains a utopia, as different approaches in terms of time and accuracy are required within these stages, however, current tools do leave room for improvements. (Allegrini et al., 2015; Tozzi & Jo, 2017).
In contrast, the review of Ferrari et al. (2019) does only look into urban / district scale tools, capable of assessing multiple energy sources and technologies, with an additional requirement of detailed and open documentation (Ferrari et al., 2019). 17 tools have been evaluated, where the majority had a time horizon of 1 year and an hourly resolution, six tools being considered 'user-friendly' have been evaluated more thoroughly on their main features and on the integration of (renewable) energy supply technologies.

The majority of the models discussed do highlight yearly time horizons and hourly resolutions as the most dominant chosen horizon respectively resolution in urban energy modelling (Hong et al., 2019; Malhotra et al., 2022; Ministerie van Binnenlandse Zaken, 2010; Quintel, 2022; Ram et al., 2021). Argue is here is also the fact , that the considered tools are comparable to a certain extent, although should only be used for the specific application they are aimed for. Tools are developed with a certain goal or perspective. Added to this the lack of integral models for heating and electricity demand, 54% of the reviewed papers in the study by Malhotra et al. (2022) did focus on heat energy demand only.

The relevance of energy planning and energy-oriented design is emphasized once more by Vreenegoor et al. pointing out the realisation among designs to incorporate energy-saving techniques and construction methods in their design, which will be taken as a premise for the tool development in finding building design in the planning of urban contexts (Vreenegoor et al., 2008).

Energy storage, renewable energy analysis and autonomy.

Another application of energy modelling and renewable energy integration is widely represented within the literature. They can best be summarized as ‘energy communities’, but in a broader approach do regard the implementation or energy storage in relation to the supply of different types of renewable energy sources, with their own characteristics. An optimal balance between energy demand and supply would not require any energy storage. However, the balance is not optimal. According to the introduced Trias Energetica, the implementation of energy storage is the next step in the cycle. Optimizing energy storage in line with energy demand and supply might lead to autonomous neighbourhood or area, energy communities. Different modelling approaches are studied by among others (Bartolini et al., 2020; Koirala et al., 2018; McKenna et al., 2017; Mendes, Ioakimidis, & Ferrão, 2011; Mengelkamp, Garttner, & Weinhardt, 2017; Schill, 2020; Siraganyan et al., 2017; Vieira et al., 2017). Among the different approaches, the distinction is mostly present in the type of evaluation; technologic, sociologic or economic, or a mix of these. Most of the tools do evaluate the integration of renewable energy supply by wind, solar and geothermal energy and evaluate the mismatch of this supply along the formed demand with battery storages. Due to the volatility of predominantly solar energy, it is widely recognized that the integration of multi-renewable energy sources i.e. (micro) wind does help in capturing more stability in the supply of renewable energy (Bartolini et al., 2020; Belussi et al., 2019; Koirala et al., 2018; Mengelkamp et al., 2017; Schill, 2020). Vieria et al. (2016) add to this the aspect of suitable conditions, where the design (orientation, placement and size) of renewable energy systems is crucial, as the right orientation of PV panels in an urban context or by building application helps in achieving demand reduction and progressively developing zero energy buildings and areas (Vieira et al., 2017). As concluded by McKenna et al. (2017), considering the local energy framework policy, the realization of a self-sufficient district is achievable above 560 households: scaling autonomy.

2.4 Framework for the tool to be developed.

Proven by literature is the extensive amount of research on energy modelling and the available tools in the field of energy modelling or related to energy demand, renewable supply and the storage of energy. The consulted tools are all developed from a certain perspective and with a certain goal, however, reviews do indicate directions for future tool improvements and conditions for new tool development, not aiming at the replacement of existing tools, but serving other unexposed points of view, features or applications.

Pointed out in future research recommendations is the integral approach of heat energy and electric energy modelling both in an equal and detailed way, fitting current new technologies, renewable energy sources and conversions (Bouw et al., 2021; Hansen et al., 2019; Siraganyan et al., 2017; Vreenegoor et al., 2008). The inclusion of more renewable energy sources and technologies is also widely recommended within the literature, as most of the tools only consider a single source of renewable energy supply, like PV or wind energy. A more accurate and globally applicable tool is expected when a scale of renewable energy sources can be modelled, dependent on their availability in the local context, state-of-the-art renewables and technologies adaptive to the local context (Bouw et al., 2021; McKenna et al., 2017; Mengelkamp et al., 2017; Sager-Klauß, 2016; Siraganyan et al., 2017; Tozzi & Jo, 2017; Vreenegoor et al., 2008).

The relevance of developing a tool capable of modelling buildings to a certain detailed level in an urban context is underlined widely (Allegrini et al., 2015; Architecture Workroom Brussels & LABO ruimte, n.d.; Borsboom et al., 2022; Bouw et al., 2021; De Pascali & Bagaini, 2019; Sager-Klauß, 2016). Especially where energy demand calculations and performances can be calculated with real values for accurate outcomes, with an integral practice and scientific nature (Bouw et al., 2021; D. Majcen, 2016).

It is lacking simple, easy-to-use, decision-supporting tools, which do reflect the complexity of integral spatial planning and energy, applicable in early planning or design phases, as these phases are decisive in the final performances of both the building and the urban area. Customization of assumptions and variables, in energy demand, supply and storage on both the building level and area level, allows to calculate and test different setups, to optimize building design and urban planning and pioneering in energy planning. (Allegrini et al., 2015; Borsboom et al., 2022; Bouw et al., 2021; Giuseppina & D'Amico, 2019; Heurkens, 2018; Ioannou & Itard, 2015; Jablonska et al., 2011; D. Majcen, 2016; Proka, 2017; Sager-Klauß, 2016; Vieira et al., 2017). Sager-Klauß (2016) does identify that such a tool in a spreadsheet format is suitable when considering different data sources, aggregation levels, building characteristics and weather conditions (Giuseppina & D'Amico, 2019). In order to make the tool generally applicable, occupant comfort behaviour should be incorporated, for example, reflected in the indoor temperature, and reflect the needs of decision-makers and end-users, suggested to be validated with a case study (Allegrini et al., 2015; Bouw et al., 2021; De Pascali & Bagaini, 2019; Fleischhacker, Lettner, Schwabeneder, & Auer, 2019; Ioannou & Itard, 2015; Sager-Klauß, 2016; Vreenegoor et al., 2008).

From the literature, a summarizing framework for the tool to-be-developed has been composed:

- Targeted at new area developments in early stage (initiation, planning or design stage), where design and concept variables can be tested in according to the stage and optimized in different setups; ‘energy planning’ and ‘energy-oriented design’.
- Integration of sophisticated building energy simulation into an area context.
- A mix between complexity, details, ease to use and computation time to get an inclusive, efficient and user-friendly tool.
- Hourly resolution, yearly scope.
- A communal approach regarding energy storage.

This page is intentionally left blank

3. Methodology

From the literature study, some first insights on the set sub-questions have been gained. This chapter will further delve into the methodology used to answer the research questions and sub-questions as part of the tool development process. Retrieved from the literature study as well, are multiple suitable methodologies to use in this research. Explained in this chapter will be the general outline of the methods and approaches being used in the thesis. The insights from the literature study will be taken as a starting point, from which the methodologies will be framed to further answer the sub-questions and the main research question. This chapter, methodology, will not deal with detailed sets of methods and calculations which form the backbone of the tool, they will be clarified in Chapter 4, tool development. This chapter will start with a description of the applied methodology and research cycle (3.1), followed by data collection (3.2), results and discussion (3.3).

3.1 Method

In order to answer the research questions, a specific structure is introduced which will be explained and shaped along the applicable research cycle. For this research, the design research cycle has been identified as the most relevant design cycle within academic research (4TU, 2021). The design research cycle is described as an iterative process according to the design science methodology theory of (Wieringa, 2014). The design science cycle is, in academic literature, recognized as a part of the engineering cycle, consisting of three phases, figure 5.

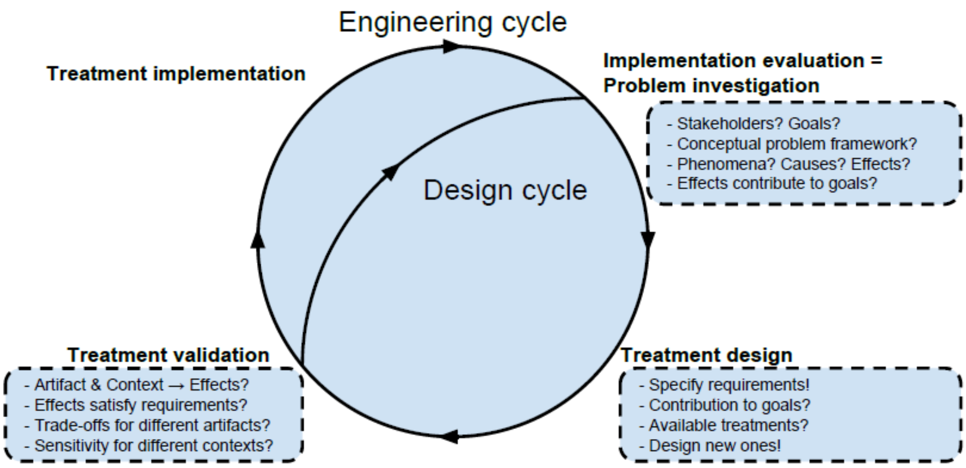


Figure 5 - Design cycle as part of the engineering cycle (Martakis, 2015; Wieringa, 2014)

Additionally, the design cycle is described as the heart of any design science research project (Hevner, 2007). Hevner (2007) points out the interaction of the design cycle with the relevance cycle and the rigour cycle, both giving input to the design cycle, where the design cycle iterates more rapidly between the construction of an artefact and the evaluation of it. Hevner (2007) links the relevance cycle to the requirements of the design artefact, and the rigour cycle to the retrieving of evaluation theories and methods.

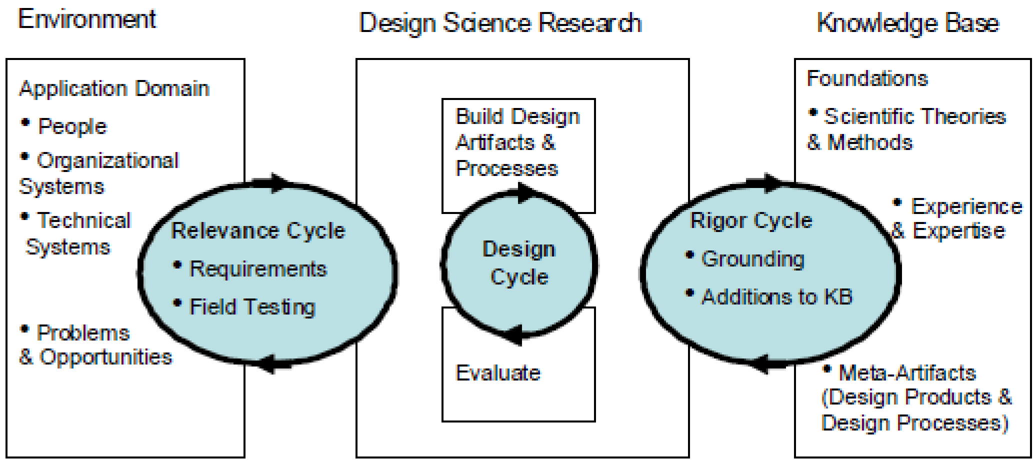


Figure 6 - Design science research cycle (Hevner, 2007)

Although from Hevner (2007) 4 phases could be differentiated, they do have the same purport as the identified three phases directly by Martakis (2015) and Wieringa (2014). This thesis will be shaped along the three identified phases within the design cycle approach by Martakis (2015) and Wieringa (2014). First, the design problem will be explored and synthesized (stage: read and plan in design research cycle) (4TU, 2021), then an artefact should be designed and developed to solve the problem (stage: solve) (4TU, 2021) and last, the designed artefact should be validated and evaluated (stage: check) (4TU, 2021). For this research, the following design artefact can be formulated: "to enhance sustainability in the built environment, an energy simulation modelling tool should be used, in early design and planning phases, on an hour resolution, with respect to area development, as this is deemed an appropriate and effective scale level".

This research will be approached in two stages, in which the design science cycle will be followed. These two stages should be seen separate from the phases identified within the above-mentioned design science cycles, the two stages are introduced to structure the thesis and are linked to the research questions.

Tool development can be classified as design-oriented scientific research (van Burg, 2011). Van Burg (2011) in his paper on design-oriented scientific research does highlight the importance of validity and reliability, in order to deliver not only research of high quality but also leads to good and effective interventions (van Burg, 2011). The interaction between practice and science is being recognised in design-oriented research, as van Burg (2011) visualised in Figure 7.

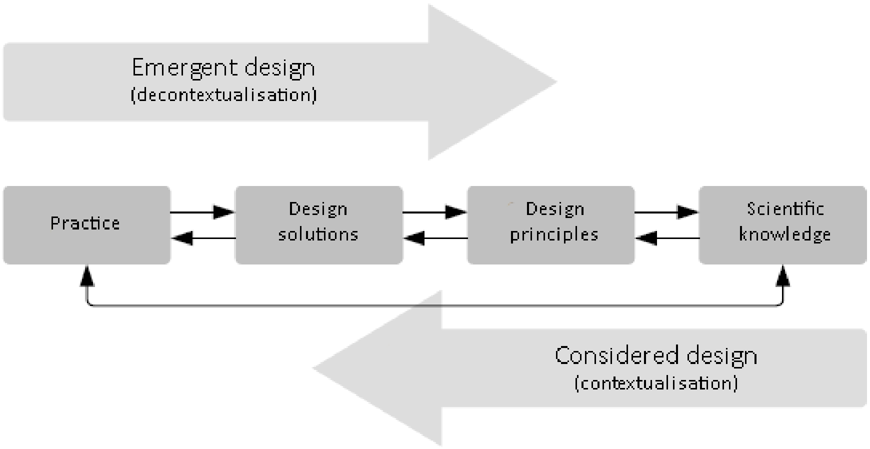


Figure 7 - Interaction between practice and science along a design-oriented approach, translated from (van Burg, 2011)

A research framework method specifically targeted to a tool development process is described in the work of Jun et al. (2011), figure 8.

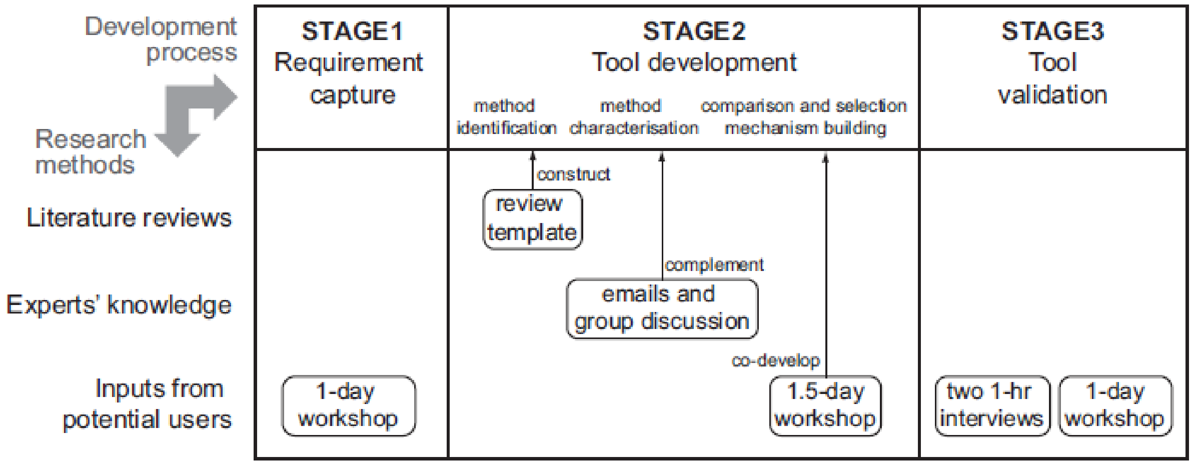


Figure 8 - Research methods used for the tool development process (Jun et al., 2011)

Based on the design science cycle and the proposed methodologies in the design-oriented research and tool development process, the methodology for this research has been shaped. The methodology will be explained by stage. Figure 9 provides a visualisation of the research design and the appropriate methodology.

The first stage is targeted towards sub-questions 1, 2 and 3. In this stage, the main research methodology will be specific literature studies and consulting several experts. The literature studies will be dedicated to identifying appropriate variables and calculation methods to quantify and qualify the sub-questions 1, 2 and 3. The competencies of the experts will be used to complement the literature where needed and alter them where needed to appropriate these to the scope of the research. The considerations by the experts regarding the literature and vice versa cannot be avoided and do result in a form of internal evaluation and validity (van Burg, 2011), also referred to as unstructured expert interviews.

The second stage is dedicated towards the fourth sub-question and could be mainly targeted towards the 'treatment validation' or 'evaluate' step in the design research cycle. The sub-question here is targeted at the future users of the tools and the stakeholders involved in energy-optimized area development. Also here, the involvement of experts is relevant, next to validation by case study is also included in the methodology.

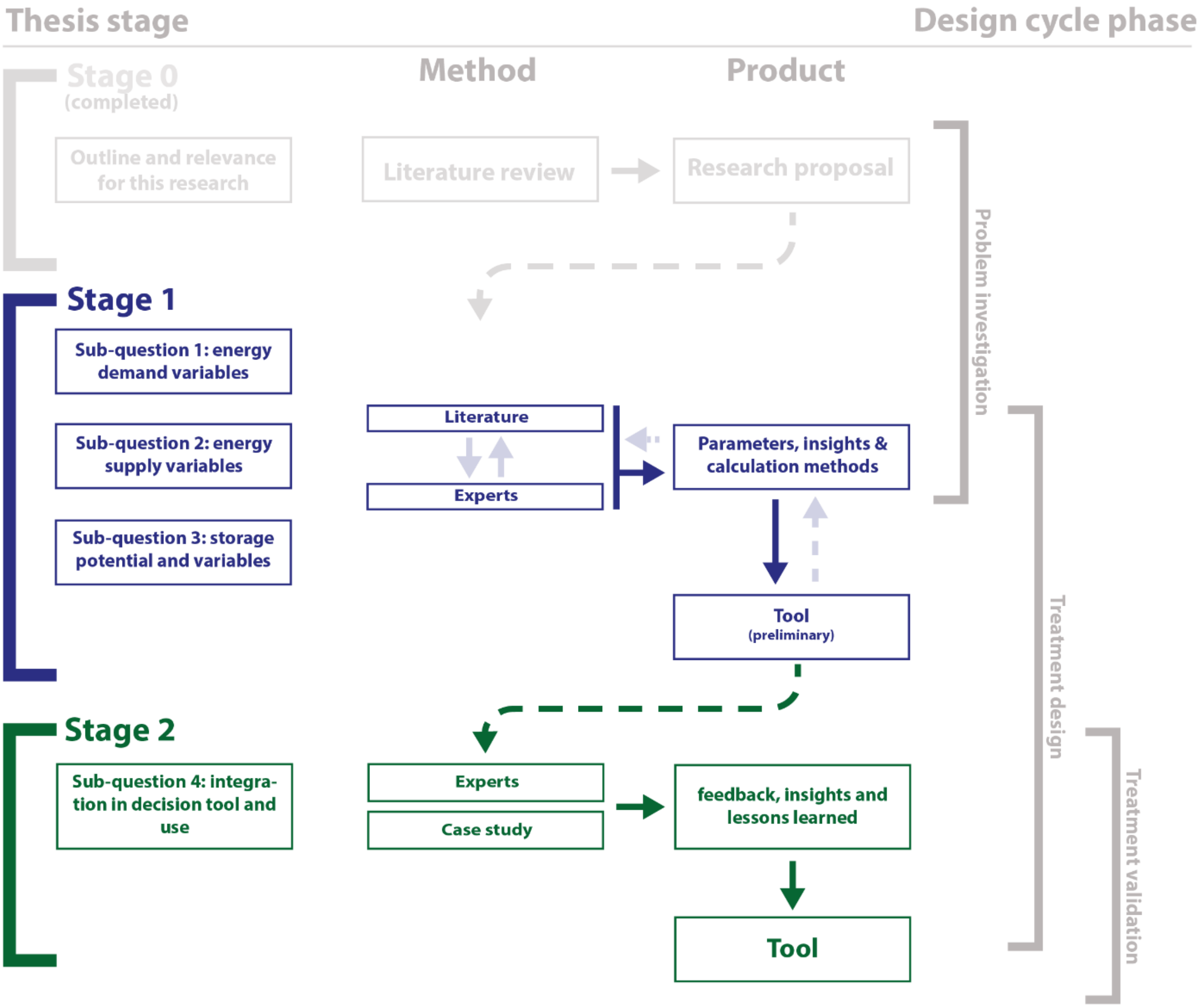


Figure 9 - Research methodology interaction visualisation

In the following sections, the introduced methodologies will be further elaborated within the context of data collection and the results. In Table 2 on the next page, an overview of the consulted and involved experts can be found, including their expertise, years of experience and a categorisation of their involvement in the process. A distinction is made between experts involved in the development of the tool content-wise, tooling in general or as a stakeholder, future user or in one of the case studies. A total of 18 experts have been involved.

Table 2 - Expert overview

Person:	*Company:*	*Job title:*	*Experience (in years):*	*Involvement*
Expert 1	Arcadis	Project manager and business developer	25+	Stakeholders and case study
Expert 2	Arcadis	Consultant building physics	5+	Technical tool content
Expert 3	Arcadis	Consultant building physics, fire safety and acoustics	30+	Technical tool content
Expert 4	Arcadis	Architect	8+	Stakeholders and case study
Expert 5	Arcadis	Senior consultant	6+	Technical tool content
Expert 6	Arcadis	Digital consultant	8+	Tooling
Expert 7	Arcadis	Consultant geo-information	3+	Tooling
Expert 8	Arcadis	Project manager and area development consultant	10+	Stakeholders
Expert 9	Arcadis	Consultant and assistant project lead energy transition	2+	Technical tool content
Expert 10	Arcadis	Senior planning economist	22+	Stakeholders and case study
Expert 11	Overmorgen	Consultant sustainable area development	2+	Stakeholders and case study
Expert 12	Arcadis	Consultant ESG and sustainability	1+	Technical tool content
Expert 13	TU Delft, Brom Architectuur	Researcher building energy and architect	10+	Technical tool content
Expert 14	ISSO	Technical specialist	15+	Technical tool content
Expert 15	Arcadis	Program manager Energy Transition	9+	Stakeholders
Expert 16	Arcadis	Consultant Building Services MEP and sustainability	10+	Technical tool content
Expert 17	Dura Vermeer	Project/area developer	20+	Stakeholders and case study
Expert 18	Arcadis	Project manager urban development and real estate	27+	Stakeholders and case study

3.2 Data sources

Stage 1

From the literature reviews and the interaction with experts in stage 1, the required data for the tool development will be framed. The next step is to collect the data after which this data should be validated by literature and/or experts or should be retrieved from officially recognized institutes. The data collected will mainly be measured and observed weather data as this is essential for the entire functionality of the tool. This collected weather data will be processed into datasets.

Further, other types of data will be collected from literature and experts like relevant formulas, key performance values and calculation methods with a base in physics or widely recognized applicability, needed to determine the quantity of energy demand, supply and storage in the individual tool components.

Stage 2

In the second stage, the data needed will be in the form of case studies data. Project information and values for the parameters in the tool are needed to test the case studies in the tool. This data will be requested and delivered by external parties, in other words, experts and potential future users of the tool. Real case data is being used and anonymization is applied where needed in agreement with the case study providers.

Additionally, feedback on the case study and the tool is collected for further tool improvement and development, performances and research recommendations.

Case studies should fulfil certain requirements to suit the current version of the tool, in order to retrieve applicable insights:

- Project size: minimum of 10 dwellings, no maximum when fulfilling requirement 2;
- Types: a maximum of 5 different dwelling types can be simulated in a single simulation run (5 unique parameter sets, figure 10);
- Property type: only residential housing;
- Location: within the Netherlands;
- Detail level: the first draft of construction parameters (or presumption on), might also be stated as 'complying with the building code';
- Other: new construction residences, projects within the scope of energy transition or pronounced sustainability targets.

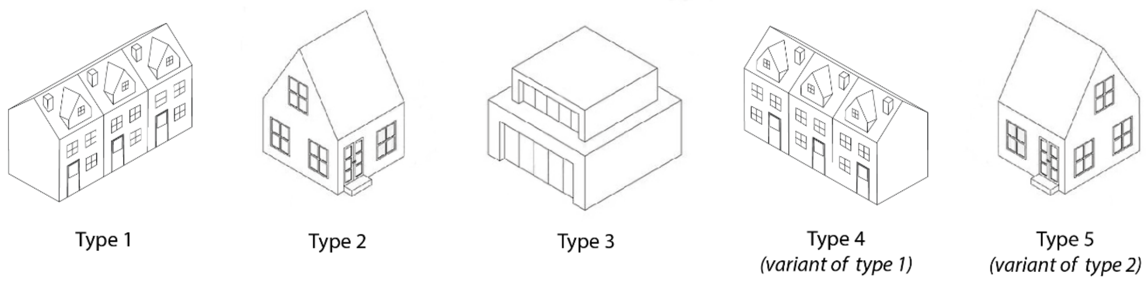


Figure 10 – illustration of the tool limit of 5 dwelling types. Of each type, multiple can be simulated in a single simulation.

3.3 Result display

Results of evaluated development projects within the tool are indicated by an interactive dashboard and infographic. The interactive aspect does allow the user to retrieve information on different levels of detail, in concrete terms; on an area level, building type level or component level. The simulation tool is intended as an additional instrument within the planning and design phases of area development. Energy flows within the simulated area development can be viewed on an hourly basis over an entire year in the infographic. The interactive dashboard does visualise energy demand shares of different buildings in the area, the supply of modelled sources and the interaction and fill-levels of simulated energy storage methods, on a selectable scale from one year to hourly level, next to overall performances of the simulated area development.

From the performances of the inserted parameter set, the end-user can retrieve insights and findings specific to the modelled setup. Therefore, the results should be interpreted with care, as they are always relative to the entered scenarios via the parameters and associated conditions.

The overall performance of the modelled area will be indicated by a ratio of self-sufficiency, reflecting how many hours of the year, the area is capable of serving its own energy demand by renewable supply within the same area. Here, the hourly resolution is of importance as well, as summed values on other horizons do lead to deceptive (mis)match between energy demanding and energy supplied or stored. The respective modelled energy storage facilities within the model run are included in the self-sufficiency ratio as well.

Based on initial performances reflected in the tool, the inserted area development by its parameters should be evaluated. Unsatisfactory performance should be re-evaluated after changes have been made in building designs and area planning. Findings and insights presented and retrieved from the tool should be interpreted here. In general changes to the energy demand component of the area can be considered (by altering design and building parameters), the energy supply (increasing by optimization or extending) or the storage of energy (e.g. capacity or type of storage).

The design proposition within this research can be summarized by the CIMO logic, (van Aken & Andriessen, 2011) Context, Intervention, Mechanism and Outcome.

Developments in the energy transition and built environment currently find and constrain each other in spatial planning (C), a tool that can help in the interests and spatial integration of sustainability, area development and energy transition (I), so that stakeholders in the area development sector obtain more insights and knowledge with respect to energy (self-sufficiency) and the relation with area and building design (M), in order to develop sustainable and energy neutral area's within the future, fulfilling sustainability targets (O).

3.4 System context, interaction and architecture

To wrap up the methodology chapter, figure 11 summarizes the system context and user interaction of the proposed tool along the system engineering method. The tool is characterised by an iterative cycle and single-time steps. In general, the performances of a simulation are being analysed and improvements are shaped by insights and considerations from these performances. The project team does implement these changes in the project and plan parameters. This cycle can be iterated until satisfying performances are returned. In relation to figure 11, figure 12 on the next page, does illustrate the system architecture and outline of the tool, visualising the computation steps within the tool. Figure 12 is, therefore, a zoom-in on the 'tool' step from Figure 11.

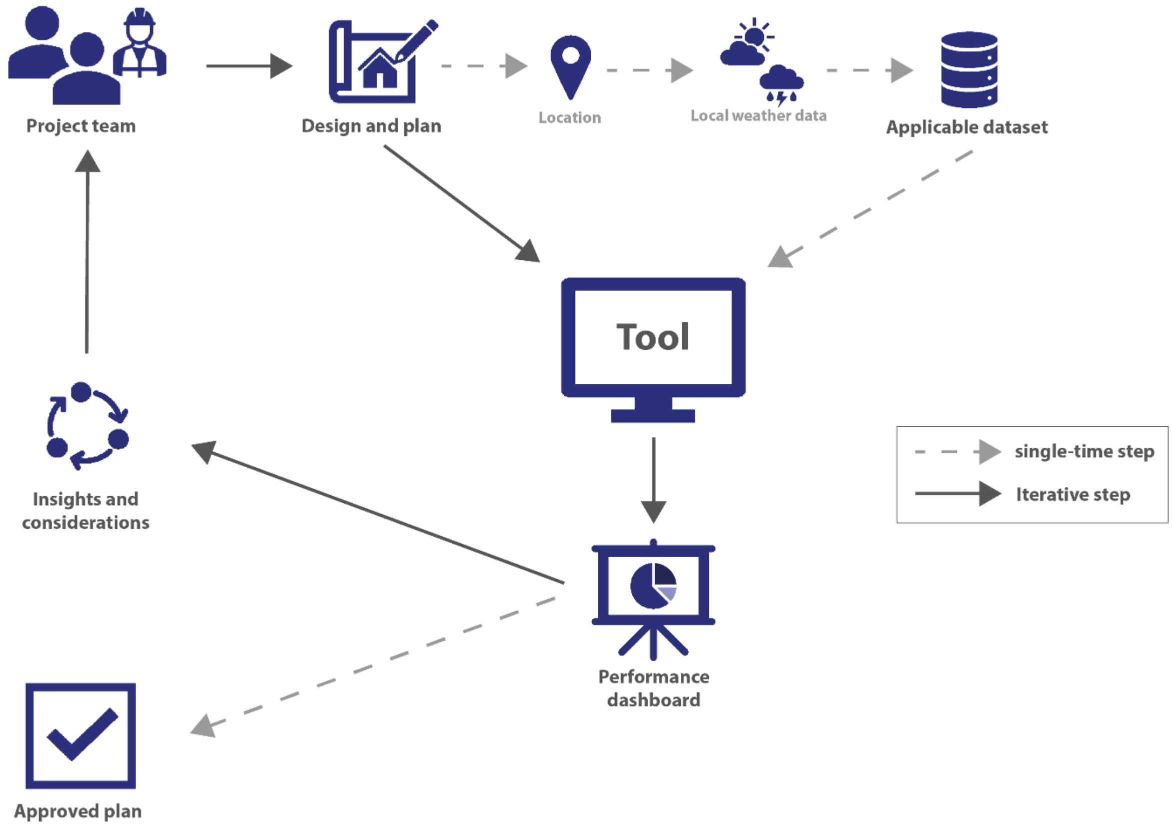


Figure 11 – System context and user interaction of the proposed tool

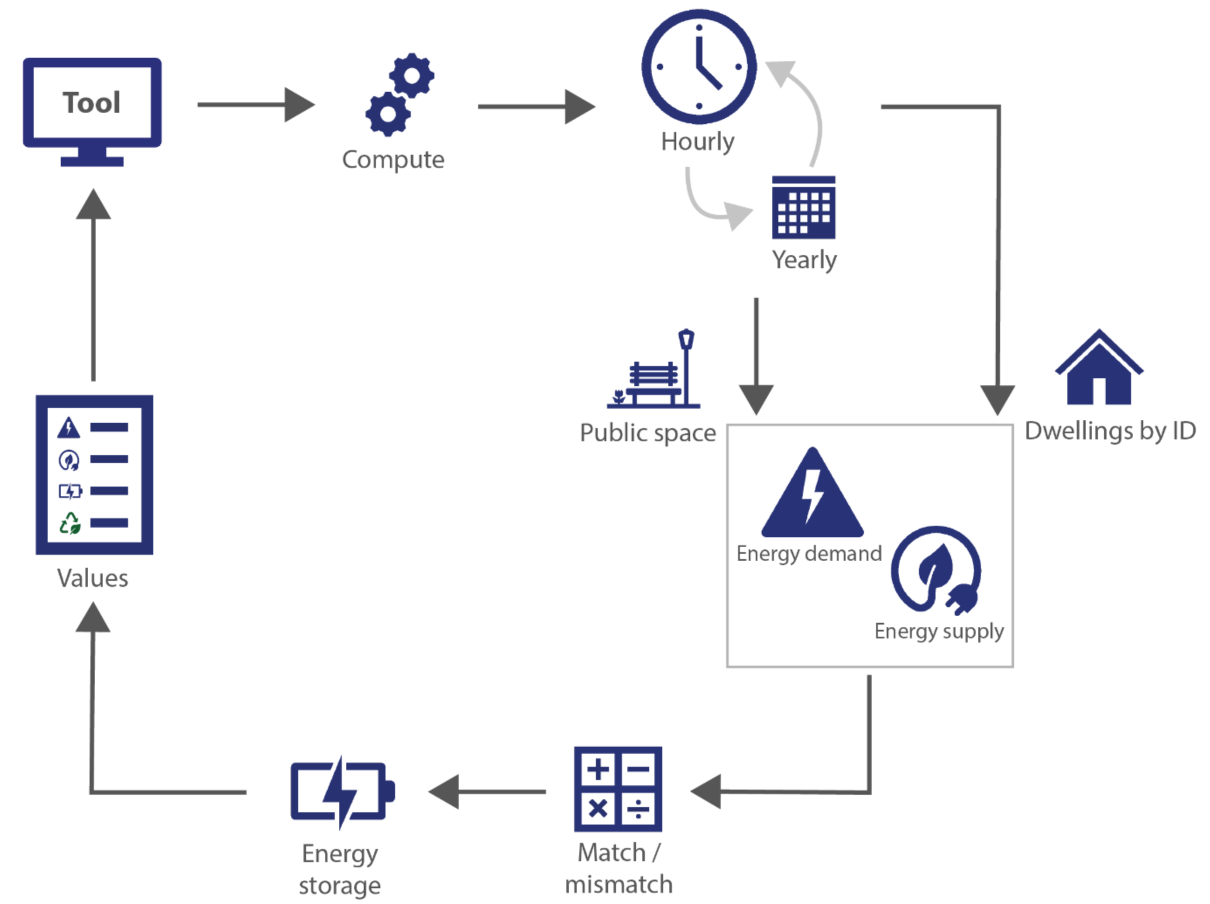


Figure 12 - Tool architecture and outline

This page is intentionally left blank

4. Tool development

As introduced already, the research question and corresponding sub-question are targeted to different components in the developed tool. Three components are distinguished, which will be wielded throughout, energy demand, energy supply and energy storage. Leading in these 3 components are the identified variables which are needed to quantify and qualify the components. The components and how they have been calculated and integrated into the tool will be explained in this chapter. Per component, first, a framework will be explained, which helps to determine and identify the relevant variables per component. These frameworks are compiled from literature and in consultation with the experts. From there onwards, more in-depth insights will be presented in the approach and data and computation section regarding the formulas and methods used for the quantification of the variables within the tool.

The three components are linked to research sub-questions 1 to 3 and will be covered in this chapter, along with the input of theoretical expertise and practical experience. The methodological approach of these sub-questions is similar to a certain extent as has been visualised in Figure 9 – section 3.1. This chapter will follow the structure as illustrated in Figure 13.

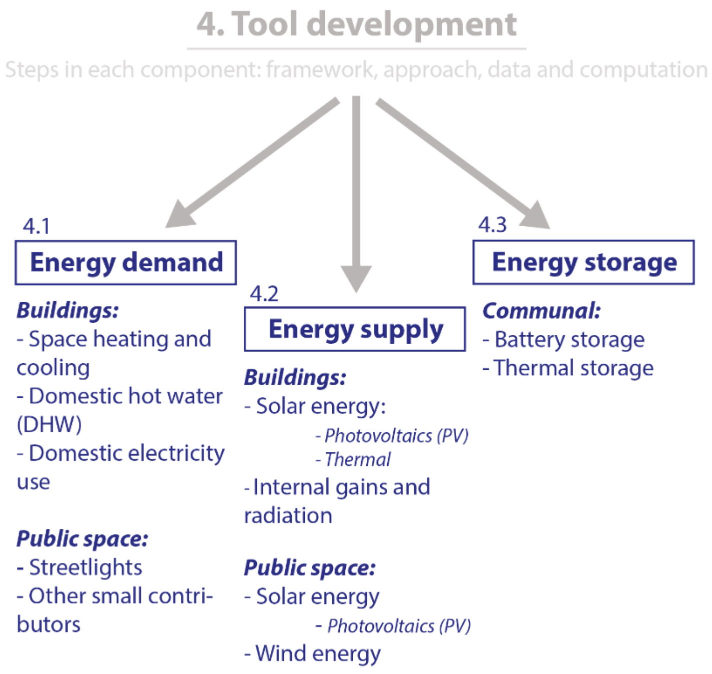


Figure 13 – Tool development structure

The fourth sub-question, considering the integration of the components into a decision support tool and how the tool can be used is approached by case studies. In the case study, actual cases will be evaluated with a 'test and try' setting, as well as feedback, will be collected on the development process of the tool and the performance of the tool in general. Stakeholders and future tool users will be incorporated into this. Chapters 5 and 6 will reflect on the development process, the use and the performance of the tool.

4.1 Method - Energy demand

The first component of the energy modelling tool is the energy demand component. The term energy demand should first be defined and delineated. What aspects should be taken into account and why, and how to quantify the 'energy demand' of buildings in the context of area development, will be deemed in the following sections.

4.1.1 Framework

For the identification of 'energy demand' in residences multiple factors have been identified. Energy demand or consumption is shaped by energy for heating, cooling, hot tap water, cooking, lighting and the use of appliances. In literature, this mostly consisted of three categories, heating & cooling, domestic hot water (DHW), and domestic electricity use. (D. Majcen et al., 2013; Shimoda et al., 2004; Swan & Ugursal, 2009; Zhao & Magoulès, 2012). These three categories of energy consumption will be further referred to within this work. They will be computed all in their own way with an appropriate method, in other the model them with accuracy. Therefore a definition of these categories will be stated first according to (Swan & Ugursal, 2009).

- Space heating and cooling: represents the energy required to maintain (living) spaces at a comfortable temperature and air quality by thermal losses across the buildings envelope by radiation and conduction, as well as air infiltration and ventilation.
- Domestic hot water: the energy required to heat water to a comfortable and appropriate temperature for occupant and appliance use.
- Domestic electricity use: contains the energy consumed to operate common appliances (e.g. refrigerator, chargers) and the provision of adequate lighting.

Quantification of these three categories is necessary in order to determine the total set of energy demands of buildings. This will require different and multiple methods which will be zoomed in later on. However, these categories are stated individually, although do have some interference. In the paper by Swan and Ugursal (2009), the total energy consumption of a dwelling is described as the energy 'required to support all energy consuming end-uses, inclusive of the losses due to appliance and system efficiencies', with, 'complex inter-related effects'. Swan and Ugursal (2009) add an example to this: 'The energy consumption of most common appliances results in heating of the conditioned living area. The energy consumption can be supplied by one or more secondary energy sources and includes on-site generation and passive solar gains'. (Swan & Ugursal, 2009). Therefore, the methodology to determine the energy demand should be a complete overview of hourly energy consumption of the three mentioned categories, as well as the potential energy gain from these 'on-site generation' or 'passive solar gains'. These should be consequently taken into account in either the energy demand modelling part or the energy supply modelling part.

Appropriate data is required in order to calculate the energy consumption of dwellings. Along with building variables and their physical characteristics (parameters), the data on ambient weather conditions, occupation and their behaviour are key in model performances (Swan & Ugursal, 2009; Zhao & Magoulès, 2012). In the next section, the required and retrieved data per methodology will be explained. Physical building characteristics and variables are not fixed factors, they should be included in the model methodology although the scope of the tool is that these are editable and therefore applicable to specific projects or plan parameters.

Within the literature distinction in energy modelling methods has been made between a statistical method (SM) and an engineering method (EM) (Swan & Ugursal, 2009). By the statistical method, regression analysis and historical information are mostly leading in order to determine relationships with attributes and estimate energy consumption. This is used widely in residential and dwelling energy demand modelling papers. Methods used indicate a dominant share of dwelling energy for space and water heating (Belussi et al., 2019). In the research by Satin and Itard (2010), even 42% of the variation in energy consumption could be explained by the components of space heating, DHW and insulation level (Olivia Guerra-Santin & Itard, 2010). Nevertheless, the energy consumption by the other categories comes across a non-negligible share (Belussi et al., 2019).

However, the statistical modelling method is unsuitable for the determination of energy consumption of dwellings being developed in future area developments. The reason for this is twofold; for accurate predictions of space heating and cooling energy consumption in the future, the model cannot use historical information, and a higher degree of freedom and precision is needed at least for the modelling of space heating and cooling, according to building characteristics, also due to developments in the building industry and the performances of systems and materials. Second; available statistical methods in the papers of among others do distinct between electric energy consumption and natural gas consumption (Giuseppina & D'Amico, 2019; ISSO, n.d.-a; van den Brom, 2020; van den Brom, Meijer, & Visscher, 2018; van der Bent, van den Brom, Visscher, Meijer, & Mouter, 2021b; Zipperer et al., 2013). However, current legislation no longer allows the use of natural gas as an energy source in new-to-built buildings, this asks for a different approach to in-dwelling design which makes energy estimation and prediction methods, like regressions, linked to electric and gas consumption no longer a sophisticated and complete approach. Therefore, the engineering method, described by Swan and Ugursal (2019) is relevant for the determination of energy consumption for space heating and cooling.

The '*Engineering method* accounts for the energy consumption of end-uses based on power ratings and use of equipment and systems and/or heat transfer and thermodynamic relationships' (Swan & Ugursal, 2009). This methodology matches the nature and parameter dependence of space heating and cooling. How the *engineering method* is applied in the tool development will be explained in the next section.

The remaining components determining a dwelling's energy consumption, DHW and domestic electricity, are less dependent on thermodynamic relationships, and historical data is available for these, like the average daily water consumption. For these, the statistical method is relevant when appropriate data can be retrieved.

As suggested in this section, the estimation of residential energy demand will be composed of multiple methods, with a statistical and engineering nature. A common attribute within the categories and methods will be the aspect of behaviour. Methods in literature indicate various ranges of percentages of the impact of behaviour on the total residential energy demand (Olivia Guerra-Santin & Itard, 2010). The impact of behaviour is non-negligible, especially considering energy-efficient dwellings, in which the share of space heating on the total demand is reduced significantly, and the share and impact of behaviour increases. Therefore, it is relevant to integrate behavioural aspects or parameters into the model, for example, an occupation parameter, consumption profiles for domestic hot water and electricity use (2 categories), and indoor comfort settings; temperature (heating and cooling related) (Ioannou & Itard, 2015).

The energy demand in public space is incorporated as well, although the impact is expected to be minimal comparatively. The public space energy demand is composed of energy consumption by streetlights (predominantly) and small other contributors (drainage and sewage systems). (Agentschap NL & Rijksdienst voor Ondernemend Nederland, 2012; Royal Haskoning, Schild, van Wijk, & Gosselink, 2015; van Bakel & Heijnens, 2015; Vreenegoor et al., 2008).

For energy demand, on the building level the energy demanded for space heating and cooling, domestic hot water and domestic electricity use will be considered. In the public domain, the demanded energy for streetlights and other small contributors is captured for the plan area. Energy consumption by mobility, i.e. electric vehicles and charge squares is not integrated into the tool so far.

4.1.2 Approach

After energy demand is being framed and different approaches have been discussed in the previous section, this section will further delve into details and the technical aspect of the energy demand calculation methods. The same sequence will be followed. Figure 14 does outline the structure within the energy demand section.

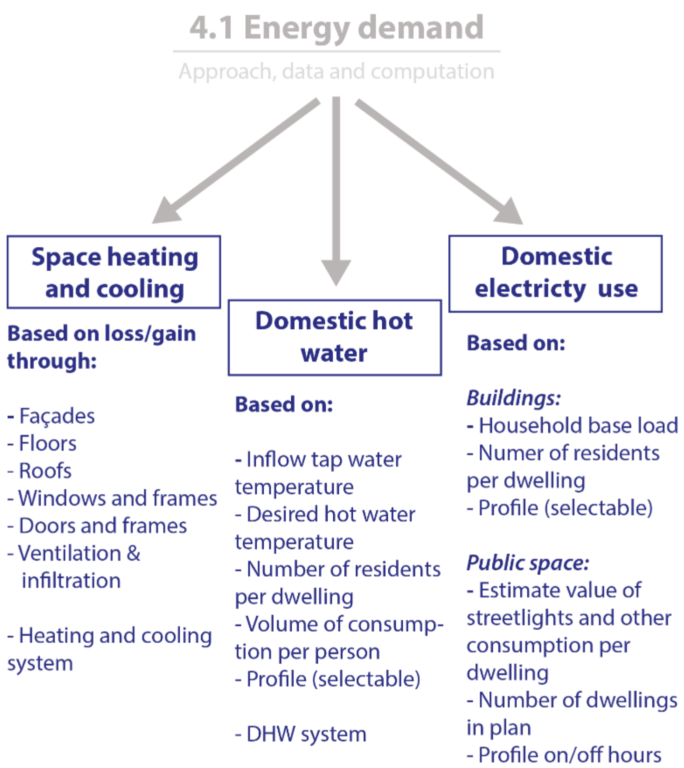


Figure 14 – Framework energy demand

Space heating and cooling

For the determination of energy consumption for heating and cooling an extensive heat loss calculation has been executed on the building's envelope. The emphasis here is on the calculation method itself, the parameter values being used here are not relevant as these are modular serving the goal of the tool. ISSO 51 (ISSO, 2017) describes all components of a heat loss calculation. The calculation is executed on the building envelope or block envelope level, not on individual room level, as this does not match the tool scope and the level of detail available in early design stages or even in urban planning, as clarified in section 2.2.

Taking the building envelope as starting point. Heat losses due occur at different parts of this envelope. From ISSO 51 (ISSO, 2017), heat losses due to the following parts can be calculated:

- Façade surface
- Floor surface
- Roof surface
- Window surface
- Door surface
- Ventilation and infiltration

In general, the quantification of these losses does work on relatively simple thermodynamic laws. The heat loss calculations based on (Agentschap NL & Rijksdienst voor Ondernemend Nederland, 2012; Belussi et al., 2019; Coakley et al., 2014; Hong et al., 2020; ISSO, 2017; Shimoda et al., 2004; van der Bent et al., 2021a), take into account the delta T, thermal resistance and surface of each part. Every calculation is repeated 8760 times, equivalent to a yearly-hour resolution (365 days with 24 hours).

The delta *T* (ΔT) is the difference between the ambient outdoor temperature and the indoor temperature at a certain moment. As working on hour resolution, this ΔT determined every hour. For the ambient outdoor temperature, a dataset is needed, more data collection can be found in the next section. The indoor temperature should be defined in this case, as the energy demand calculation is performed for a new (to build) dwelling. No information on actual indoor temperature is therefore available. The indoor temperature is therefore defined by an indoor temperature setpoint, in other words, a desired indoor temperature being considered comfortable by the resident.

Thermal resistance (abbreviated: *R*), is a material property stating the energy flow through the material. These values are material specific and can be summarized to a so-called R_c value to indicate the thermal resistance of, for example, a total wall package or roof package existing out of multiple, different material layers. The thermal resistance is expressed in m^2K/W, indicating the energy flow through the material or package in Watt, per square meter surface, per Kelvin temperature difference between the two sides.

Conclusively, the quantity of surfaces is needed per part in order to calculate the actual energy loss with the thermal resistance formula:

$$General\ heat\ loss\ formula: Q = \frac{1}{Rc} * A * \Delta T * h \qquad (1)$$

Q	= energy loss (W)
R_c	= thermal resistance of a material or composite layer (m^2K/W)
A	= surface of the calculated area (m^2)
ΔT	= temperature difference between the two sides, where the heat flow occurs (°C or K).
h	= time period over which the heat loss is calculated

The heat loss formula is applicable for the calculation of the heat loss by the floor, façade and roof. However, the variables have to be handled consequently. The ΔT for the floor calculation will, for example, be deviating as the ambient outdoor temperature is not taken into account but the soil temperature. Furthermore, in the specific case of this thesis, the energy flow (Q) will not have the unit Watt (W), but Watt-hour (Wh) due to the hour resolution implemented. Therefore, as stated before, the ΔT is determined every hour, and the calculation is iterated every hour. Therefore, the following formula is relevant for the remainder of this thesis:

$$Q_h = \frac{1}{Rc} * A * \Delta T \qquad (2)$$

Q_h	= energy loss in an hour (Wh, for non-transparent surfaces)
R_c	= thermal resistance of a material or composite layer (m^2K/W)
A	= surface of the calculated area (m^2)
ΔT	= hourly average temperature difference between the two sides, where the heat flow occurs (°C or K)

Considering the window and door surfaces, a similar calculation approach is retrieved (Agentschap NL & Rijksdienst voor Ondernemend Nederland, 2012; Belussi et al., 2019; Coakley et al., 2014; Hong et al., 2020; ISSO, 2017; van der Bent et al., 2021a). Directly formulated in the proper resolution level:

$$Q_{h\ window} = U_w * A_w * \Delta T \qquad (3)$$
$$Q_{h\ door} = U_d * A_d * \Delta T \qquad (4)$$

Q_h	= energy loss in an hour (Wh) by windows or doors
U	= U_w or U_d, thermal transmittance value (W/m^2*K)
A	= A_w or A_d, summed surface per building of the windows or doors respectively (m^2)
ΔT	= temperature difference between the two sides, where the heat flow between occurs (°C or K)

The U_w value, applicable to windows, does take into account the transparent part of the windows as well as the window frame, a combined value.

The last factor being identified determining the energy consumption for space heating are the losses by ventilation and infiltration (Hoes, 2014; Ioannou & Itard, 2015; ISSO, 2017; D. Majcen et al., 2013).

$$Q_h = c_p * \rho * q_v * f_v * \Delta T \qquad (5)$$

Where: $q_v = 0.0009 * A_{tot}$

Q_h	= energy loss in an hour (Wh) by ventilation and infiltration
C_p	= specific heat capacity (J/(kg*K)) for air -> 1005 J/Kg*K
ρ	= density (volumetric mass density) (kg/m^3) for air -> 1.293 kg/m^3
q_v	= volume flow ventilation and infiltration air (m^3/s)
f_v	= correction factor inflow air temperature
A_{tot}	= total surface living area (m^2)
0.0009	= Building code value (ISSO, 2017)
ΔT	= temperature difference between the two sides, where the heat flow between occurs (°C or K)

Based on the explained formula the energy demand relative to space heating can be calculated. A key variable for this quantification is the indoor temperature setpoint, as the energy flows and therefore losses are strongly dependent on this indoor setpoint. Additionally, the outdoor ambient temperature (on-hour resolution) should be integrated from a climatic dataset. More on the retrieval and use of data can be found in the next section. The other variables required for the computation of space heating energy consumption are case-specific and will be depending on the case or user input.

Buildings within the model are temperature simulated. They will require *heating* when, due to heat losses, the indoor temperature will drop below the set indoor temperature. Next to this set point temperature, there is also a maximum desired indoor temperature setpoint. The model considers this maximum temperature setpoint as a threshold for *space cooling*. When the indoor temperature exceeds the threshold, a cooling demand arises. Both the space heating and cooling demand are denominated in relative energy demand. In order to process the relative quantity of energy demand to the specific energy demand, the efficiency of heating/cooling technology should be taken into account. This conversion is linked to such technologies' COP value (Coefficient of Performance), which indicates a varying ratio of heat/cool generation over the electricity consumption of the device, in which a higher COP value indicates a higher efficiency (Czétány et al., 2021).

Domestic hot water

The second category in energy demand modelling for dwellings is the energy consumption for delivering hot tap water, named domestic hot water. (Ahmed, Pylsy, & Kurnitski, 2016; ISSO, 2019, 2020; Langer & Volling, 2020; Nederlandse technische afspraak & Koninklijk Nederlands Normalisatie Instituut, 2022; van den Brom, 2020; van den Brom et al., 2018; Yao & Steemers, 2005) indicates a calculation for the domestic hot water consumption in dwellings. This energy demand is expressed in kWh/year, although the calculation can be altered to an hourly computation in order to match the general tool resolution of an hour. The consumption is strongly dependent on the daily hot water demand (strongly dependent on the number of persons per household), inflow temperature and the desired outflow water temperature. The altered formula for the consumption per hour is indicated below:

$$Q_{dhw,hour} = 0.0012 * (\theta_{hw} - \theta_{cw}) * \rho * V_{hour} \qquad (6)$$

Q_h	= energy required in an hour (Wh) to meet DHW demand
0.0012	= (4180 (J/kgK) * 10^{-6} * 1000)/3600 = 0.0012 (kWh/MJ) (ISSO, 2017)
Θ_{hw}	= hot water temperature (°C)
Θ_{cw}	= cold water temperature (°C)
ρ	= density (volumetric mass density) (kg/m^3) for water -> 997 kg/m^3
V_{hour}	= household volume flow of hot water per hour

The remaining challenge in the domestic hot water energy consumption determination is the hourly volume of hot water consumption per household. Based on a yearly consumption profile (Ahmed et al., 2016; ISSO, n.d.-a; Luthander et al., 2016; Moreau, 2011; Zipperer et al., 2013), a daily quantity of hot tap water consumption per person (ISSO, 2019; Uitzinger, n.d.; Verwin, Bakker, Mooren, & Boonstra, 2022; WML, Verwin, & CBS, 2019) and the number of persons per dwelling the volume of hourly hot tap water is composed. Again, this indicates an energy demand quantity, not actual power consumption. To determine this, the COP value of the tap water systems must be familiar.

Domestic electricity

As outlined in section 3.2.1, domestic electricity consumption indicates the electricity consumed by lighting and appliances (among which cooking). Literature did emphasize different methods how to estimate domestic electricity consumption (Bedir, Hasselaar, & Itard, 2013; Firth, Lomas, Wright, & Wall, 2008; Papachristos, 2015; Santin, 2011) however, multiple of them do frame this consumption into a high level of detail, by the specific presence of appliances, day-night rhythms and occupation schedules. Despite, this will result in the best estimate, this lies outside the scope of the tool and this level of detail is not expected to be known from a new area development, certainly not at the stages this tool is relevant to be applied. Therefore, a more general domestic electricity estimation method is wielded based (Centraal Bureau voor de Statistiek, 2020; Nibud & Vattenfall, 2021; Tigchelaar, 2013; van den Brom, 2020; van der Bent et al., 2021b). The method makes use of a year-round baseline consumption of a household, with an additional consumption per person in a household. As these are year values, they do not match the hour resolution the tool is calibrated to. Therefore, a normalized consumption profile is used, which does indicate how this year's demand is distributed throughout the year on hour level. Such profiling, although containing other values, is also applied in the DHW energy calculation.

4.1.3 Data and Computation

Space heating and cooling

The main source of data next to building characteristics and building code requirements is weather data and COP values of different heating systems. To create the most accurate energy demand, the resolution of the data is preferably on hour resolution.

Regarding the weather data, datasets have been created on the ambient outdoor temperature in the Netherlands by KNMI data (KNMI, n.d.). This is historic weather data on hour resolution, per meteorological station. KNMI does sort its historic weather data in sets of 10 years, in order to take current weather trends into account as much as possible, the dataset created contains the data of the last complete 10-year series, which is 2011-2020.

In total 28 datasets regarding ambient outdoor temperature have been created, all linked to another meteorological station. By this, the tool is able to retrieve the closest weather dataset to the location of the planned development.

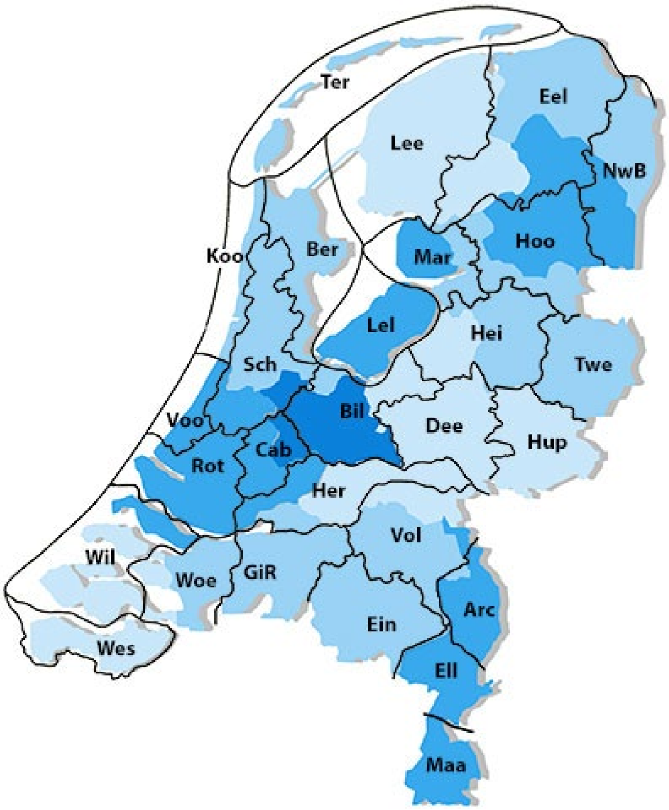


Figure 15 - KNMI weather station distribution in the Netherlands (KNMI, n.d.; Volandis & KNMI, n.d.)

Those 28 meteorological station locations have been chosen strategically to have nationwide coverage, figure 15 (Volandis & KNMI, n.d.). Per weather station, the dataset contains an average ambient temperature per hour, as well as a maximum and minimum temperature, allowing scenario analysis later on in the use phase of the tool. Figure 16 indicates the differences among the created dataset regarding the temperature.

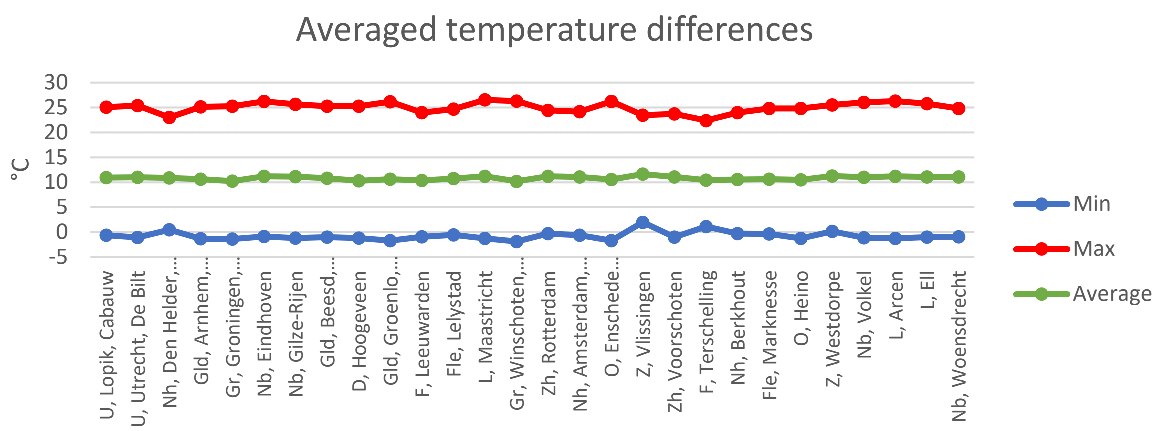


Figure 16 - Minimum, maximum and average temperature per meteorological station (computed from KNMI, n.d.)

Figure 17 - Average, maximum and minimum spatial scatter

The variety in the average temperature differs by 1.44 °C within the Netherlands, the maximum temperature by 4.13 °C and the minimum temperature by 3.86 °C, over the 10-year dataset computed from KNMI (n.d.) data. Figure 17 indicates the geographic locations of the variety in extremes.

Additional data required in order to compute the actual power consumption from the relative quantity of demand which has been calculated so far requires the COP values of the present technology for the heating system, cooling system and DHW system. Overlap in technology is quite common here, especially since heat pumps can, under the right conditions, fulfil all these energy-specific energy demand requirements. The Coefficient of Performance (COP) is next to the type of system also depending on the ambient/source temperature and the required output temperature. Ruhnau et al. (2019) indicate an hourly time computation series to determine COP values hourly of 3 different heat pump systems: air-source heat pump (ASHP), ground-source heat pump (GSHP) and groundwater-source heat pump (WSHP). These different heat pumps including some other systems will be integrated into the tool, so the user can choose between different systems and the impact of these systems on the energy balance. Obviously, the choice of these systems serves a higher complexity as some systems might only work on larger scale levels or require specific location characteristics. For the sake of completeness and general applicability of the tool, the choice for systems is kept extensive and a user's parameter choice.

$$\text{COP values}_h = (ASHP)\ 6.08 - 0.09 * \Delta T + 0.0005 * \Delta T^2 \qquad (7)$$
$$(GSHP)\ 10.29 - 0.21 * \Delta T + 0.0012 * \Delta T^2 \qquad (8)$$
$$(WSHP)\ 9.97 - 0.20 * \Delta T + 0.0012 * \Delta T^2 \qquad (9)$$

With $\Delta T_h = T_{h,\ sink} - T_{h,\ source}$
where $T_{h,\ source}$ is depending on the source, soil, temperature or air
where $T_{h,\ sink} = 30℃ - 0.5 * T_h^{ambient}$

The ambient temperature data from the created weather dataset is therefore required to calculate the COP values of heat pumps. COP values of other systems have been assumed by (de Vree, n.d.; Regionaal Energieloket, n.d.; Ruhnau, Hirth, & Praktiknjo, 2019), divided into heating, cooling and DHW application.

Domestic hot water

As explained in the methodology the data required for calculating the hourly domestic hot water energy consumption does require a user profile and a volume of hot water consumption on a daily base.

From (ISSO, 2019; van den Brom, 2020; WML et al., 2019) the daily hot tap water consumption per person has been defined at 71 L/day/pp. This volume needs to be heated, staggered throughout a day, demand depending, from inflow tap water temperature +/- 13 °C (ISSO, 2019; WML et al., 2019) to an average hot water temperature of 50 °C (Ruhnau et al., 2019). The average hot water temperature is considered for overall energy demand estimation, this does not mean that no water above 50°C is demanded. Also, in detail, for legionella prevention, the DHW system should be heated above 60°C, occasionally, captured by an average 50°C setpoint for DHW demand.

Three separate hot water withdrawal profiles (Appendix B) have been computed (Ahmed et al., 2016; Moreau, 2011). Applying these to the daily hot tap water consumption provides the hourly consumption of hot tap water. Then the hourly required energy for heating that water volume can be calculated with the physics formula 6.

Domestic electricity

For the distribution of domestic electricity consumption throughout a year-on-hour resolution, profiles have been consulted as well. In the tool, also 3 profiles for domestic electricity consumption have been computed and integrated (ISSO, n.d.-a; NEDU & Pure Energie, n.d.; Zipperer et al., 2013). These profiles are combined with a yearly consumption value of domestic electricity (Appendix B). The distinction here has been made between a base load of domestic electricity consumption for a household and the additional consumption of household members. Based on data from CBS and Vattenfall the following assumptions are applied:

- Baseload of domestic energy consumption of a household (1 person in a dwelling): 1310 kWh
- Additional consumption per extra household member: 500 kWh

Public space demand

Determining the public space demand is being achieved by a similar approach to the domestic electricity demand. In the first instance, a profile of streetlight use is obtained (VREG, 2021). Requirements for this profile, are similar to previously collected profiles, as they must match the hour resolution and year horizon. For streetlight energy consumption this is of relevance due to the variety of use throughout the year, matching the changing sunset and sunrise times. This profile has been coupled to an assumption value of public space demand expressed per dwelling, on a yearly base. This value is assumed at 79.5 kWh on an annual basis according to literature insights (Agentschap NL & Rijksdienst voor Ondernemend Nederland, 2012; van Bakel & Heijnens, 2015; Vreenegoor et al., 2008).

4.2 Method - Energy supply

The second component being modelled in the area simulation tool is the energy supply (potential). The definition and how energy supply is being treated for the area simulation tool is being explained first, followed by the qualification and quantification of energy supply sources being incorporated in the model.

4.2.1 Framework

Within the energy supply component, a range of potential renewable energy sources could be identified. The most common renewable energy source is Photovoltaic panels (PV), generally embraced by the built environment, however, does have its pros and cons. An overview of renewable energy sources which can be identified:

- Solar energy
    - Photovoltaics (PV)
        - Electricity
    - Solar Thermal
        - Heating
        - Cooling
- Wind energy
        - Electricity
- Marine energy
    - Dams and tidal barrages
        - electricity
- Hydropower
        - Electricity
- Geothermal energy
    - Geothermal
    - Heat pumps
        - Electricity
        - Heating
        - Cooling
- Bioenergy
    - Biomass combustion and plants
        - Electricity
        - Heating
        - Cooling
    - Biofuels
        - Transport

Despite there being many renewable energy supply options available, implementation into area development or residential context is more complex. The applicability of choice for a certain energy supply source depends on specific area characteristics, and typology - the availability of a (re)source. (Belussi et al., 2019; ECA, 2018; Urban Land Institute, 2022).

As the energy simulation tool being developed, is focused on residential developments at a moderate scale in the context of the Netherlands, some potential energy sources are not applicable and therefore excluded for the tool; marine energy, hydropower and bio-energy (however residual heat might be relevant for specific locations, in the context of district heating).

What further can be distinguished in the component of energy supply is building-related energy supply and non-building-related energy supply, like in the public domain. This distinction is applied in the tool. As the tool evaluates the energetic performances of future area developments, the potential of renewable energy should be incorporated at both these levels. According to experts and reviewed literature, three types of potential energy supply sources have been included in the tool (see section 2.3 as well):

- Wind
- PV
- Thermal

A range of other tools have not been implemented in the tool, deemed not to be technically ready for implementation in the short or medium term, or not being suitable for application in the built environment. (Agentschap NL & Rijksdienst voor Ondernemend Nederland, 2012; Belussi et al., 2019; McKenna et al., 2017; Schill, 2020; Tozzi & Jo, 2017; Vieira et al., 2017)

Additionally, on the building level, the impact of internal gains and radiation has been taken into account. (Catalina et al., 2013; Cuerda, Guerra-Santin, Sendra, & Neila González, 2019; O. Guerra-Santin & Silvester, 2017; Hoes, 2014; Li & Wen, 2014; Lubina & Nantka, 2009; D. Majcen et al., 2013; Ouf, O'Brien, & Gunay, 2018; Paauw, Roossien, Aries, & Santin, 2009; van den Brom et al., 2018)

To wrap up the framework for the energy supply component, on the building level the energy supply by solar energy (both thermal collectors and PV panels), internal gains and solar radiation will be considered. In the public domain, energy supply gain can be simulated from wind energy and PV panels.

4.2.2 Approach

The energy sources as distinguished in the previous section need a quantification method. Per source, the used calculation methods will be presented and elaborated. From the energy supply framework, figure 18 has been computed, summarizing the framework.

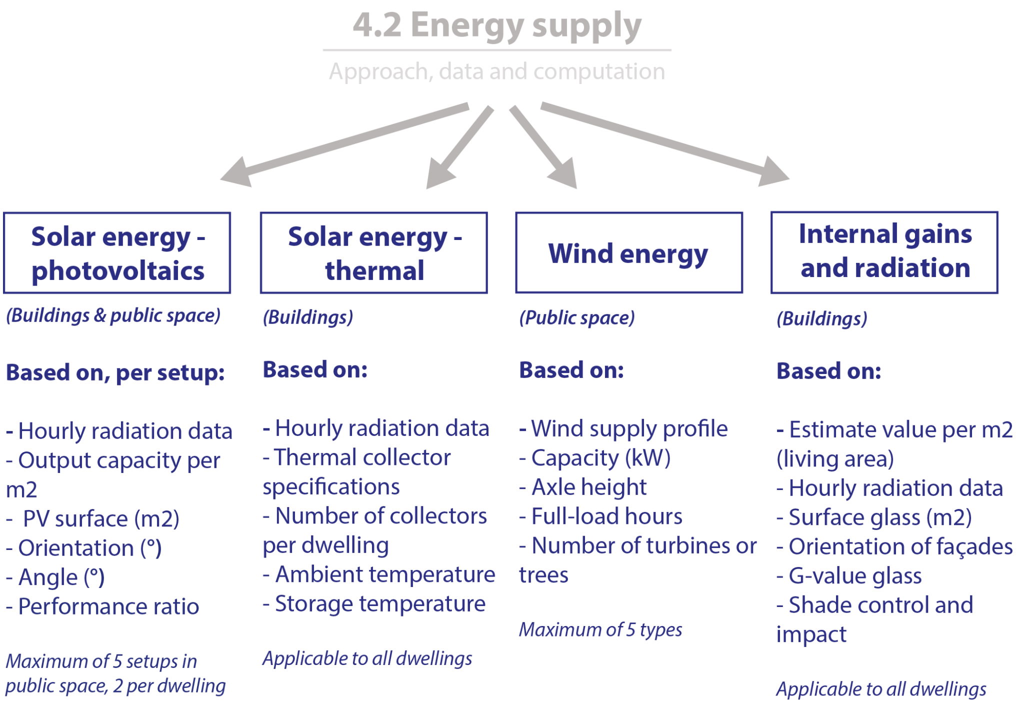


Figure 18 - Framework energy supply

Solar energy - Photovoltaics

The determination of PV energy is strongly dependent on the characteristics of the installed PV setup. However, a method of relative yield per square meter can be determined with variable PV panel parameters, which allows the method to be scalable. With (ISSO, 2019, 2020; Luthander et al., 2016) the key aspect of PV generation can be modelled, which is the correction of the panel orientation and angle towards the received radiation.

Next to the performance and capacity figures of specific PV panels, the uncorrected radiation is needed on the hour level as data, in order to compute hourly PV energy potential. This data is available and retrieved into a dataset, see section 4.2.3 – solar energy.

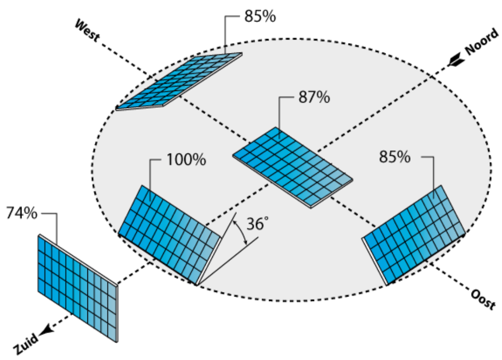


Figure 19 – Panel orientation and angle

Solar energy - Thermal energy

The collection of thermal energy by a thermal collector does work somehow similarly to the PV panel. For thermal collectors, also the orientation and angle of placement are key aspects in order to their performances (ISSO, 2019; Lämmle, Oliva, Hermann, Kramer, & Kramer, 2017). The same method to align received radiation with the emitted radiation can be operated.

The actual thermal energy output of the collector is depending on the collector's efficiency. This collector efficiency can be determined by the following formula by ISSO (2019):

$$Q_{col} = (n_0 * G - a_1 * \Delta T - a_2 * \Delta T^2) * A_{ap} \qquad (10)$$

Q_{col}	= collector yield (W)
N_0	= collector efficiency when no heat exchange with the surroundings occurs ($\Delta T = 0$)
G	= radiation on the panel (W/m^2) (so should be corrected for the orientation and the angle)
a_1	= first-order heat loss factor
a_2	= second-order heat loss factor
A_{ap}	= aperture surface of the collector (m^2)
ΔT	= temperature difference between the collector and the ambient temperature (°C)

The n_0, a_1 and a_2 values are specific characteristics of a thermal collector panel, and they will vary among different panel brands and types, also the aperture surface per collector may differ per type. The ΔT is furthermore also unknown. The ambient temperature is being composed in a dataset for space heating/cooling demand and can therefore be used once more here. However, the collector temperature should be modelled. A thermal collector system will always interact with a certain type of thermal storage, where the gained energy can be stored in a transport medium – most often water.

$$\Delta T = T_{col} - T_{amb} \qquad (11)$$

$$\text{where } T_{col} = T_{storage} + \frac{G * n_0 * A_{ap,tot} - U_{col} * A_{ap,tot} * (T_{storage} - T_{amb})}{Cp_{water} * V_{col} * n} \qquad (12)$$

T_{col}	= temperature of the collector (°C)
N_0	= collector efficiency when no heat exchange with the surroundings occurs ($\Delta T = 0$)
G	= radiation on the panel (W/m^2) (so should be corrected for the orientation and the angle)
$U_{collector}$	= U-value heat loss by collector (W/m^2*K)
Cp_{water}	= specific heat of water (J/(Kg*K))
$A_{ap,\ tot}$	= total aperture surface of installed thermal collectors (m^2)
V_{col}	= flow in the collector – characteristic (kg/s)
n	= number of collectors
$T_{storage}$	= temperature of the storage (°C)

The interaction with thermal storage, being required for a thermal collector, already tends to the third component of the tool, energy storage. For now, the fact that the storage temperature is a variable within the thermal collector yield is validated. The storage temperature will depend on the withdrawal of temperature/energy from the storage (demand), the deposit of energy into it (supply) and the loss of energy during storage or conversion inefficiencies (ISSO, 2019; Lämmle et al., 2017; Lund University, Davidsson, Perers, & Karlsson, 2012).

Wind energy
The theoretical supply of energy by wind energy can be determined with the following variables and methods:

- Full-load hours (collection height and location dependent)
- Installed capacity

The year-round yield of wind energy is the product of the full-load hours and the installed capacity (kWh/year). However, the tool is functioning on an hourly level and therefore the wind energy potential is also a pre-requisite to be on the hourly level. To process the year energy production to the desired hour level a normalized wind profile will be used, created on hour windspeed values on the 10 yearly average/minimal/maximum windspeed dataset, upon own scenario choice.

$$Q_{wind} = E_{installed} * h_{vlu} * Wp \qquad (13)$$

Q_{wind} = wind energy supply (kWh)
$E_{installed}$ = installed capacity (kW)
H_{vlu} = full load hours (h)
Wp = wind profile

$$Wp_{hour,x} = \frac{V_{wind,x}}{\sum V_{wind,year}} \qquad (14)$$

$Wp_{hour,x}$ = normalised profile value (average/min/max) in hour x
$V_{wind,\,x}$ = windspeed (average/min/max) in hour x (m/s)
$\Sigma v_{wind,year}$ = summed year value of windspeed (average/min/max) (m/s)

The data for full-load hours and the wind profile will be elaborated in the next section (Kok & DNV-GL, 2019; NWEA, NVDE, Londo, Blauwbroek, & Kooi, 2022; RVO, n.d., 2021).

Internal gains and radiation
Two other, indirect, sources of energy supply can be identified, internal gains and radiation. 'Internal gains' can be described as the indoor heat gain by appliances, occupation and lighting, radiation is the indoor heat gain literally due to sun radiation mainly due to translucent areas.

Different methods (section 4.3.1) have been evaluated to determine the quantity of these internal gains, although this comes with a high level of detail, as multiple methods do describe the use and even the presence of specific appliances on an hour level, beyond the framework of the tool (section 2.4). For internal gains, a deliberate assumption has been taken upon literature findings (section *assumptions* – in the tool).

Sun radiation through windows can be computed with some basic calculation steps, of the correct data. Dependent on the orientation of the window (variable) the hourly radiation, which is also used for the solar energy potential, can be corrected for the orientation and the vertical position of windows. When this corrected radiation value is known, this can be multiplied by the surface area of the glass relative to the orientation and the g-value. The g-value of glass is a specific characteristic, a solar energy transmittance coefficient, indicating how much heat is transmitted through a window, and so a variable within the model (Alders, 2016; Belussi et al., 2019; Bouwfysica Kennisbank & van der Linden, 2005; ISSO, 1975; Vadiee, Yaghoubi, Martin, & Bazargan-Lari, 2016).

4.2.3 Data and Computation

Solar energy (PV and Thermal)

The technical parameters of a PV/thermal setup, as mentioned in the approach and method section, do define the total installed setup capacity. However, next to these technical parameters, the amount of radiation is needed to predict PV and/or thermal energy generation.

Same as for the temperature, the historic data on radiation in the Netherlands can be retrieved from KNMI (n.d.). The KNMI does measure the global radiation per hour in Joule per square meter (J/m^2). Global radiation does not only take into account direct sunlight but also diffuse light. For the same 28 meteorological weather stations, as mentioned in the heat loss calculation of section 4.1.3, the radiation can be retrieved. From this, a dataset has been created in which the same scenarios of average, maximum and minimum have been incorporated over the same 10-yearly period. Figure 20 does indicate the relevance of these 28 datasets again, as the summed value among these sets does differ significantly (Δ= 113 J/cm^2, (approx. 10%). The extreme values do represent a large geographic spread within the Netherlands as well.

This radiation dataset is used to compute the PV potential, but also the thermal energy collection, and radiation through translucent surfaces of buildings.

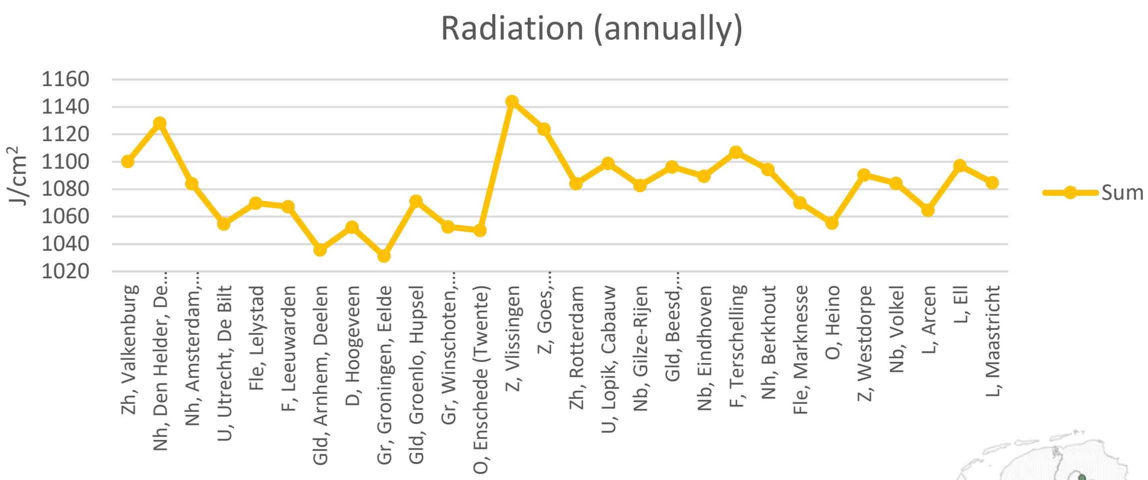


Figure 20 - Yearly radiation per meteorological station (computed from KNMI, n.d.)

Wind energy

To determine the wind energy potential data on full-load hours is needed which expresses the total number of hours (in a year) the installed setup will run at its maximum capacity, this is an equivalent.

The full-load hours of a wind harvest installation are linked to an average windspeed (m/s). This windspeed, in turn, is depending again on which height this is a measure. Normally, the height of 100m is maintained in order to determine the number of full-load hours, however, on an urban scale, wind harvest installation might also be sized smaller which makes the full-load hours determination on 100m height an overestimation.

Therefore, the average yearly wind speed at the 28 used weather stations is retrieved at 25m, 55m and 100m height, Appendix C, from RVO (2021). With data from (NWEA et al., 2022; RVO, n.d., 2021) the number of full-load hours could be coupled to the average yearly wind speed values, at different heights. This introduces the inclusion of a height wind energy harvest height, in order to make a more accurate wind energy potential.

To transfer the year-round energy supply of wind energy to the hour resolution, a wind profile is needed. This profile can be composed by normalizing the hourly windspeed (formula 14). Again, the 28 similar meteorologic station locations will be used to withdraw the average, maximum and minimum windspeed (m/s) per hour in the time period of 2011-2020, to perform scenario studies later on. The average variety in windspeed among the stations does differ significantly (figure 21), declaring why a general Dutch weather dataset would reduce the tool's accuracy. Inland the lowest average windspeed data is measured, differing over 3.3 m/s in comparison to the maximum average annual value measured on the Dutch Wadden islands. (KNMI, n.d.).

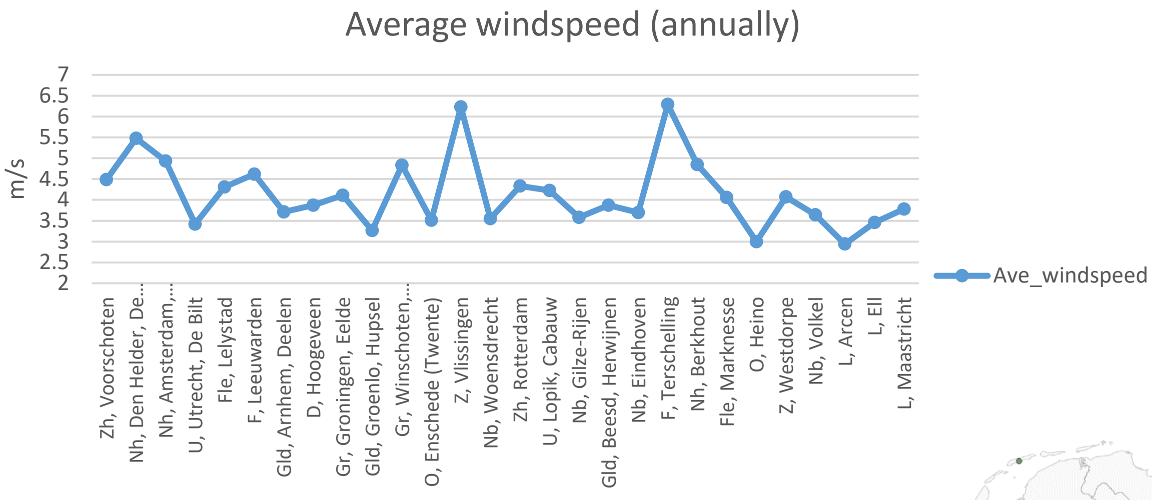


Figure 21 - Average windspeed per meteorological station (computed from KNMI, n.d.)

In Appendix D, a full dataset of a single weather station, Amsterdam, is inserted as an example.

4.3 Method - Energy storage

The last component being integrated into the area energy simulation tool is energy storage. As stated, energy storage can considerably increase the self-consumption and sufficiency of an area in terms of energy by balancing and peak-shaving, the mismatch between energy supply and demand can be buffered or diminished, which has numerous advantages.

4.3.1 Framework

There is a diverse range of ESTs available, however, with their pros and cons. As stated in section 4.2 – Energy supply, the precondition for the use of thermal collectors is the presence of thermal energy storage (TES). However, a TES is not suitable for storing a surplus of electrical energy, when being recalled as electricity again. Conversion into thermal energy is however possible with a surplus of electric energy, however, the TES cannot be deployed for electricity production. Buffering of electric energy surplus for periods of large demand than supply of electric energy does require another type of storage. It is widely concluded that batteries are, currently, the most suitable EST for electric energy storage (Berenschot, 2022; Dunn et al., 2011; Kapur, 2022; Murray, Orehounig, Grosspietsch, & Carmeliet, 2018; Roberts et al., 2019; Siraganyan et al., 2017). However, pointed out as a short-cycle storage option. The self-discharge of batteries makes them unsuitable for long-term storage or seasonable storage (Budischak et al., 2013; Gür, 2018; ISSO, n.d.-b; Papaefthymiou & Dragoon, 2016; Schlachtberger et al., 2017; Sharma, Haque, & Aziz, 2019). The combination of TES and batteries is deemed most suitable for application in residential areas.

The inclusion of other ESTs or materials (listed below) has been evaluated and concluded not suitable in the context of residential area development, due to underperformance of not being deemed market-ready soon. (Baldukhaeva, Baldynova, Erbaeva, & Zudaeva, 2021; Bartolini et al., 2020; Berenschot, 2022; Brown, Schlachtberger, Kies, Schramm, & Greiner, 2018; Budischak et al., 2013; Chen et al., 2009; Comodi et al., 2015; Dunn et al., 2011; Goodenough & Manthiram, 2014; Guerra et al., 2020; Gür, 2018; Hoffman et al., n.d.; Kapur, 2022; Kock, 2013; Koirala et al., 2018; Koohi-Fayegh & Rosen, 2017; Luo et al., 2015; Mengelkamp et al., 2017; Murray et al., 2018; Papaefthymiou & Dragoon, 2016; Pleßmann, Erdmann, Hlusiak, & Breyer, 2014; Schill, 2020; Schlachtberger et al., 2017; Sharma et al., 2019; Siraganyan et al., 2017; Vieira et al., 2017).

- hydrogen
- flywheel
- pumped hydro
- compressed air

The scope within the tool is therefore, for now, limited to the modelling of battery storage and thermal energy storage, which does capture the short- and long-term (often referred to as seasonal storage) scope of energy storage needed in energy-autonomous areas.

4.3.2 Approach

The two energy storage technologies selected in the previous section do need further quantification in order to model these in the tool. This section will continue with defining the quantification of the variables along the shaped framework of section 4.3.1, being summarized in figure 22.

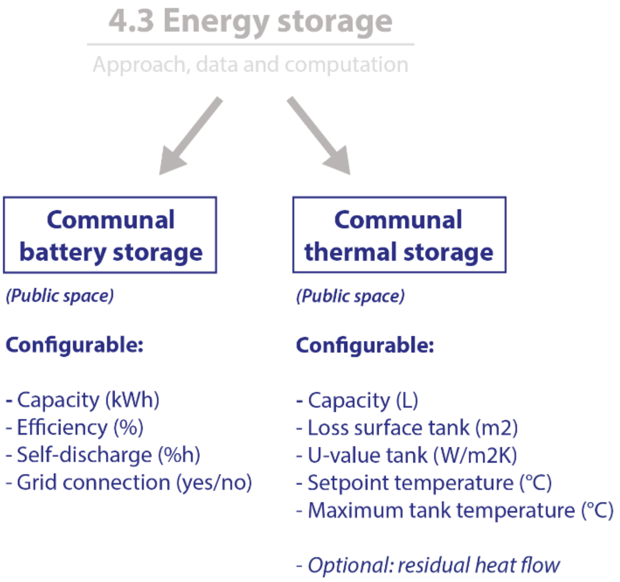


Figure 22 - Framework energy storage

Battery storage

The required parameters to model battery storage does exist out of three variables (Brown et al., 2018; Budischak et al., 2013; Chen et al., 2009; Iwell, 2023; Schlachtberger et al., 2017):

- Capacity: how much energy can be stored in a single or series of batteries.
- Roundtrip efficiency: percentage of effective available energy after storage relative to the battery input.
- Self-discharge: percentage of loss in stored charge in the battery without any load.

These three parameters are integrated into the tool and do allow for scenario and optimization study. The capacity, efficiency and self-discharge rate are editable, although do have an initial value based on the studies, they are included as assumptions in the model.

Thermal storage
To model a thermal energy storage, 5 parameters have been included in the model (ISSO, 2019; Lämmle et al., 2017; Langer & Volling, 2020; Lund University et al., 2012):

- Volume: what is the size of the storage tank, determining the energy storage capacity (in litres or cubic meters)
- Medium: what type of liquid is used to store the energy, commonly water
- Thermal resistance: hot water is stored in a tank exposed to the ambient temperature or soil temperature, energy loss will occur here in heat loss to the surroundings, the size of this heat loss is determined by the thermal resistance of the tank (U-value), the surface of the tank, and the ΔT between the surroundings and the content of the tank.
- Surface: indicating the surface area of the tank to determine the heat loss due to the exposed surface.
- Temperature window: depending on the liquid being used in the thermal storage, there will be a temperature window to operate in. In the case of water; the water temperature should not drop below the 0°C and not exceed +/- 90°C, to avoid phase changes.

Depending on the type of thermal storage that should be modelled in the tool, the user can edit the parameters with their own insights, especially the capacity and surface. The other parameters will be foreseen with thoroughly considered assumptions.

4.3.3 Data and Computation

Battery storage
The following parameters are needed to model a battery storage in the tool. The capacity is scalable, and for the efficiency and the self-discharge rate validated assumptions are listed.

- Capacity: scalable, 15kWh – >50 MWh (multiple modules) (Iwell, 2023)
- Roundtrip efficiency: 90% (Dunn et al., 2011; Iwell, 2023; Murray et al., 2018; Siraganyan et al., 2017)
- Self-discharge: 0.1% per hour (Dunn et al., 2011; Iwell, 2023; Murray et al., 2018; Siraganyan et al., 2017)
-

In the tool, per hour, will be analysed if energy demand and supply do match. The result per hour will indicate a surplus or shortage of (electrical) energy. In case of surplus, over that hour, this surplus will be stored in the battery. In the model, the 90% efficiency is directly applied, indicating that every 1 kWh of energy surplus in the balance results in 0.9 kWh of charge in the battery.

Self-discharge is modelled over the stored charge in the battery. The stored energy will every hour drop by 0.1%. When an energy shortage occurs over an hour, the volume of shortage will be extracted from the battery.

Thermal storage

For the modelling of a thermal storage the following parameters are needed for the modelling of the thermal energy storage:

- Volume: scalable (up to 100.000 m^3 connecting 8000 dwellings, illustrated by examples (Ecovat, 2023)
- Medium: specific heat capacity of water 4180 J/(Kg*K)
- Surface of tank: dependent on the capacity (m^2)
- U-value of tank: <= 1 (W/m2*K) (ISSO, 2019; Lund University et al., 2012)
- Maximum temperature: 0°C - 90°C (Ecovat, 2023)

The simulation of a thermal energy storage will be optionally available in the tool. As deemed before the TES does interact with thermal collector panels, installation of a storage facility without collector panels is not evident and vice versa. By the parameters indicated above and data on the soil temperature/ambient temperature (dependent on the placement of the tank), the heat loss through the surface of the tank can be calculated, per hour. With the volume of the tank and the specific heat capacity of the storage liquid, this heat loss can be expressed in temperature decrease.

The buffered thermal energy in a TES can be consumed by (pre)heating of space heating circuits or hot tap water circuits in the (residential) buildings. The withdrawal of thermal energy is expressed in °C, to hourly model the TES temperature, and in Wh to calculate the savings by space heating and/or hot tap water, due to (pre)heating of these circuits. This saving is achieved as the ΔT for the heating systems is reduced or vanished in an optimal case.

A temperature increase of the TES is modelled optionally threefold:

- The harvested thermal energy by the thermal collectors will be stored in the thermal storage. This hourly thermal energy gained computed in °C, raised the tank temperature when radiation is perceived.
- If there are heat pumps placed in the area development, these can mechanically increase the TES temperature. Heat pumps do work with high efficiency (COP) when ambient temperatures are high, although they consume electricity. However, when there is a surplus of electrical energy, also over the battery storage (threshold value is incorporated as an assumption here), the electric energy, can be conversed, with a high efficiency, into the thermal, long-term, storage.
- Residual heat, by any facility in the vicinity of the residential area, can be thermally buffered as well, this is being integrated into the model by a continuous flow of energy in Wh.

The withdrawal of thermal energy from the tank is possible by consumption.

- (pre)heating of the space heating circuit and/or DHW circuit.

4.4 Application and integration

The three components are integrated and do form the base of the tool. In short, the tool does identify the energy demand of the buildings and public space of the plan to be assessed, the renewable energy supply as well in the private and public domain. These hourly data profiles are being composed, where (mis)match between demand and supply of energy can be identified on the area level. As indicated in the calculation method parts, the model does address electric energy demand and heat demand. Conversion of electric energy into heat is being captured by selectable technologies for the user, in order to express demand and supply in a single unit: kWh.

To accommodate supply surplus and release in moments of supply deficits, different setups and interactions of energy storage can be modelled. The application of energy storage can therefore be used to optimise the assessed plan, in terms of energy. The tool does allow the modelling of short-term storage by changeable battery setups, and long-term storage by thermal energy storage in liquid. The optimisation does not solely have to come from energy storage. The separate modelling of the energy demand and supply components in the tool, along with the relevant parameters do also allow for optimisation of the quantity of energy demand or supply, tracing back to building and area parameter values. Integral optimisation and alignment of an area's energy demand, supply and storage facility is what is being strived for. An important built-in indicator to measure the performance of integral optimisation is the self-sufficiency percentage, on the result dashboard. Self-sufficiency is here not defined, as commonly, as the total quantity of renewable energy annually relative to the total demand of energy on an annual basis but reflects the number of hours the area can fulfil its own energy demand without external energy supply, over a year. This fulfilment can either be direct consumption from renewable energy generation in the area or consumption of previously stored energy in the available storage devices.

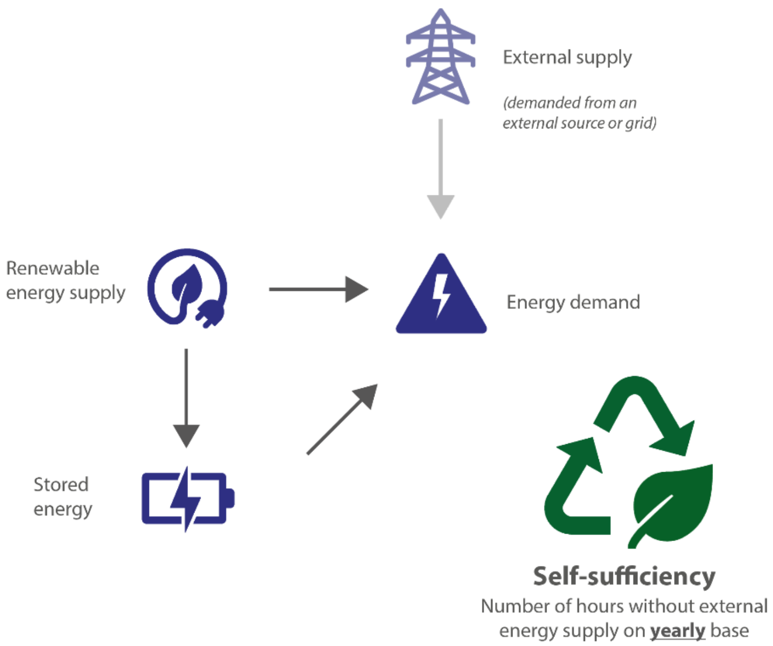


Figure 23 – Visualisation definition of self-sufficiency indicator

Deployment of this tool in the early design stage or already in the planning phase allows for design adjustments among different stakeholders to contribute to better integration of energy utilisation at the proposed area development.

The required input for the area analysis should be provided in the 'parameter' tab (Appendix E1). After the simulation is completed, the performance results of the area can be retrieved from the dashboard (Appendix E3) and infographic (Appendix E4) in the same spreadsheet file. Both the dashboard and the infographic indicate overall performances and detailed data and values. Results and insights of the performances can be gathered at specific times or periods throughout the year, according to the user(s)s needs. Think of hourly estimates for the demand and supply of energy, as well as energy flows between buildings and storages within the simulated area. The dashboard is interactive and can be used dynamically by the user. The three dynamic main elements of the dashboard are highlighted and explained below. The complete dashboard can be found in Appendix E3.

Figure 24 indicates the energy flows within the area. These flows can be looked up per contributor (either one of the building types along their ID or the public space) or summed into a total energy flow. Distinguished is between the energy demanded, the electric energy supply and the thermal energy supply. The current window indicates the annual overview, although this period can be reduced up to an individual hour within a year.

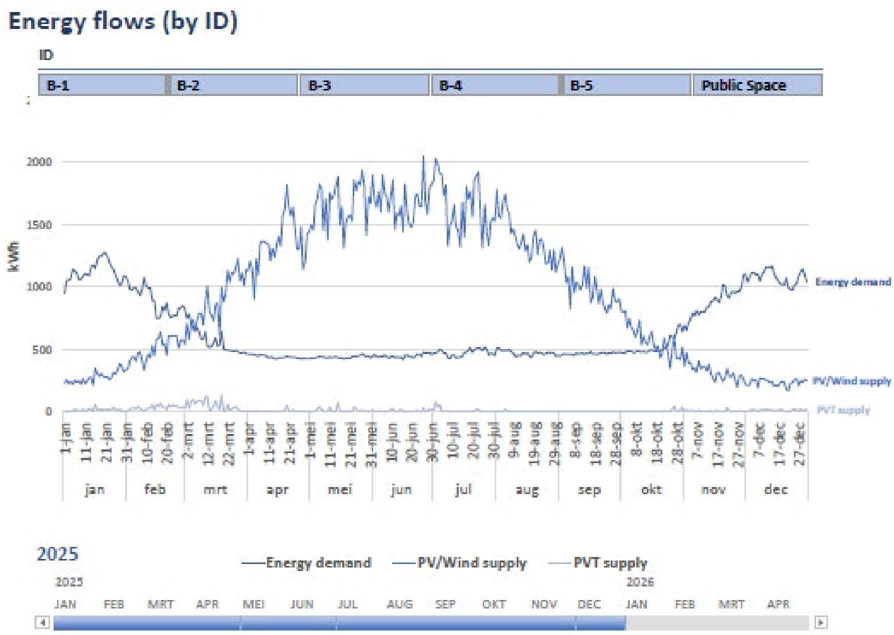


Figure 24 – (summed) Energy flows (current view: annually)

In Figure 25, the area energy overview is shown. This overview contains the total energy balance indicating positive if external energy is needed, and negative if there is a surplus of energy. If there is a surplus of energy, this will be stored or fed into the grid depending on the setup and conditions. Furthermore, this overview indicates the moments and quantity of surplus energy fed into the grid or demanded from the grid (which is the case if the area is not 100% energy self-sufficient).

Figure 25 - Area overview (current view: annually)

In addition, figure 26 shows the storage fill levels over time, only if a type of storage has been included in the simulation. For figure 26 holds as well that the current window indicates an annual overview. This can be reduced to an hourly view.

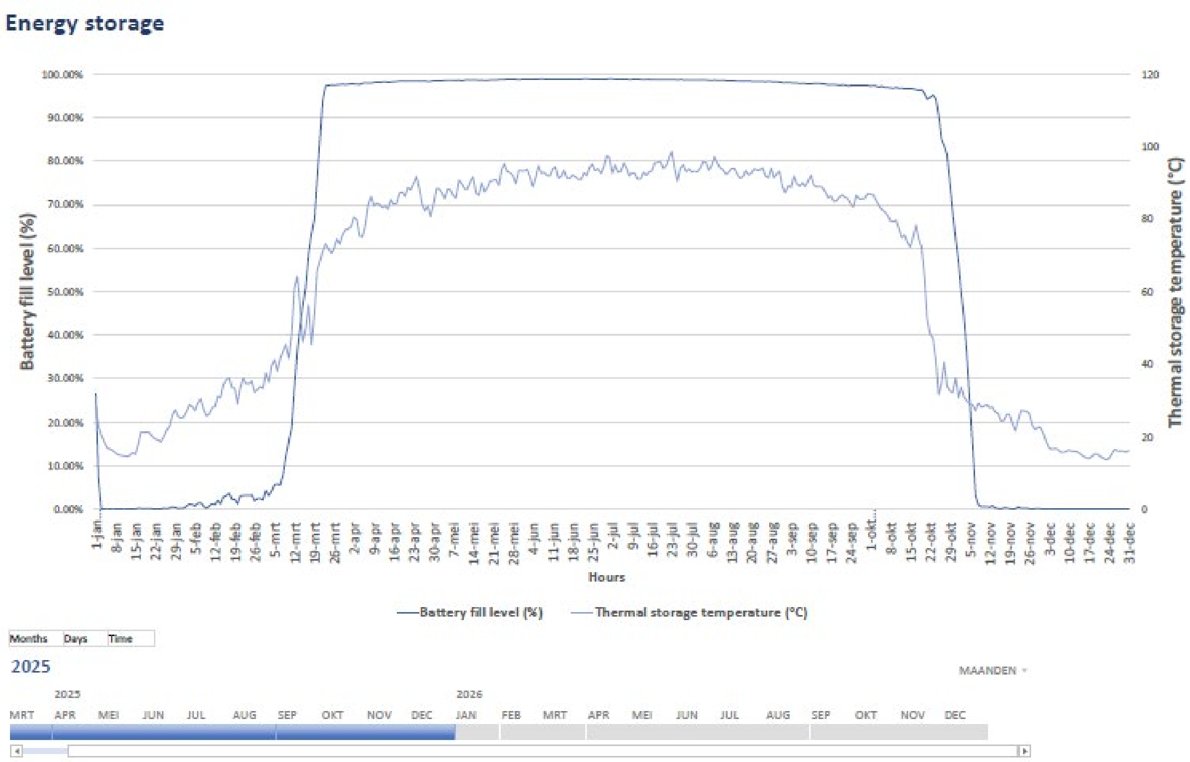


Figure 26 - Storage type and fill levels (current view: annually)

Additionally, there is an ‘assumption’ tab within the spreadsheet model (Appendix E2). This sheet does contain some predefined values for a limited number of variables. These values are established according to literature and expert experience, although may be altered by users according to their own insights or specific case context.

In Appendix E, an overview of the input sheet, assumption sheet, dashboard and infographic can be found. The values in here should not be valued, these are fictive values and not used for any concrete case modelling.

5. Practical application: case study

The performance evaluation of the tool in practice is secured by the test of two case studies of real greenfield developments. Validation of the relevance and proper working of the tool is deemed as the goal of case study testing. The cases will be treated individually, starting with a short introduction on the case and the relevant context of it. After that, the base scenario of each case will be tested. The base scenario is the initial plan for the area as provided by the case study, and so does contain the data directly obtained from the case. This is data upon all parameters as needed for evaluation and has been filled in for evaluation into the parameter sheet (as shown in Appendix E1) per (sub)case. Where needed, adjustments will be made to the assumption in the assumption sheet, whether this is necessary is assessed on the data by (sub)case. After modelling, the energy performances of the base scenario can be read from the dashboard, containing among others three key values: energy demand, energy supply and the level of self-sufficiency. These three key values are indicated within the case studies for the initial performance check.

Based on the results and insights from the complete dashboard, parameter values can be altered in the seek for optimisations in the performances. Per case, only a limited number of variables have been altered, and their impact has been re-tested. For each (sub)case there is an appendix included, indicating the base scenario performance dashboard and the performance dashboard after the potential changes (Appendix F – J).

As for none of the case studies specific indoor temperatures have been indicated nor expected user profiles, these have remained consistent among all case studies for reasons of fairness and comparison, unless indicated otherwise to show the impact of indoor temperature and comfort. The temperature thresholds for heating and cooling are respectively 20°C and 26°C.

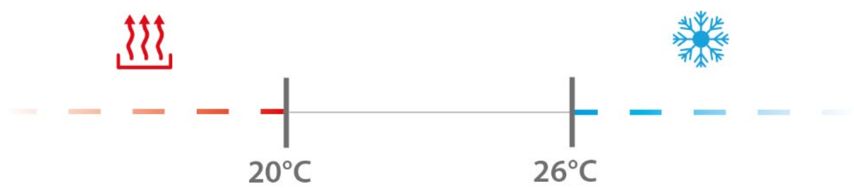


Figure 27 – Indoor temperature range for the case studies

Furthermore, per (sub)case only the impact of a limited number of parameter optimizations has been tested to indicate the capabilities and possibilities of the tool. Among the (sub)cases the type of optimized parameters varies to indicate the majority of the parameters which can be tweaked. Per (sub)case at least one optimization for the energy demand, supply and storage has been tested, taking into account the phase of the development and to what extent changes are still applicable there.

5.1 Case 1: West Betuwe

In the municipality of West Betuwe, a greenfield development is initiated containing over 200 residential dwellings. The development is not yet in the design phase, but still in the planning phase. The land use plan is currently being shaped in order to regulate the development. This case study has been obtained by Arcadis, involved in the spatial plan development. The buildings included are indicated by estimates and key values, incorporated in the plan. Due to the actual state of the project, some details might not be available required to execute the area energy performance, which does lead to small, agreed assumptions. Although, the initial plan does contain 4 different dwelling types, which match the tool's maximum capacity of 5 unique types, the proposed organic layout of the development does force to model more than the 4 dwellings types, as within a single dwelling type the parameter set cannot be generalized for all the dwellings of the same type, mainly due to their widely varying orientation. Simplification by clustering has been applied here. Figure 28 does illustrate the initiated development as applied for analysis:

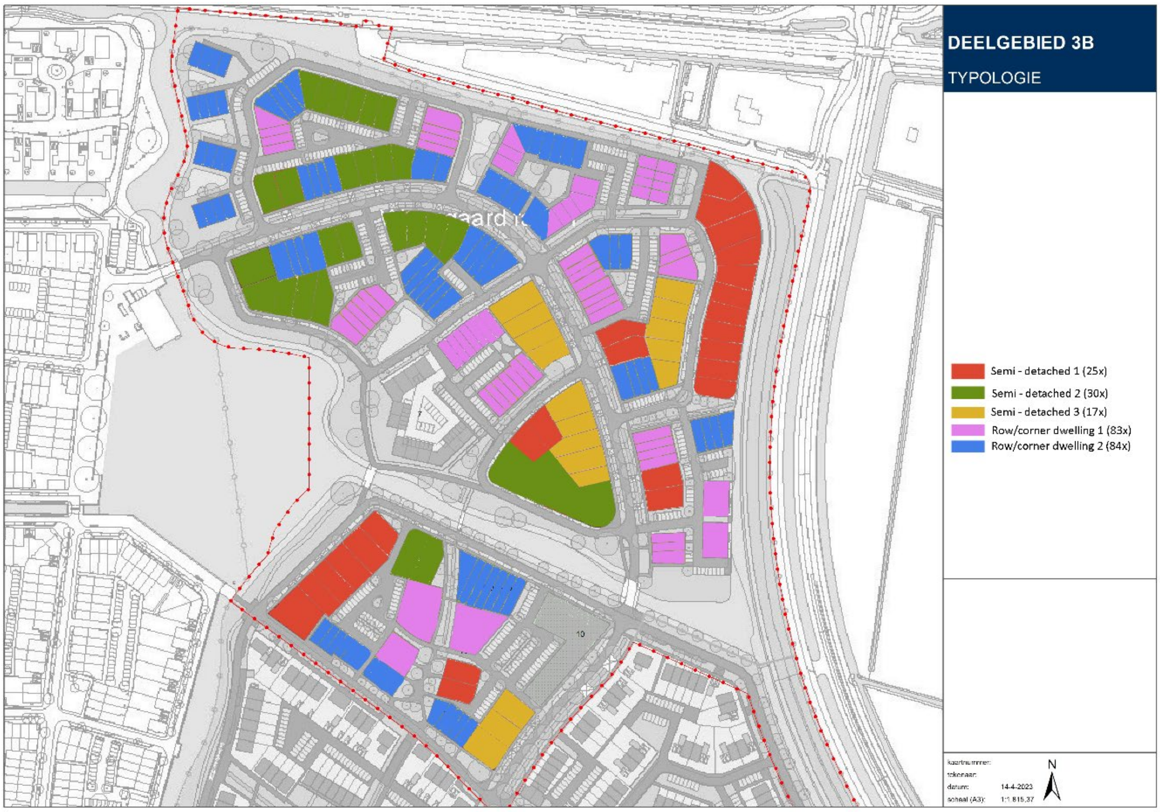


Figure 28 - Spatial plan West Betuwe for case study 1

5.1.1 Analysis

The first analysis run according to the five types and the corresponding parameters, does give the following estimates from the tool:

- Energy demand: 1,328,916 kWh
- Energy supply: 957,983 kWh
- Self-sufficiency: 59.1%

The full performance dashboard is added in Appendix F. Just over half of the year (hour resolution) this neighbourhood can fulfil its energy demand, however, optimisations are preferable, fulfilling higher sustainability ambitions. The initial development did not contain any type of energy storage. As the project is still in the planning phase, parameters related to this are currently of most interest before they are fixed in land use plans, mainly deemed the position and orientation of the dwellings. Table 3 below will indicate the impact of some indicative parameter changes on the three key indicators. The effects will be relative to the base scenario performances as indicated above. At least a single parameter change has been tested upon its impact per component; demand, supply or storage.

Table 3 - Parameter optimisations examples case study 1

Potential parameter change	*Key value*	*Impact (relative to base scenario)*
1 - Orientation *- all dwelling types 20° more north orientated*	Energy demand	1,304,997 kWh (-1.8%)
	Energy supply	895,376 kWh (-6.5%)
	Self-sufficiency	58.1% (-1.2%)
2 - Energy storage *- Adding central battery storage of 3000 kWh*	Energy demand	1,328,916 kWh (-%)
	Energy supply	957,983 kWh (-%)
	Self-sufficiency	70.5% (+11.2%)
3 - Energy storage *– increasing to 6000 kWh capacity (200%)*	Energy demand	1,328,916 kWh (-%)
	Energy supply	957,983 kWh (-%)
	Self-sufficiency	70.7% (+11.4%)
4 - Public supply *– adding: 2x urban wind tree, I.e.: 10.8 kW capacity, approx. axle height 6.5m (New World Wind, 2023)*	Energy demand	1,328,916 kWh (-%)
	Energy supply	1,008,743 kWh (+5.3%)
	Self-sufficiency	61.8% (+2.5%)
5 - Public supply *– adding: A total of 200 m2 PV, 20° South, 30° angle.*	Energy demand	1,328,916 kWh (-%)
	Energy supply	1,002,888 kWh (+4,7%)
	Self-sufficiency	59.7% (+0.4%)
6 - Private demand *– improving: Rc values of walls, floors and roofs by 20%, to building code*	Energy demand	1,315,574 kWh (-1.0%)
	Energy supply	957,983 kWh (-%)
	Self-sufficiency	60.5% (+1.2%)
7 - Private demand *– improving: Rc values of walls, floors and roofs by 50%, to building code*	Energy demand	1,304,398 kWh (-1.8%)
	Energy supply	957,983 kWh (-%)
	Self-sufficiency	61.7% (+2.4%)
Combi 1, 2, 4, 5, 6 *– improvement of 5 parameters*	Energy demand	1,292,085 kWh (-2.8%)
	Energy supply	991,042 kWh (+3.5%)
	Self-sufficiency	74.0% (+14.9%)

Considering Table 3, only a small number of parameters represented in the tool have been evaluated on optimisation, especially the parameters relevant to the early planning stage of the development. In other words, variable changes which can still be applied respectively to the status of the project. However, what can be concluded from these few parameter changes, is that the impact per change differs considerably. Change 1, does decrease the energy demand, a desired note, although the supply does decrease to a larger extent. A side note to change 1; the proposed change of 20° is rather rigorous and is not specifically evaluated in the context. Also, orientation could be distinguished between building orientation and roof orientation linked to PV supply in energy-oriented designing. Change 2 and 3 do show that the addition of a central battery storage does improve the self-sufficiency, however, a doubled capacity of the battery does only increase the self-sufficiency by 0.2%. Potential changes 6 and 7 are related to the isolation values of the building envelopes. An increase of the Rc value by 20% (change 6) does reduce the demand for energy only by one per cent. Underlying is the fact that the reduced demand for space heating energy barely outweighs the increased cooling demand. A higher thermal resistance value by the building envelope, increases the resistance of heat loss to outside, in desired (winter) and undesired (summer) periods. An amplified effect of this can be seen in the results of potential change 7. With a higher thermal resistant shell, the chance of overheating increases in summer periods underlying the increased demand for cooling. A combined set of improving parameter changes (1, 2, 4, 5 & 6) does specify a substantial improvement in all three key values.

5.2 Case 2: Buitengoed Heiloo

A second case study has been executed in the region of Heiloo, where a large-scale greenfield development of over 1200 dwellings is proposed in different stages. One of these stages is titled 'Buitengoed' and will be developed by Dura Vermeer. This case study is agreed upon and associated with Dura Vermeer and Overmorgen (a company of Arcadis). In comparison to case study 1, this case can be framed in a more advanced stage, as the design stage is almost completed, however, execution is delayed by energy- and nitrogen-related problems. Optimisations in the design and area can therefore still be implemented to some extent.

Figure 29 – Spatial plan Buitengoed Heiloo (Dura Vermeer, 2022)

Executing the case study did encounter limitations within the tool. As Figure 29 does indicate the total plan of 93 dwellings, the number of unique dwelling types (including the variety of orientation), within the plan does exceed the current tool limit of 5. The case has therefore been split into three smaller cases (subcases), where different parts of the plan will be evaluated. This is included in the following three sections.

Table 4 – Case study 2 classification

Title	*Project phase*	*Number of dwellings*	*Remark*
Subcase 1 (5.2.1)	Phase 1 (partial)	13	Detailed modelling, does contain 5 unique dwelling configurations
Subcase 2 (5.2.2)	Phase 1	40	Small (orientation) corrections to reduce the number of configurations to the maximum of 5
Subcase 3 (5.2.3)	Phase 2 (partial)	25	Detailed modelling, does contain 5 unique dwelling configurations
Subcase 1 (5.2.4)	Phase 1 (partial)	13	Same area as subcase 1 (5.2.1.), aiming at a 100% self-sufficiency area.

5.2.1 Analysis – subcase 1

Subcase 1 does evaluate the dwellings on plots 68 to 80 of the greenfield development *Buitengoed*. Within this subcase, 5 unique dwelling types could be identified, which allows to model these 13 dwellings in full detail, without any simplifications or design-related assumptions. Figure 30 does highlight the included plots. This simulation run does include five-row houses, four semi-detached dwellings and four detached dwellings in three different configurations.

Figure 30 - Subcase 1 cut-out

Corresponding to the received data on the dwellings in subcase the performance dashboard is included in Appendix G. The three key estimates are as follows:

- Energy demand: 61,272 kWh
- Energy supply: 27,834 kWh
- Self-sufficiency: 43.2%

The share of renewable energy supply and self-sufficiency are rather low within the base scenario. In numbers, only 5 of the include 13 dwellings do have PV panels installed. Adding additional PV surface could be desirable. The current suggested PV supply does peak (due to their orientation) in the rough period of March till and including June (based on grid feed-in).

Adding additional PV is suggested related to the periods where the demand for external grid demand is relatively high. Additional PV production should match the period of cooling demand, as analysis on the cooling demand did turn out that the cooling demand has a large share in the total energy demand in the period of April up to September (PV panel performances have remained uniform according to the provided case data unless indicated otherwise). Some sample improvements along the case parameters are suggested within Table 5, taking into account the stage of development. Roof angle changes are therefore not considered, however, when fully committed to energy-oriented design, roof angles are important variables linked to PV modelling. Within the limited amount of renewable energy production in subcase 1, the impact of energy storage is limited, as there is barely oversupply.

Table 5 – Parameter optimisations examples case study 2 – subcase 1

Potential parameter change	*Key value*	*Impact (relative to base scenario)*
1 – Adding PV (suggestion):	Energy demand	61,272 kWh (-%)
Type E: 10 panels, 110° south, 38°	Energy supply	43,226 kWh (+55.3%)
Type F: 6 panels, 20° south, 59°	Self-sufficiency	52.2% (+9.0%)
Type G1: 10 panels, 110°, 60°		
***2 – Energy storage** - Adding central*	Energy demand	61,272 kWh (-%)
battery storage of 500 kWh	Energy supply	27,834 kWh (-%)
	Self-sufficiency	46.0% (+2.8%)
***3 – Shade control** – adding shade*	Energy demand	56,437 kWh (-7.9%)
control overall, with a reduction value	Energy supply	27,834 kWh (-%)
of 30% when radiation exceeds a	Self-sufficiency	41.5% (-1.7%)
threshold of 0.35 kWh/m2		
***4 – Indoor comfort** – change in indoor*	Energy demand	57,438 kWh (-6.3%)
temperature	Energy supply	27,834 kWh (-%)
Space heating set point: 20°C -> 18°C	Self-sufficiency	44.3% (+1.1%)
Space cooling threshold: 26°C -> 28°C		
	Energy demand	54,757 kWh (-10.6%)
Combi 1, 2, 3 & 4	Energy supply	43,226 kWh (+55.3%)
	Self-sufficiency	67.5% (+24.3%)

In accordance with Table 5, the addition of more PV surface in combination with energy storage could substantially increase the self-sufficiency of the modelled plots. Especially, the combination of these two is considerable, as both measures individually show a much more limited effect on the three of the key values. The third parameter measure, of the few tested optimisations, does have a notable impact on the cooling demand of the included buildings, as the summed cooling demand (on an annual basis) of the 13 dwellings drops to 10,343 kWh (-35.1%).

5.2.2 Analysis- subcase 2

The second subcase does include a total of 40 dwellings, whereof the dwellings of subcase 1. This subcase evaluates all ground-level dwellings of phase 1 of the Buitengoed greenfield development. Among these 40 dwellings, 5 different types of dwellings could be identified, however, different configurations of these 5 types are present within the plan, coping with the tool limit of 5 unique parameter sets, some simplifications and summed averages have been used to model the indicated area till the best possible practice. Figure 31 illustrates the consulted plan of subcase 2: including 14-row houses (2 configurations); 10 semi-detached dwellings and 16 detached dwellings (2 configurations).

Figure 31 - Subcase 2 cut-out

When simulating subcase 2 upon the received dwelling and parameter data, the performances according to three of the key values are as follows (dashboard plot appendix H):

- Energy demand: 167,863 kWh
- Energy supply: 93,464 kWh
- Self-sufficiency: 48.5%

Evaluating subcase two, the share of renewable energy (on an annual base) is rather low. Only 16 out of 40 dwellings considered in this subcase do have PV panels installed. However, the planned sets of PV installations do generate oversupply in some periods, resulting in a large amount of grid feed-in, especially in the months of April and May. The installation of PV on only a small number of dwellings in the area does suggest the exchange of renewable energy among the different dwellings. In that case, the addition of a battery could significantly improve the mismatch of energy in the context of a microgrid and a high level of energy self-sufficiency. Table 6 below, contains the evaluation of some example measures being proposed from the base scenario. The impact (positively or negatively) on the three previously used key values is listed.

Table 6 – Parameter optimisations examples case study 2 – subcase 2

Potential parameter change	*Key value*	*Impact (relative to base scenario)*
1 – Improving R values above building code level *- uniform Wall: 5.5; Roof: 7.0; Floor: 4.5*	Energy demand	167,928 kWh (+0.04%)
	Energy supply	93,464 kWh -%)
	Self-sufficiency	49.0% (+0.5%)
2 – Energy storage - *Adding central battery storage of 100 kWh*	Energy demand	167,863 kWh (-%)
	Energy supply	93,464 kWh (-%)
	Self-sufficiency	46.0% (+6.3%)
3 – Shade control *– adding shade control overall, with a reduction value of 50% when radiation exceeds a threshold of 0.35 kWh/m2*	Energy demand	147,046 kWh (-12.4%)
	Energy supply	93,464 kWh (-%)
	Self-sufficiency	41.5% (-7.1%)
4 – PV panel standard – *modelling current standard values of PV panels: 400 Wp each panel = 225 Wp/m2*	Energy demand	167,863 kWh (-%)
	Energy supply	110,681 kWh (+18.4%)
	Self-sufficiency	50.3% (+1.8%)
5 – Public renewable energy – *adding one urban wind turbine in public space. I.e.: eocycle EOX S-16, 25 kW capacity, 32m axle height (Eocycle, 2023)*	Energy demand	167,863 kWh (-%)
	Energy supply	152,214 kWh (+62.9%)
	Self-sufficiency	72.4% (+23.9%)
Combi A - 2, 3 & 5	Energy demand	147,073 kWh (-12.4%)
	Energy supply	152,214kWh (+62.9%)
	Self-sufficiency	82.4% (+33.9%)
Combi B - 2, 3, 5 and thermal storage *– of 10 m3 for collective use, interaction for space heating and DHW (pre)heating*	Energy demand	126,888 kWh (-24.4%)
	Energy supply	152,214 kWh (+62.9%)
	Self-sufficiency	82.3% (+33.8%)

Table 6 shows the impact of a small number of variable change suggestions. Should be noted here that within the simulation tool, a more extensive number of variables and combinations could have been tested on performance impact.

As the values indicate (per parameter change) not all of them have a desired contribution to the energy performances of the area. Change 1, however slightly, increases energy consumption. This can be explained by the fact that the improved thermal resistance reduces the energy required for space heating, however, does also increase the energy needed for space cooling, and in this case to a larger extent, as heat is kept inside the building (longer period of overheating in summer). Regarding change 3, the decrease in self-sufficiency might seem odd. Although, explained by the fact that the energy demand for cooling is significantly dropped, especially in the periods where this cooling demand occurred, the share of renewable energy peaks (by PV production). As this renewable energy supply is less consumed by space cooling, the self-sufficiency indicator shows a decrease. Change 4 is left out of scope on purpose for further analysis, as the PV panel standard is likely selected when the area development got designed and does not match current values due to technological development. The results of change 4 are logical, as the total supply shifts upwards, also in periods of only a small renewable energy supply contributing to an increased share of self-sufficiency. Implementation of the current on-market PV panels is likely when the projects get executed.

By change 5, the impact of a more stable renewable energy source added to the public space of this development is shown. Due to the characteristics of the modelled urban wind turbine, the supply of renewable energy massively increases, as does the self-sufficiency. However, thorough analysis also indicates an increased share of energy supplied to the grid (feed-in due to mismatch). The fact that wind is considered a more stable renewable energy source is indicated by the results as well, as the demand peak of external energy demand is reduced (-12.6%).

The positive impact of changes 2, 3 and 5 have been combined to determine the compiled impact, which significantly improves the subcase 2 area self-sufficiency. Analysis of the combined simulation still indicates some oversupply in summer periods (due to PV characteristics). In a second combi simulation, a thermal storage has been added to the subcase 2 area. Although the energy demand drops due to the thermal storage interaction, self-sufficiency does not indicate an improvement.

5.2.3 Analysis - subcase 3

Subcase 3 captures the majority of the dwellings being planned in phase 2 of the *Buitengoed* greenfield development. Due to the tool limit of 5 unique dwelling configurations, phase 2 cannot be completely captured and 5 custom detached dwellings have been skipped from phase 2. The maximum number of similar dwellings has been captured within the boundaries of the current tool. Therefore, the subcase 3 simulation includes 25 dwellings: 4-row houses, 8 semi-detached dwellings (2 configurations) and 13 detached dwellings (2 configurations). Figure 32 indicates the analysed plots.

Again, first, a base simulation run is executed on the delivered initial case data (dashboard plot Appendix I):

- Energy demand: 103,342 kWh
- Energy supply: 71,617 kWh
- Self-sufficiency: 51.2%

A similar conclusion can be drawn in comparison to subcases 1 and 2. Although there is a considerable share of renewable energy supply by own generation within the area (69.3% on an annual basis) this is not reflected in its full extent in the self-sufficiency indicator (51.2%). This does denote a large mismatch, which is meant that self-sufficiency is high in summer periods, although low in winter months with barely renewable energy supply. Of the included dwellings 12 do have a PV installation. Table 7 does indicate some example improvements to the buildings and area to improve energy performances.

Figure 32 - Subcase 3 cut-out

Table 7 – Parameter optimisations examples case study 2 – subcase 3

Potential parameter change	*Key value*	*Impact (relative to base scenario)*
1 – Energy storage *- Adding central battery storage of 100 kWh*	Energy demand	103,342 kWh (-%)
	Energy supply	71,617 kWh (-%)
	Self-sufficiency	65.6% (+14.4%)
2 – Shade control *– adding shade control overall, with a reduction value of 50% when radiation exceeds a threshold of 0.35 kWh/m2*	Energy demand	89,992 kWh (-12.9%)
	Energy supply	71,617 kWh (-%)
	Self-sufficiency	44.0% (-7.2%)
3 – PVT collectors and thermal storage *– adding 2 PVT panels and 400L thermal storage with PHS interaction for every building in the subcase with varying orientations according to roof pitches.*	Energy demand	99,258 kWh (-4.0%)
	Energy supply	88,682 kWh (+23.8%)
	Self-sufficiency	51.9% (+0.7%)
4 – Public renewable energy *– adding one urban wind turbine in public space. I.e.: eocycle EOX S-16, 25 kW capacity, 32m axle height (Eocycle, 2023)*	Energy demand	103,342 kWh (-%)
	Energy supply	130,367 kWh (+82.0%)
	Self-sufficiency	83.8% (+32.6%)
Combi A - 1, 2, 3 & 4 *– thermal storage for space heating and DHW*	Energy demand	73,684 kWh (-28.7%)
	Energy supply	132,483 kWh (+85.0%)
	Self-sufficiency	96.3% (+33.9%)
Combi B - 1, 2, 3 & 4 *– thermal storage for DHW only, no mechanical increase*	Energy demand	85,746 kWh (-17.0%)
	Energy supply	172,699 kWh (+141.1%)
	Self-sufficiency	95.6% (+44.4%)

Table 7 summarizes some potential parameter optimisations upon subcase 3. The results are comparable and in line with the results seen in the previous subcase evaluations. According to the executed combi A simulation, almost 100% self-sufficiency could be achieved by adding thermal collectors, thermal storage, electric storage, shade control and an urban wind turbine. In both simulations, the ground source heat pumps, being the primary heating system (Dura Vermeer, 2022), are deployed to increase the thermal storage temperature when there is an oversupply of renewable electricity. In the combi A simulation, this thermal storage is used for space heating and domestic hot water interaction, in the combi B scenario the thermal storage is only used for domestic hot water preheating. The primary heating system(s) is then also not deployed for interaction with the thermal storage. Oversupply of energy will not be transferred into thermal energy to be buffered.

The differences among these simulations can be explained by the functioning of the thermal collectors. The amount of thermal energy they can harvest depends on the temperature difference of the thermal storage, the collector and ambience (section 4.2.2 – formula 10,11 and 12), and is, therefore, larger in the combi B simulation. Both combined simulations do indicate a huge over-dimensioning of renewable energy supply in order to approach area energy self-sufficiency, as can be read out from the grid feed-in. In terms of self-sufficiency this might be a desirable situation, however, in practice, a trade-off will be made among the potential parameter appropriate to change and other aspects of such a situation will be considered like costs and material use.

5.2.4 Energy self-sufficient – subcase 1

Reflecting upon all simulated cases, none of them led to an energy self-sufficient greenfield development, on the suggestive parameter changes. Within this section, subcase 1, which best fitted the tool as explained in section 5.2, will be further evaluated in order to quantify the parameters of an energy-self-sufficient greenfield development. In this case, containing 13 dwellings, as being modelled within subcase 1 already (section 5.2.1). The starting point is again the base scenario of the dwellings in the subcase 1 area with their characteristics, resulting in the following estimates (appendix G):

- Energy demand: 61,272 kWh
- Energy supply: 27,834 kWh
- Self-sufficiency: 43.2%

Next, a couple of parameters have been optimised stepwise in order to reach 100% energy self-sufficiency in the context of subcase 1. The stepwise approach, as applied, followed the three steps from the trias energetica (section 2.2), by saving energy first, ensuring renewable energy sources and efficient use of storage and conversion.

Table 8 - Parameter optimisations in order to achieve 100% self-sufficiency

Potential parameter change	*Key value*	*Impact (relative to base scenario)*
*1 – **Energy saving**: blinds, activation >300W/m2, g-value to 0.2*	Energy demand	51,164 kWh (-16.5%)
	Energy supply	27,834 kWh (-%)
	Self-sufficiency	35.8% (-7.4%)
*2 – **Energy saving:** thermal resistance: - Rc values: + 20% (resp. 4.4, 5.6, 7.6) - U_{window} value: - 20% (0.8) - U_{door} value: - 20% (1.2)*	Energy demand	61,154 kWh (-0.2%)
	Energy supply	27,834 kWh (-%)
	Self-sufficiency	43.8% (+0.6%)
*3 – **Energy supply:** thermal and wind:* - 2x Thermal collector per dwelling *- 1x Urban wind tree; 10.8 kW, approx. axle height 6.5m*	Energy demand	61,272 kWh (-%)
	Energy supply	95,152 kWh (+241.9%)
	Self-sufficiency	75.3% (+32.1%)
*4 – **Energy storage:** - Central battery storage: capacity 8000 kWh (initial fill 3000 kWh) - Central thermal storage: 13m3 (with HP support, initial temperature 13°C)*	Energy demand	60,829 kWh (-0.7%)
	Energy supply	27,834 kWh (-%)
	Self-sufficiency	50.4% (+7.2%)
Combi: 1, 2, 3 & 4	Energy demand	43,690 kWh (-28.7%)
	Energy supply	57,581 kWh (+106.9%)
	Self-sufficiency	100% (+56.8%)

A combination of the suggested parameter measures 1, 2 3 and 4, can make the area within the context of subcase 1, self-sufficient in terms of their energy demand, throughout the whole year.

According to a conventional definition of energy neutral, the area would be energy neutral according to change 3 only, as this definition looks only at the balance of demand and supply on an annual basis, however, the change 3 results do indicate that the area is definitely not energy self-sufficient or neutral when defining this on an hourly resolution, as done within this research (e.g. section 4.4).

From the combined situation can be concluded that there is a major over-dimensioning needed for the battery storage in order to achieve the stage of self-sufficiency. Other parameter change configurations have been tested and analysed as well with a 100% self-sufficient aim. What can be concluded from this analyse is the fact that the capacity of energy storage can only be reduced notably when stable renewable sources are added to the area. However, the occurrence of oversupply cannot be prevented either, when adding stable renewable sources such as urban wind trees. Scaling the area could help here, in order to find a good matching capacity to the relevant energy demand.

In the case of only relying on PV energy in an energy-neutral development, in combination with a smaller 500 kWh battery, the addition of >1500 m^2 of PV surface in the public space would be needed with varying orientations to match the energy demand throughout the year. This setup is even more over-dimensioned and does contribute to the increase of the grid congestion, as such PV field has an enormous oversupply of solar energy during summer months, and cannot fulfil energy demand in winter months, mismatch. In general, an energy self-sufficient area cannot solely rely on PV energy supply without the installation of oversized energy storage.

This page is intentionally left blank

6 Discussion: tool evaluation

Evaluation of the tool has been collected by different means and during different phases. A distinction has been made regarding the structure of this chapter in, tool development evaluation and an evaluation of the conducted case studies in Chapter 5.

6.1 Tool development evaluation

The development process of the tool has been described in Chapter 4. The involvement of experts and consulted literature have resulted in the tool version as has been used for the case study analysis in Chapter 5. In this section, the tool development process will be evaluated.

Modelling choices and calculation methods have been evaluated and tested by experts and users throughout the development process. These inputs led to the consideration of modelling choices and calculation methods, intending to increase the tool's features, extensiveness and of most importance the performances. So did an early tool version consider the use of proportional research shares of energy consumption and regression methodologies as being estimates for the energy demand components as identified within the literature. Although, regressions from studies and papers were reviewed as incomplete or unsuitable, as additional regressions cannot cope with the amount of detail desired within the tool and do reason from historic data which makes it difficult to model new technological development and situations. However, regressions did show the relevance and impact of variables. The evaluation of existing regressions and proportional shares did therefore contribute to the identification process of relevant variables and initiated the search into more specific calculation methods for energy modelling.

For the computation of energy demand for space heating and space cooling, the degree day method allowed to model indoor temperature comfort in relation to outdoor temperature data. Degree day refers to a Δ temperature between outdoor and a desired indoor temperature and is direct input for the calculation of heat losses along an object's surfaces. This way of modelling has remained within the current tool and has been linked to an indoor temperature balance, indicating the demand for heating and cooling, and the uncorrected quantities. Uncorrected quantities are specified by COP values, coefficient of performance. These values are specific for each type of heating and cooling system. In the first instance, a year-round estimate value had been used. However, the COP is strongly dependent on the outdoor temperature, in order to add more detail to the model, especially as this is running on an hourly resolution, a method to compute hourly COP values for different heat and cooling sources has been integrated.

Additional detailing has been put into the underlying datasets of the tool upon the advice of experts in the field of building physics. 10-yearly averaged climate data have been used instead of a single-year dataset to compute heat demand, cool demand, radiation, solar energy and wind energy potential. Initial datasets did indicate very typical profiles which stretches the uncertainty and inaccuracy for generally applicable modelling.

Discussion of early tool version performance with the experts did stress the breakdown of transparent surfaces relative to their orientation, in order to model with high accuracy, as window orientation and window surface become more relevant according to the radiation, and therefore important variables within energy-oriented design. Furthermore, quick building analysis with an early tool version did indicate the major contribution of radiation to building temperature increase. A positive aspect within periods of space heating demand, however, a negative aspect in periods when this contributes to overheating and generates additional cooling demand. New model features have been integrated upon advice to account for this: shade control, heat recovery and dynamic ventilation as well as a more extensive cooling component linked to indoor temperature modelling.

The tool has been aimed at applicability in the early design stages of greenfield developments. Feedback on projects in the early design stages did validate the usability of the tool in these stages. Nevertheless, some included parameters, predominantly the orientation of buildings already have limited design freedom within an early design stage. Such aspect is already captured in an even earlier (before design) stage, spatial plan development. Although, a spatial planning phase does not contain any specific information on building parameters. Modelling in such a spatial plan development stage then mostly rests on assumptions which do not improve the accuracy and performance of the simulation. To come across this issue and make the tool usable in both stages, the inclusion of predefined building types was suggested. These predefined building types have been composed out of national data registers and comply with the Dutch building code as only greenfield developments are considered.

The development of the tool has been executed stepwise, by testing and evaluating the performances of separate components before being added to validated parts of the tool. The tool development process was completed by a final series of troubleshooting, a complete rebuilding of the model, dashboard building, a walkthrough with an expert and another series of troubleshooting.

6.2 Case study evaluation

In Chapter 5, the tool has been evaluated with two different cases and subcases, both at different stages within area development. Lessons learned from the case studies indicate once more that the development process of a tool is an iterative process. The case studies pointed out valuable insights on how the tool can be used in practice, as well as the limitations of the tool in the context of the case studies giving direction for further improvement and development of the tool.

As the current tool results are presented in the dashboard, the case studies showed that in some specific cases, even more important results can be collected from the tool to better evaluate building and area designs, instead of only the stated energy demand, supply and the level of self-sufficiency or other graph data which can be directly read out from the dashboard, for example, the heating demand to cooling demand ratio of building types. This information can be retrieved from the computed data, however, was not affixed to the dashboard. The introduction of a second dashboard, for more in-depth information and results, could enhance this, especially when the dashboard is dedicated to specific users, for example, a general dashboard (as made), a building dashboard (dedicated to building physics experts and architects) and an area dashboard (for spatial planners, urban designers and energy specialists).

The model capacity of five unique parameter sets or dwelling types has been noted as a serious limitation within the tool, due to the software and time scope for this thesis. Extending the tool in order to handle more building types within a single simulation could be achieved within the same system architecture, although has not been managed due to time restrictions and the performances of the software in the development mode, the extension asks for a serious extensive update on the model. However, in a next version of the tool it is suggested to extend the number of building types for a single simulation at least to 10 unique types, perhaps also in a stand-alone version.

The availability of case studies has been a challenge for this research. Case study 1 is in the spatial planning stage, but it already has elaborated dwellings types based on estimates and key values. Case study 2 is already in the pre-construction phase, and so consists of fully elaborated dwellings as well. Both cases lend themselves to be tested in the tool in the general energy aspect, although not up to all parameters, as both the dwellings are fully detailed. It would be interesting to additional test the model in a case study, along the design process, where dwelling types are being designed within an area development, and the tool can really fulfil the aim of energy-oriented design, with the main aspects of window orientation and sizing.

Nevertheless, evaluating the two case studies with the developed tool did suggest some building and area changes to achieve a higher level of self-sufficiency, the reduction of energy demand and a more optimised utilization of renewable energy sources. Especially the addition of energy supply and communal storage systems are measures which can still be applied in both cases, taking into account permits and legislations of design being submitted and granted already. In particular, the application of shade control could be a simple measure to reduce the energy demand component, without asking for major changes or procedures.

In that way, the tool did where it was intended for, gaining insights into the energy performance of a greenfield development and evaluating potential optimisations along the buildings and the area being simulated, deployable during the planning and (early) design phases.

This page is intentionally left blank

7 Conclusion

The last chapter of this research will focus on the lessons learned and the extent to which the research has been able to answer the research questions. Furthermore, will be discussed how the tool contributes in a societal and scientific way as well as recommendations for future tool development and research.

Building characteristics have an important role in the estimation of residential energy consumption. Next to this, the role of the residents and their behaviour does have a substantial role in the energy consumption and therefore energy demand of dwellings. Within the tool, variables are included to take this behaviour into account by asking about behavioural characteristics as far as they may already be known at the time this tool is deployed. The number of occupants is also strongly determining the energy consumption for hot water and domestic energy use. Other variables identified by research and therefore included in the tool for defining energy demand are building envelope-related parameters like surfaces, windows, doors and their technical specifications, as also the present building systems that ensure ventilation, heating, cooling and domestic hot water.

For the quantification of energy supply in area developments, three types of renewable sources have been identified being market-ready solutions for implementation in the public and or private domain of greenfield developments: photovoltaic panels, thermal collectors and wind turbines. Variables underlying these renewable sources are included to model any of these sources into a general context and size, these are location (determining radiation and windspeed), orientation, angle and axle height (for wind modelling only). Next to the renewable energy sources, also other types of energy supply have been identified in the research and included in the tool, internal gains (due to occupancy, lighting and appliances) and irradiance mainly through translucent surfaces.

The modelling result did indicate a severe impact of radiation on indoor building temperature, with a high chance to cause overheating. Especially the modelling of properly insulated buildings (in accordance with the building code or better) did show that the demand for space cooling can even exceed the space heating energy demand. Energy-oriented design should therefore give appropriate attention to design and building solutions preventing overheating and reducing space cooling energy and not only focus on energy consumption for space heating, formerly common scope. Passive solutions are preferred here over mechanical solutions, due to their energy consumption pointing out energy neutrality.

The third research sub-questions, targeted towards the potential of energy storage on a communal level have been modelled into the tool by two market-ready energy storage options. For the short-term storage cycle, a battery can be dimensioned within the model, and for the long-term, the options for thermal energy storage have been incorporated. Interaction between these two storage cycles can be enabled upon users' scenario choice. Concluded from the model evaluation and the case studies is the serious contribution of energy storage to the mismatch between energy demand and renewable energy supply. Especially short-term energy storage does boost self-sufficiency in the area context. Long-term storage has large potential as well, although shows more complexity and implementation is less accessible. The potential is redeemed given some pre-conditions towards renewable energy supply and building-related installations. However, concluding from the tool, energy storage has undoubtedly potential towards energy self-sufficiency of areas and the energy transition.

Towards the involvement and interests of stakeholders, a distinction between policymakers, designers and developers can be made. Dominantly, the involvement of designers and developers has been highlighted within this research, as the tool was introduced as a design support decision and evaluation tool. Policy, especially regarding sustainability and energy transition legislation, designs and areas can be tested on the fulfilment of requirements and ambitions with the tool. The tool does show that alignment of energy demand, supply and the addition of energy storage can lead to a substantial increase of energy self-sufficiency in areas and therefore contribute to the solution towards the energy transition and grid congestion. A precondition in order to get communal energy storage, energy-neutral areas and a high level of energy self-sufficiency actually implemented is the legalisation of mutual exchange of energy among different plots.

The parameters identified in the sub-questions did result in the development of a tool able to test the energy self-sufficiency of a greenfield area development, on hour resolution, along the components of demand, supply and storage. Testing the tool with case studies did show that the tool is able to bridge that gap towards the practice and provides guidance toward the implementation of the energy transition and sustainability goals into the built environment, in specific greenfield residential developments, by area modelling on hour level.

7.1 Scientific and societal relevance

The research carried out has been initiated from a national and global climate change approach. The proportion of the built environment in this change is widely recognized. And from the available knowledge and expertise, the researcher seeks to contribute to improvement by developing a tool that analyses energy efficiency down to its roots in new area developments, which can still be shaped and thereby enables the implementation of new approaches.

Performance indicators, by tool evaluation on such new area development, do indicate the total energy demand, total renewable energy supply and in per cent how many hours within a year the area can be self-sufficient in its energy demand, contrary to a conventionally used definition of energy neutral on an annual base which is not conclusive. The variables being input for the performance calculations can be filled in according to plans already made or expectations. Variable changes can be made according to the plan evaluation and performance on the indicators, which does allow to test if a specific variable change does give the desired result.

This research has tried to bridge the gap between science and practice in the field of area development, energy planning and energy transition, by developing a tool coping these topics, from a scientific perspective. The developed tool is able to support the design decision process towards hourly energy self-sufficient greenfield development covering energy demand, production and storage**.** Broad-based implementation of the tool should result in future area developments with energy-optimized architectural designs, which consume less energy and perform better on energy efficiency, or ideally fully self-sufficient or even energy positive. In turn, they then contribute to a more emission-free, cleaner and hopefully better world.

7.2 Future directions of research

From the conducted research and the limitation dealt with, recommendations for further research into urban energy modelling and tool development can be framed, in specific the further development of the proposed tool.

The time constraint of this research did force to stop the development of the tool at some point. Although, as argued an inclusive tool could have been delivered in the available time, it is suggested to expand the model with other available storage and renewable energy solutions, although not being market ready or deemed feasible in studies. Technological development can have an impact on this, especially as the model is orientated towards future developments, it is important to keep state-of-the-art technology aligned within the tool. However, it is currently not possible to indicate to what extent the tools' system architecture needs changes upon future available technologies. What can be stated upon this, is the fact that performance improvements of currently integrated technologies or the incorporated profiles can be refreshed with new data, either by changing values along the parameter or assumption sheet of inserting a specific user profile.

Extending the model towards more capacity, in terms of unique parameter sets and types within a single simulation run, is recommended in order to ensure the wide applicability of the tool in Dutch area developments. What should be reconsidered is the software package, currently a spreadsheet, into, for example, a web viewing tool running on Python script. As it is expected that the current spreadsheet approach will reach its capacity and result in longer development and calculation times. The easy interface of the spreadsheet approach should in that case still trade-off the calculation times, as the used spreadsheet approach is very common and deemed user-friendly through its wide-scale use. This tool is limited to the simulation range of a single year, this does mean that initial values had to be assumed for some parts of the model, for example, the storage fill levels. Multi-year simulation might help in identifying appropriate initial values as well as scenario analysis on the dimensioning of systems.

The delivered tool did only look into the energy efficiency aspect in terms of energy quantity. To increase the relevance and broad-based introduction of the tool, energy-oriented design could be supported by initial and long-term costs and investment propositions. Design decisions on for example passive and active solutions of space cooling could then be better framed and substantiated when considering the energetic impact as well as the cost aspect. Especially when regarding costs, the link towards grid congestion and the energy market from the tool perspective does frame an interesting topic for future research and model extensions. Interaction of (almost) self-sufficient energy communities (microgrids) with the grid might lead to conclusive business cases, considering the feed-in of energy into the grid in case of undersupply and extraction of energy in case of oversupply, to temporarily store energy locally or increase energy storage fill-levels for the longer term. Also, the expansion towards mobility and electric vehicles also offers interesting opportunities, given the expected impact on both energy demand and energy storage.

This page is intentionally left blank

References

4TU. (2021). *Graduation Guide CME* (Vol. 1.14).

Abbenhuis, M., Jetten, R., & RTL Z. (2022). Het stroomnet zit vol: hoe kan dat, en hoe erg is het? Retrieved from https://www.rtlnieuws.nl/economie/artikel/5314115/stroomnet-tennet-verstopping-brabant-limburg-wat-er-aan-de-hand

Agentschap NL, & Rijksdienst voor Ondernemend Nederland. (2012). *GebiedsEnergieTool en financiële arrangementen*.

Ahmed, K., Pylsy, P., & Kurnitski, J. (2016). Hourly consumption profiles of domestic hot water for different occupant groups in dwellings. *Solar Energy*, *137*, 516–530. https://doi.org/10.1016/j.solener.2016.08.033

Alders, N. (2016). *Adaptive Thermal Comfort opportunities for dwellings: Providing thermal comfort only when and where needed in Dwellings in the Netherlands*. *A+BE Architecture and the Built Environment* (Vol. 13). https://doi.org/10.7480/abe.2016.13

Allegrini, J., Orehounig, K., Mavromatidis, G., Ruesch, F., Dorer, V., & Evins, R. (2015). A review of modelling approaches and tools for the simulation of district-scale energy systems. *Renewable and Sustainable Energy Reviews*, *52*, 1391–1404. https://doi.org/10.1016/j.rser.2015.07.123

American Enterprise Institute, & Zycher, B. (2019). The trouble with “renewable” energy. Retrieved from https://www.aei.org/articles/the-trouble-with-renewable-energy/

Architecture Workroom Brussels, & LABO ruimte. (n.d.). Ruimte voor de energie transitie.

Asadi, S., Amiri, S. S., & Mottahedi, M. (2014). On the development of multi-linear regression analysis to assess energy consumption in the early stages of building design. *Energy and Buildings*, *85*, 246–255. https://doi.org/10.1016/j.enbuild.2014.07.096

Baldukhaeva, I. I., Baldynova, A. A., Erbaeva, L. L., & Zudaeva, V. V. (2021). Hydrogen technologies in the energy supply system of the housing and communal sector. *IOP Conference Series: Earth and Environmental Science*. https://doi.org/10.1088/1755-1315/751/1/012113

Bartolini, A., Carducci, F., Muñoz, C. B., & Comodi, G. (2020). Energy storage and multi energy systems in local energy communities with high renewable energy penetration. *Renewable Energy*, *159*, 595–609. https://doi.org/10.1016/j.renene.2020.05.131

Bedir, M., Hasselaar, E., & Itard, L. (2013). Determinants of electricity consumption in Dutch dwellings. *Energy and Buildings*, *58*, 194–207. https://doi.org/10.1016/j.enbuild.2012.10.016

Belussi, L., Barozzi, B., Bellazzi, A., Danza, L., Devitofrancesco, A., Fanciulli, C., … Scrosati, C. (2019). A review of performance of zero energy buildings and energy efficiency solutions. *Journal of Building Engineering*, *25*(March), 100772. https://doi.org/10.1016/j.jobe.2019.100772

Berenschot. (2022). *Provincie Limburg Energieopslag en – conversie*.

Borsboom, W. A., Mossallam, B. E., & Van Der Linden, R. J. P. (2022). Reducing peak load of renewable energy at district level with predictive twins. *IOP Conference Series: Earth and Environmental Science*, *1085*(1), 9DUMMY. https://doi.org/10.1088/1755-1315/1085/1/012007

Bosseboeuf et al. (2015). Energy Efficiency Trends and Policies in the Household and Tertiary Sectors, (June), 97. Retrieved from https://www.odyssee-mure.eu/publications/archives/energy-efficiency-trends-policies-buildings.pdf

Bouw, K., Noorman, K. J., Wiekens, C. J., & Faaij, A. (2021). Local energy planning in the built environment: An analysis of model characteristics. *Renewable and Sustainable Energy Reviews*, *144*(April). https://doi.org/10.1016/j.rser.2021.111030

Bouwfysica Kennisbank, & van der Linden, A. C. (2005). Zonwering, 1–16.

Brown, T., Schlachtberger, D., Kies, A., Schramm, S., & Greiner, M. (2018). Synergies of sector coupling and transmission reinforcement in a cost-optimised, highly renewable European energy system. *Energy*. https://doi.org/10.1016/j.energy.2018.06.222

Budischak, C., Sewell, D., Thomson, H., Mach, L., Veron, D. E., & Kempton, W. (2013). Cost-minimized Combinations of wind, solar and storage powering the grid up 99.9% of time. *Journal of Power Sources 225*. https://doi.org/http://dx.doi.org/10.1016/j.jpowsour.2012.09.054

Catalina, T., Iordache, V., & Caracaleanu, B. (2013). Multiple regression model for fast prediction of the heating energy demand. *Energy and Buildings*, *57*, 302–312. https://doi.org/10.1016/j.enbuild.2012.11.010

Catalina, T., Virgone, J., & Blanco, E. (2008). Development and validation of regression models to predict monthly heating demand for residential buildings. *Energy and Buildings*, *40*(10), 1825–1832. https://doi.org/10.1016/j.enbuild.2008.04.001

Centraal Bureau voor de Statistiek. (n.d.). Welke sectoren stoten broeikasgassen uit. Retrieved from https://www.cbs.nl/nl-nl/dossier/dossier-broeikasgassen/welke-sectoren-stoten-broeikasgassen-uit-#:~:text=In 2020 werd van de,het stoken van aardgas voor

Centraal Bureau voor de Statistiek. (2020). Energieverbruik particuliere woningen; woningtype en regio's. Retrieved from https://www.cbs.nl/nl-nl/cijfers/detail/81528NED

Centraal Bureau voor de Statistiek. (2021). Hernieuwbare Energie in Nederland 2020. Retrieved from https://www.cbs.nl/nl-nl/longread/aanvullende-statistische-diensten/2021/hernieuwbare-energie-in-nederland-2020?onepage=true#c-4--Windenergie

Centraal Bureau voor de Statistiek. (2022a). Aandeel hernieuwbare elektriciteit met 20 procent gestegen in 2022. Retrieved from https://www.cbs.nl/nl-nl/nieuws/2023/10/aandeel-hernieuwbare-elektriciteit-met-20-procent-gestegen-in-2022

Centraal Bureau voor de Statistiek. (2022b). SDG 13 Klimaatactie. Retrieved from https://www.cbs.nl/nl-nl/dossier/brede-welvaart/monitor-brede-welvaart-sustainable-development-goals-2022/sdg-s/sdg-s/sdg-13-klimaatactie

Chen, H., Cong, T. N., Yang, W., Tan, C., Li, Y., & Ding, Y. (2009). Progress in electrical energy storage system: A critical review. *Progress in Natural Science*, *19*(3), 291–312. https://doi.org/10.1016/j.pnsc.2008.07.014

Clashen, A., & Lever, H. (2022). Bouwend Nederland wil voorrang woningbouw bij aansluiting elektriciteitsnet. Retrieved from https://fd.nl/economie/1452884/bouwend-nederland-wil-voorrang-woningbouw-bij-aansluiting-elektriciteitsnet-nnd3catd4Rjw

Coakley, D., Raftery, P., & Keane, M. (2014). A review of methods to match building energy simulation models to measured data. *Renewable and Sustainable Energy Reviews*, *37*, 123–141. https://doi.org/10.1016/j.rser.2014.05.007

Comodi, G., Giantomassi, A., Severini, M., Squartini, S., Ferracuti, F., Fonti, A., … Polonara, F. (2015). Multi-apartment residential microgrid with electrical and thermal storage devices: Experimental analysis and simulation of energy management strategies. *Applied Energy*, *137*, 854–866. https://doi.org/10.1016/j.apenergy.2014.07.068

Crawley, D. B., Hand, J. W., Kummert, M., & Griffith, B. T. (2008). Contrasting the capabilities of building energy performance simulation programs. *Building and Environment*, *43*(4), 661–673. https://doi.org/10.1016/j.buildenv.2006.10.027
Cuerda, E., Guerra-Santin, O., Sendra, J. J., & Neila González, F. J. (2019). Comparing the impact of presence patterns on energy demand in residential buildings using measured data and simulation models. *Building Simulation*, *12*(6), 985–998. https://doi.org/10.1007/s12273-019-0539-z
Czétány, L., Vámos, V., Horváth, M., Szalay, Z., Mota-Babiloni, A., Deme-Bélafi, Z., & Csoknyai, T. (2021). Development of electricity consumption profiles of residential buildings based on smart meter data clustering. *Energy and Buildings*, *252*. https://doi.org/10.1016/j.enbuild.2021.111376
De Pascali, P., & Bagaini, A. (2019). Energy transition and urban planning for local development. A critical review of the evolution of integrated spatial and energy planning. *Energies*, *12*(1), 1–21. https://doi.org/10.3390/en12010035
de Vree, J. (n.d.). COP waarde. Retrieved from https://www.joostdevree.nl/shtmls/cop-waarde.shtml
Dunn, B., Kamath, H., & Tarascon, J. M. (2011). Electrical energy storage for the grid: A battery of choices. *Science*, *334*(6058), 928–935. https://doi.org/10.1126/science.1212741
Dura Vermeer. Buitengoed Heiloo (2022).
ECA. (2018). Renewable energy for sustainable rural development: significant potential synergies, but mostly unrealised., *287*(05), 93. Retrieved from https://www.eca.europa.eu/Lists/ECADocuments/SR18_05/SR_Renewable_Energy_EN.pdf
Ecovat. (2023). Ecovat. Retrieved from https://www.ecovat.eu/over-ecovat/werkingsprincipe-energie-opslag/
Eocycle. (2023). Windturbines en microgrids. Retrieved from https://eocycle.com/nl/
Ferrari, S., Zagarella, F., Caputo, P., & Bonomolo, M. (2019). Assessment of tools for urban energy planning. *Energy*, *176*, 544–551. https://doi.org/10.1016/j.energy.2019.04.054
Firth, S., Lomas, K., Wright, A., & Wall, R. (2008). Identifying trends in the use of domestic appliances from household electricity consumption measurements. *Energy and Buildings*, *40*(5), 926–936. https://doi.org/10.1016/j.enbuild.2007.07.005
Fleischhacker, A., Lettner, G., Schwabeneder, D., & Auer, H. (2019). Portfolio optimization of energy communities to meet reductions in costs and emissions. *Energy*, *173*, 1092–1105. https://doi.org/10.1016/j.energy.2019.02.104
Fumo, N., & Rafe Biswas, M. A. (2015). Regression analysis for prediction of residential energy consumption. *Renewable and Sustainable Energy Reviews*, *47*, 332–343. https://doi.org/10.1016/j.rser.2015.03.035
Giuseppina, C., & D'Amico, A. (2019). Building energy performance forecasting: A multiple linear regression approach. *Applied Energy*, *253*(November). https://doi.org/10.1016/j.apenergy.2019.113500
Goodenough, J. B., & Manthiram, A. (2014). A perspective on electrical energy storage. *MRS Communications*. https://doi.org/10.1557/mrc.2014.36
Guerra-Santin, O., & Silvester, S. (2017). Development of Dutch occupancy and heating profiles for building simulation. *Building Research and Information*, *45*(4), 396–413. https://doi.org/10.1080/09613218.2016.1160563
Guerra-Santin, Olivia, & Itard, L. (2010). Occupants' behaviour: Determinants and effects on

residential heating consumption. *Building Research and Information*, *38*(3), 318–338. https://doi.org/10.1080/09613211003661074
Guerra, O. J., Zhang, J., Eichman, J., Denholm, P., Kurtz, J., & Hodge, B. M. (2020). The value of seasonal energy storage technologies for the integration of wind and solar power. *Energy and Environmental Science*, *13*(7), 1909–1922. https://doi.org/10.1039/d0ee00771d
Gür, T. M. (2018). Review of electrical energy storage technologies, materials and systems: Challenges and prospects for large-scale grid storage. *Energy and Environmental Science*. https://doi.org/10.1039/c8ee01419a
Hansen, K., Breyer, C., & Lund, H. (2019). Status and perspectives on 100% renewable energy systems. *Energy*, *175*, 471–480. https://doi.org/10.1016/j.energy.2019.03.092
Heurkens, E. (2018). Succesvol energiebeleid in gebiedsontwikkeling vereist pionierswerk. Retrieved from https://www.gebiedsontwikkeling.nu/artikelen/succesvol-energiebeleid-gebiedsontwikkeling-vereist-pionierswerk
Hevner, A. R. (2007). A Three Cycle View of Design Science Research. *Scandinavian Journal of Information Systems*, *19*(2), 87–92.
Hoes, P.-J. (2014). *Computational performance prediction of the potential of hybrid adaptable thermal storage concepts for lightweight low-energy houses*. *Bouwstenen*. Retrieved from http://dx.doi.org/10.1016/j.solener.2015.12.020
Hoffman, J., Akkerboom, S., Harmsen, R., de Jongh, P., Schram, W., van Sark, W., … Kouwen, M. (n.d.). Energie van de toekomst. Retrieved from https://www.uu.nl/organisatie/verdieping/energie-van-de-toekomst
Hong, T., Chen, Y., Lee, S. H., Piette, M. P., Chen, Y., & Piette, M. P. (2019). CityBES: A Web-based Platform to Support City-Scale Building Energy Efficiency environment. *Urban Integrated System*, (August), 107–111.
Hong, T., Chen, Y., Luo, X., Luo, N., & Lee, S. H. (2020). Ten questions on urban building energy modeling. *Building and Environment*, *168*(August 2019), 106508. https://doi.org/10.1016/j.buildenv.2019.106508
Huang, Z., Yu, H., Peng, Z., & Zhao, M. (2015). Methods and tools for community energy planning: A review. *Renewable and Sustainable Energy Reviews*, *42*(4800), 1335–1348. https://doi.org/10.1016/j.rser.2014.11.042
Hygh, J. S., DeCarolis, J. F., Hill, D. B., & Ranji Ranjithan, S. (2012). Multivariate regression as an energy assessment tool in early building design. *Building and Environment*, *57*, 165–175. https://doi.org/10.1016/j.buildenv.2012.04.021
Ioannou, A., & Itard, L. C. M. (2015). Energy performance and comfort in residential buildings: Sensitivity for building parameters and occupancy. *Energy and Buildings*, *92*, 216–233. https://doi.org/10.1016/j.enbuild.2015.01.055
IPCC. (n.d.). *Global Warming of 1.5 ºC*. Retrieved from https://www.ipcc.ch/sr15/
ISSO. KennisKaart 208 Gebruikersprofielen voor bepaling grootte energieopslagsystemen voor woningen.
ISSO. (n.d.-b). *Ontwerpen van gebouwen met een thuisaccu*.
ISSO. (n.d.-c). ThemaTech 25 Energieneutraal bouwen.
ISSO. (1975). Zontoetredingsfactoren. Rotterdam.
ISSO. (2017). *Warmteverliesberekening voor woningen en woongebouwen*.
ISSO. (2019). *Handboek HBze Zonne-energie*.
ISSO. (2020). *EnergieVademecum: Energiebewust ontwerpen van nieuwbouwwoningen*.
Iwell. (2023). Battery storage.

J. Gerdes, S. Marbus, M. B. (2014). *Energietrends*. ECN, Energie-Nederland, Netbeheer Nederland.
Jablonska, B., Ruijg, G., & Willems, E. (2011). Innovatieve energieconcepten en pilots voor de energieneutrale gebiedsontwikkeling in 2050. *ECN Rapport E--10-071, …*. Retrieved from https://www.ecn.nl/publications/PdfFetch.aspx?nr=ECN-E--10-071
Jun, G. T., Morris, Z., Eldabi, T., Harper, P., Naseer, A., Patel, B., & Clarkson, J. P. (2011). Development of modelling method selection tool for health services management: From problem structuring methods to modelling and simulation methods. *BMC Health Services Research*, *11*(1), 108. https://doi.org/10.1186/1472-6963-11-108
Kapur, A. (2022). Evaluating Energy Storage Systems for Renewable Energy Integrated Urban Community Microgrids. *ECS Transactions*, *107*(1), 1981–2001. https://doi.org/10.1149/10701.1981ecst
KNMI. (n.d.). KNMI - weerstations - uurwaarnemingen. Retrieved from https://daggegevens.knmi.nl/klimatologie/uurgegevens
Kock, R. (2013). *Elektriciteitsopslag: rendabel of niet?* Eindhoven University of Technology.
Koirala, B. P., Koliou, E., Friege, J., Hakvoort, R. A., & Herder, P. M. (2016). Energetic communities for community energy: A review of key issues and trends shaping integrated community energy systems. *Renewable and Sustainable Energy Reviews*, *56*, 722–744. https://doi.org/10.1016/j.rser.2015.11.080
Koirala, B. P., van Oost, E., & van der Windt, H. (2018). Community energy storage: A responsible innovation towards a sustainable energy system? *Applied Energy*, *231*(September), 570–585. https://doi.org/10.1016/j.apenergy.2018.09.163
Kok, S. A., & DNV-GL. (2019). *Self-sufficient energy systems: a scenario analysis of key design decisions for a small-scale agricultural community*. University of Groningen, Newcastle University.
Koohi-Fayegh, S., & Rosen, M. A. (2017). Optimization of seasonal storage for community-level energysystems: status and needs. *Energ. Ecol. Environ.* https://doi.org/DOI 10.1007/s40974-017-0051-1
Lämmle, M., Oliva, A., Hermann, M., Kramer, K., & Kramer, W. (2017). PVT collector technologies in solar thermal systems: A systematic assessment of electrical and thermal yields with the novel characteristic temperature approach. *Solar Energy*, *155*(October 2017), 867–879. https://doi.org/10.1016/j.solener.2017.07.015
Langer, L., & Volling, T. (2020). An optimal home energy management system for modulating heat pumps and photovoltaic systems. *Applied Energy*, *278*(August), 115661. https://doi.org/10.1016/j.apenergy.2020.115661
Li, X., & Wen, J. (2014). Review of building energy modeling for control and operation. *Renewable and Sustainable Energy Reviews*, *37*, 517–537. https://doi.org/10.1016/j.rser.2014.05.056
Lubina, P., & Nantka, M. (2009). Internal heat gains in relation to the dynamics of buildings heat requirements. *Architecture Civil Engineering Environment*, *2*, 137–142.
Lund University, Davidsson, H., Perers, B., & Karlsson, B. (2012). *System analysis of a multifunctional PV/T hybrid solar window*. *Solar Energy* (Vol. 86). https://doi.org/10.1016/j.solener.2011.12.020
Luo, X., Wang, J., Dooner, M., & Clarke, J. (2015). Overview of current development in electrical energy storage technologies and the application potential in power system operation. *Applied Energy*. https://doi.org/10.1016/j.apenergy.2014.09.081
Luthander, R., Widén, J., Munkhammar, J., & Lingfors, D. (2016). Self-consumption

enhancement and peak shaving of residential photovoltaics using storage and curtailment. *Energy*, *112*, 221–231. https://doi.org/10.1016/j.energy.2016.06.039

Majcen, D. (2016). *Predicting energy consumption and savings in the housing stock*. Delft University of Technology.

Majcen, D., Itard, L. C. M., & Visscher, H. (2013). Theoretical vs. actual energy consumption of labelled dwellings in the Netherlands: Discrepancies and policy implications. *Energy Policy*, *54*, 125–136. https://doi.org/10.1016/j.enpol.2012.11.008

Majcen, Daša, Itard, L., & Visscher, H. (2015). Statistical model of the heating prediction gap in Dutch dwellings: Relative importance of building, household and behavioural characteristics. *Energy and Buildings*, *105*(2015), 43–59. https://doi.org/10.1016/j.enbuild.2015.07.009

Malhotra, A., Bischof, J., Nichersu, A., Häfele, K. H., Exenberger, J., Sood, D., … Schweiger, G. (2022). Information modelling for urban building energy simulation—A taxonomic review. *Building and Environment*, *208*(June 2021), 108552. https://doi.org/10.1016/j.buildenv.2021.108552

Martakis, A. (2015). *Framework for Enterprise Uncertainty-Driven Decision - Making*. University of Twente. https://doi.org/10.13140/RG.2.1.3578.2165

McKenna, R., Merkel, E., & Fichtner, W. (2017). Energy autonomy in residential buildings: A techno-economic model-based analysis of the scale effects. *Applied Energy*, *189*, 800–815. https://doi.org/10.1016/j.apenergy.2016.03.062

McKinsey&Company, Roelofsen, O., de Pee, A., & Speelman, E. (2016). *Versnellen van de energietransitie: kostbaar of kansrijk?* Retrieved from https://www.mckinsey.com/~/media/mckinsey/featured insights/europe/accelerating the energy transition cost or opportunity/versnellen van de energietransitie.pdf

Mendes, G., Ioakimidis, C., & Ferrão, P. (2011). On the planning and analysis of Integrated Community Energy Systems: A review and survey of available tools. *Renewable and Sustainable Energy Reviews*, *15*(9), 4836–4854. https://doi.org/10.1016/j.rser.2011.07.067

Mengelkamp, E., Garttner, J., & Weinhardt, C. (2017). The role of energy storage in local energy markets. *International Conference on the European Energy Market, EEM*. https://doi.org/10.1109/EEM.2017.7981906

Ministerie van Binnenlandse Zaken. (2010). DPL - duurzaamheidsprofiel van een locatie, (juni), 1–3.

Ministerie van Binnenlandse Zaken en Koninkrijksrelaties. (2022a). *Beleidsprogramma versnelling verduurzaming gebouwde omgeving*.

Ministerie van Binnenlandse Zaken en Koninkrijksrelaties. (2022b). Wat is het doel van het klimaatakkoord? Retrieved from https://www.klimaatakkoord.nl/klimaatakkoord/vraag-en-antwoord/wat-is-het-doel-van-het-klimaatakkoord

Ministerie van Economische Zaken en Klimaat. (2021). Wat is het klimaatakkoord? Retrieved from https://www.rijksoverheid.nl/onderwerpen/klimaatverandering/klimaatakkoord/wat-is-het-klimaatakkoord

Moreau, A. (2011). Control strategy for domestic water heaters during peak periods and its impact on the demand for electricity. *Energy Procedia*, *12*(December 2011), 1074–1082. https://doi.org/10.1016/j.egypro.2011.10.140

Murray, P., Orehounig, K., Grosspietsch, D., & Carmeliet, J. (2018). A comparison of storage

systems in neighbourhood decentralized energy system applications from 2015 to 2050. *Applied Energy*, *231*(May 2018), 1285–1306. https://doi.org/10.1016/j.apenergy.2018.08.106
Nederlandse technische afspraak, & Koninklijk Nederlands Normalisatie Instituut. (2022). *NTA 8800:2022*. *ICS 91/120.10:91.140.30*.
NEDU, & Pure Energie. (n.d.). Procentuele verdeling jaarlijks stroom- en gasverbruik in Nederlands. Retrieved from https://www.google.com/url?sa=i&url=https%3A%2F%2Fpure-energie.nl%2Fkennisbank%2Finvloed-seizoenen-op-energieverbruik%2F&psig=AOvVaw3vOTyJajGpM_xAscqtDaWp&ust=1682444171400000&source=images&cd=vfe&ved=0CBEQjRxqFwoTCLDQ55GHw_4CFQAAAAAdAAAAABAD
New World Wind. (2023). WindTree. Retrieved from https://www.newworldwind.com/windtree
Nibud, & Vattenfall. (2021). Gemiddeld energieverbruik. Retrieved from https://www.vattenfall.nl/energie/gemiddeld-energieverbruik/
NOS, Stigter, E., & Nijpels, E. (2022). Grote problemen op stroomnet, provincies willen kiezen wei aansluiting krijgt. Retrieved from https://nos.nl/artikel/2413833-grote-problemen-op-stroomnet-provincies-willen-kiezen-wie-aansluiting-krijgt
NWEA, NVDE, Londo, M., Blauwbroek, N., & Kooi, K. (2022). *Cohortenmodel Wind op Land*. Retrieved from https://www.nvde.nl/nvdeblogs/nieuwe-rekentool-toekomstige-opbrengst-windenergie-op-land-en-zee-hoger/
Ouf, M. M., O’Brien, W., & Gunay, H. B. (2018). Improving occupant-related features in building performance simulation tools. *Building Simulation*, *11*(4), 803–817. https://doi.org/10.1007/s12273-018-0443-y
Paauw, J., Roossien, B., Aries, M., & Santin, O. G. (2009). Energy Pattern Generator; Understanding the effect of user behaviour on energy systems. *1st European Conference Energy Efficiency and Behaviour*. Retrieved from http://www.ecn.nl/docs/library/report/2009/m09146.pdf
Papachristos, G. (2015). Household electricity consumption and CO2 emissions in the Netherlands: A model-based analysis. *Energy and Buildings*, *86*, 403–414. https://doi.org/10.1016/j.enbuild.2014.09.077
Papaefthymiou, G., & Dragoon, K. (2016). Towards 100% renewable energy systems: Uncapping power system flexibility. *Energy Policy*, *92*, 69–82. https://doi.org/10.1016/j.enpol.2016.01.025
Petersen, J. P., & Heurkens, E. (2018). Implementing energy policies in urban development projects: The role of public planning authorities in Denmark, Germany and the Netherlands. *Land Use Policy*, *76*(May), 275–289. https://doi.org/10.1016/j.landusepol.2018.05.004
Planbureau voor de Leefomgeving, & Ros, J. (2015). *Energietransitie: zoektocht met een helder doel*. Den Haag.
Pleßmann, G., Erdmann, M., Hlusiak, M., & Breyer, C. (2014). Global energy storage demand for a 100% renewable electricity supply. *Energy Procedia*. https://doi.org/10.1016/j.egypro.2014.01.154
Polman, J., & McDonalds, O. (2022). Propvol stroomnet zet streep door klimaatambities van Amsterdam. Retrieved from https://fd.nl/bedrijfsleven/1438356/propvol-elektriciteitsnet-zet-streep-door-klimaatambities-van-amsterdam-nnd3catd4Rjw

Programma Aardgasvrije Wijken. (2020). De opgave waar we voor staan is groot en complex ” Essaybundel over aardgasvrije wijken.
Proka, A. (2017). *Buurtbatterij: A Neighbourhood battery and its impact on the energy transition*.
Pront-van Bommel, S. (2012). Energie-efficiëntie en gebiedsontwikkeling. *Bouwrecht: Documentatieblad Voor Rechtspraak En Literatuur Op Het Stuk van Bouwrecht*. Retrieved from https://dare.uva.nl
Quintel. (2022). Energy Transition Model. Retrieved from https://energytransitionmodel.com/
Ram, K., Swain, P. K., Vallabhaneni, R., & Kumar, A. (2021). Critical assessment on application of software for designing hybrid energy systems. *Materials Today: Proceedings*, *49*, 425–432. https://doi.org/10.1016/j.matpr.2021.02.452
Reed, R., & Sims, S. (2015). *Property Development* (6th editio). Routledge.
Regionaal Energieloket. (n.d.). Koelen met een warmtepomp. Retrieved from https://kennisbank.regionaalenergieloket.nl/warmtepomp/koelen-met-een-warmtepomp/
Rijksdienst voor Ondernemend Nederland. (2009). *Bouwstenen*.
Rijksoverheid, & Studiegroep Duurzame groei. (2016). Kiezen voor duurzame groei: Rapport Studiegroep Duurzame Groei, 110.
Roberts, M. B., Bruce, A., & MacGill, I. (2019). Impact of shared battery energy storage systems on photovoltaic self-consumption and electricity bills in apartment buildings. *Applied Energy*. https://doi.org/10.1016/j.apenergy.2019.04.001
Royal Haskoning, Schild, J., van Wijk, O., & Gosselink, P. (2015). *Rapportage Nulmeting Energieverbruik Beheer en Onderhoud wegen en vaste kunstwerken Provincie Zuid Holland*.
Ruhnau, O., Hirth, L., & Praktiknjo, A. (2019). Time series of heat demand and heat pump efficiency for energy system modeling. *Scientific Data*, *6*(1), 1–10. https://doi.org/10.1038/s41597-019-0199-y
RVO. (n.d.). Windviewer SDE++ en SCE. Retrieved from https://geocontent.rvo.nl/windviewer/
RVO. (2021). Windsnelheid per gemeente SDE++ en SCE, 2021. Retrieved from https://www.rvo.nl/sites/default/files/2021/02/Windkaart windsnelheid per gemeente versie februari 2021.pdf
Sager-Klauß, C. V. (2016). *Energetic Communities: planning support for sustainable energy transition in small- and medium-sized communities*.
Santin, O. G. (2011). Behavioural patterns and user profiles related to energy consumption for heating. *Energy and Buildings*. https://doi.org/10.1016/j.enbuild.2011.06.024
Schill, W. P. (2020). Electricity Storage and the Renewable Energy Transition. *Joule*, *4*(10), 2059–2064. https://doi.org/10.1016/j.joule.2020.07.022
Schlachtberger, D. P., Brown, T., Schramm, S., & Greiner, M. (2017). The benefits of cooperation in a highly renewable European electricity network. *Energy*, *134*, 469–481. https://doi.org/10.1016/j.energy.2017.06.004
Schuttenhelm, R., Brouwers, J., Zeman, M., & IEA. (n.d.). Kan het Nederlandse stroomnet all duurzame opgewerkte energie wel aan? *2019*. Retrieved from https://www.nu.nl/klimaat/6007516/kan-het-nederlandse-stroomnet-alle-duurzaam-opgewekte-energie-wel-aan.html
Schuttenhelm, R., Slootweg, H., ten Brinck, T., Zeman, M., & Brouwers, J. (2022). Overbelast

stroomnet: panelen draaien, thuisbatterij of even afschakelen? Retrieved from https://www.nu.nl/nu-klimaat/6179319/overbelast-stroomnet-panelen-draaien-thuisbatterij-of-even-afschakelen.html

Sharma, V., Haque, M. H., & Aziz, S. M. (2019). Energy cost minimization for net zero energy homes through optimal sizing of battery storage system. *Renewable Energy*. https://doi.org/10.1016/j.renene.2019.03.144

Shimoda, Y., Fujii, T., Morikawa, T., & Mizuno, M. (2004). Residential end-use energy simulation at city scale. *Building and Environment*, *39*(8 SPEC. ISS.), 959–967. https://doi.org/10.1016/j.buildenv.2004.01.020

Siraganyan, K., Mauree, D., Perera, A. T. D., & Scartezzini, J. L. (2017). Evaluating the need for energy storage to enhance autonomy of neighborhoods. *Energy Procedia*, *122*, 253–258. https://doi.org/10.1016/j.egypro.2017.07.464

Stoeglehner, G., & Abart-Heriszt, L. (2022). Integrated spatial and energy planning in Styria – A role model for local and regional energy transition and climate protection policies. *Renewable and Sustainable Energy Reviews*, *165*(January), 112587. https://doi.org/10.1016/j.rser.2022.112587

Swan, L. G., & Ugursal, V. I. (2009). Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. *Renewable and Sustainable Energy Reviews*, *13*(8), 1819–1835. https://doi.org/10.1016/j.rser.2008.09.033

Tigchelaar, C. (2013). Methodiek voor opsplitsing CBS statistiek huishoudelijk gas- en elektriciteitsverbruik. *Confidential ECN-E--13-075*.

Torabi Moghadam, S., Lombardi, P., & Mutani, G. (2017). A Mixed Methodology for Defining a New Spatial Decision Analysis towards Low Carbon Cities. *Procedia Engineering*, *198*(September 2016), 375–385. https://doi.org/10.1016/j.proeng.2017.07.093

Tozzi, P., & Jo, J. H. (2017). A comparative analysis of renewable energy simulation tools: Performance simulation model vs. system optimization. *Renewable and Sustainable Energy Reviews*. https://doi.org/10.1016/j.rser.2017.05.153

Uitzinger, J. (n.d.). Analyse EPC en energieverbruik bij woningen. *IVAM Research and Consultancy on Sustainability*.

Urban Land Institute. (2022). Renewable Energy Strategies for Real Estate. Retrieved from https://digitalcommons.wpi.edu/iqp-all/3255/

Vadiee, A., Yaghoubi, M., Martin, V., & Bazargan-Lari, Y. (2016). Energy analysis of solar blind system concept using energy system modelling. *Solar Energy*, *139*, 297–308. https://doi.org/10.1016/j.solener.2016.09.039

van Aken, J., & Andriessen, D. (2011). *Hanboek ontwerpgericht wetenschappelijk onderzoek: Wetenschap met effect*. Boom Lemma.

van Bakel, H., & Heijnens, J. (2015). *Beleids- en beheerplan openbare verlichting*.

van Burg, J. C. (2011). Kwaliteitscriteria voor ontwerpgericht wetenschappelijk onderzoek. *Hanboek Ontwerpgericht Wetenschappelijk Onderzoek: Wetenschap Met Effect*.

van den Brom, P. (2020). *Energy in Dwellings*.

van den Brom, P., Meijer, A., & Visscher, H. (2018). Performance gaps in energy consumption: household groups and building characteristics. *Building Research and Information*, *46*(1), 54–70. https://doi.org/10.1080/09613218.2017.1312897

van der Bent, H. S., van den Brom, P. I., Visscher, H. J., Meijer, A., & Mouter, N. (2021a). The energy performance of dwellings of Dutch non-profit housing associations: Modelling actual energy consumption. *Energy and Buildings*, *253*, 111486. https://doi.org/10.1016/j.enbuild.2021.111486 van der Bent, H. S., van den Brom, P. I., Visscher, H. J., Meijer, A., & Mouter, N. (2021b). The energy performance of dwellings of Dutch non-profit housing associations: Modelling actual energy consumption. *Energy & Buildings*. https://doi.org/https://doi.org/10.1016/j.enbuild.2021.111486

van Vlimmeren, L. (2021). *An explorative scenario study into a 100 % renewable energy system in the Netherlands in 2050*. Radbound University.

van Weezel, T. G., van de Weijer, B., & Visser, M. (2022). Recordreeks van groene stroom leidt tot nieuwe problemen voor producenten en netbeheerder. Retrieved from https://www.volkskrant.nl/economie/recordreeks-van-groene-stroom-leidt-tot-nieuwe-problemen-voor-producenten-en-netbeheerder~b707ed72/?referrer=https%3A%2F%2Fwww.google.com%2F

Verdaas, C. (2020). Energie & gebiedsontwikkeling: een winnende combinatie. In *Programma Aardgasvrije Wijken* (pp. 8–15).

Vereniging Eigen Huis. (n.d.). Gestegen energieprijzen leiden tot gasbesparende maatregelen. Retrieved from https://www.eigenhuis.nl/nieuws/gestegen-energieprijzen-leiden-tot-gasbesparende-maatregelen

Verwin, Bakker, J., Mooren, F. Van Der, & Boonstra, H. J. (2022). CBS - watergebruik thuis (WGT) 2021.

Vieira, F. M., Moura, P. S., & de Almeida, A. T. (2017). Energy storage system for self-consumption of photovoltaic energy in residential zero energy buildings. *Renewable Energy*, *103*, 308–320. https://doi.org/10.1016/j.renene.2016.11.048

Volandis, & KNMI. (n.d.). Indeling 28 weerstations. Retrieved from https://www.weerverlet.nl/indeling-28-weerstations/

Vreenegoor, R., Hensen, J., & Vries, B. de. (2008). Review of existing energy performance calculation methods for district use. *Proceedings of the Symposium Gebouwsimulatie: Ontmoeten & Ontdekken*, (2008), 1–8.

VREG. (2021). Verbruikprofiel openbare verlichting S19. Retrieved from https://www.vreg.be/nl/verbruiksprofielen-en-productieprofielen

Walker, A., & Kwon, S. (2021). Analysis on impact of shared energy storage in residential community: Individual versus shared energy storage. *Applied Energy*, *282*(PA), 116172. https://doi.org/10.1016/j.apenergy.2020.116172

Wieringa, R. J. (2014). *Design science methodology: For information systems and software engineering*. *Design Science Methodology: For Information Systems and Software Engineering*. Springer. https://doi.org/10.1007/978-3-662-43839-8

WML, Verwin, & CBS. (2019). Waterverbruik. Retrieved from https://www.wml.nl/alles-over-water/waterverbruik#:~:text=Droogte en hitte-,Waterverbruik,van zo'n 31 procent.

Yao, R., & Steemers, K. (2005). A method of formulating energy load profile for domestic buildings in the UK. *Energy and Buildings*, *37*(6), 663–671. https://doi.org/10.1016/j.enbuild.2004.09.007

Zhao, H. X., & Magoulès, F. (2012). A review on the prediction of building energy consumption. *Renewable and Sustainable Energy Reviews*, *16*(6), 3586–3592. https://doi.org/10.1016/j.rser.2012.02.049

Zipperer, A., Aloise-Young, P. A., Suryanarayanan, S., Roche, R., Earle, L., Christensen, D., … Zimmerle, D. (2013). Electric energy management in the smart home: Perspectives on enabling technologies and consumer behavior. *Proceedings of the IEEE*. https://doi.org/10.1109/JPROC.2013.2270172

Appendices

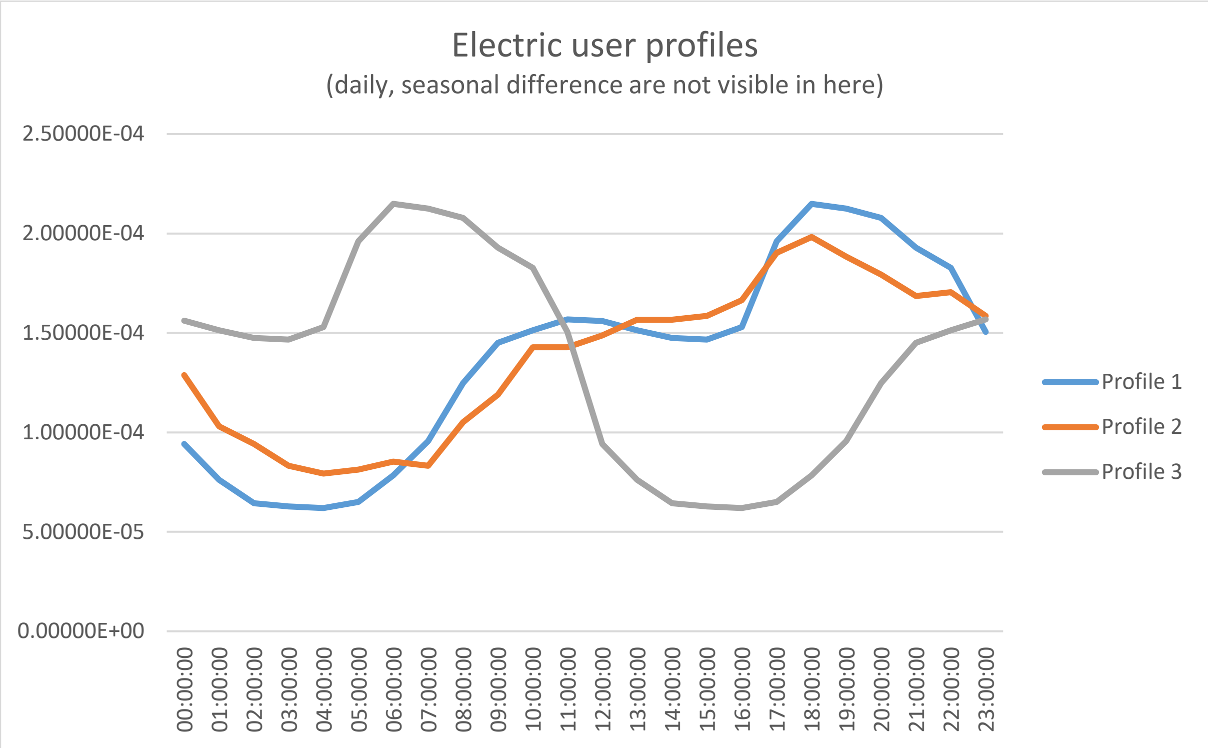
Appendix A

Expert overview

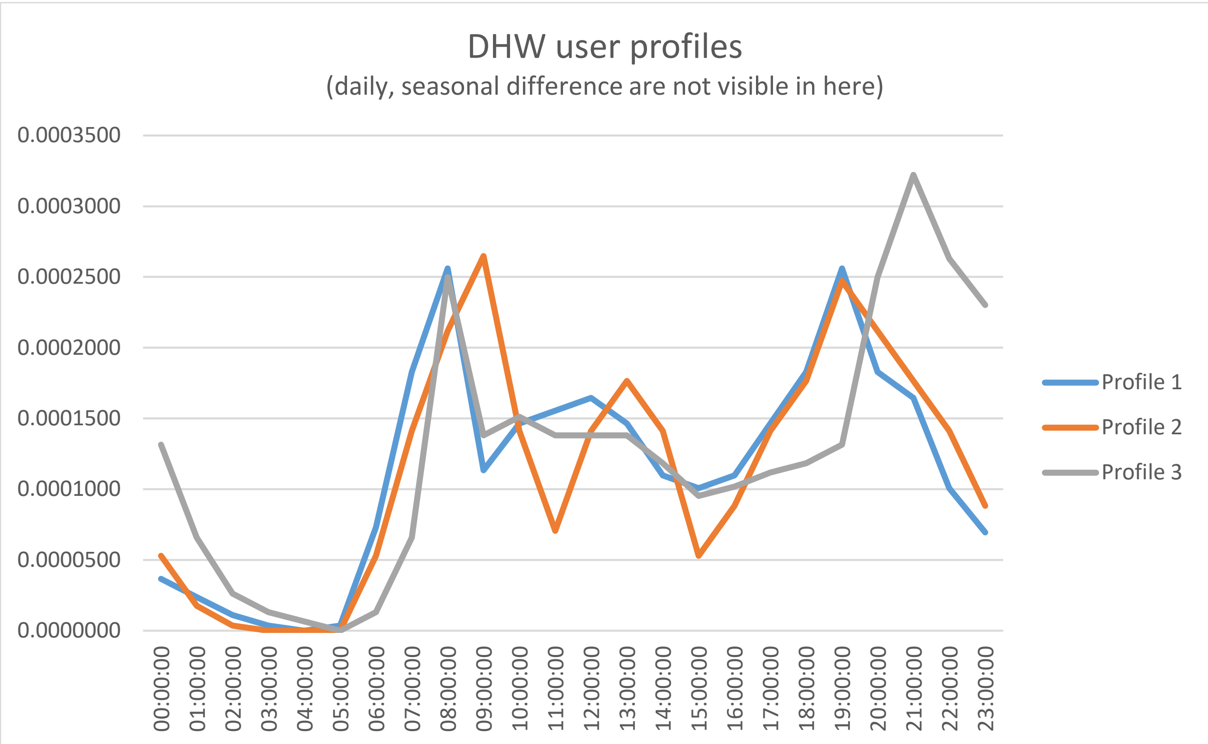
Person:	*Company:*	*Job title:*	*Experience (in years):*	*Involvement*
Expert 1	Arcadis	Project manager and business developer	25+	Stakeholders and case study
Expert 2	Arcadis	Consultant building physics	5+	Technical tool content
Expert 3	Arcadis	Consultant building physics, fire safety and acoustics	30+	Technical tool content
Expert 4	Arcadis	Architect	8+	Stakeholders and case study
Expert 5	Arcadis	Senior consultant	6+	Technical tool content
Expert 6	Arcadis	Digital consultant	8+	Tooling
Expert 7	Arcadis	Consultant geo-information	3+	Tooling
Expert 8	Arcadis	Project manager and area development consultant	10+	Stakeholders
Expert 9	Arcadis	Consultant and assistant project lead energy transition	2+	Technical tool content
Expert 10	Arcadis	Senior planning economist	22+	Stakeholders and case study
Expert 11	Overmorgen	Consultant sustainable area development	2+	Stakeholders and case study
Expert 12	Arcadis	Consultant ESG and sustainability	1+	Technical tool content
Expert 13	TU Delft, Brom Architectuur	Researcher building energy and architect	10+	Technical tool content
Expert 14	ISSO	Technical specialist	15+	Technical tool content
Expert 15	Arcadis	Program manager Energy Transition	9+	Stakeholders
Expert 16	Arcadis	Consultant Building Services MEP and sustainability	10+	Technical tool content
Expert 17	Dura Vermeer	Project/area developer	20+	Stakeholders and case study
Expert 18	Arcadis	Project manager urban development and real estate	27+	Stakeholders and case study

Appendix B

Composed user profiles – domestic electricity consumption.



Composed user profiles – domestic hot water.



Appendix C

Average windspeed data at 25, 55 and 100m height for determination of full load hours wind corresponding to the 28 integrated meteorological stations in the tool in the Netherlands.

Location Meteorological station	***Average yearly windspeed at height (x m)***			***Corresponding full load hours***		
	25	***55***	***100***	***25***	***55***	***100***
F, Terschelling	7.1	8.1	9.1	2760	3410	4050
Nh, Den Helder, De Kooy	6.4	7.5	8.6	2350	3080	4050
F, Leeuwarden	5.7	6.8	8.0	2350	2570	3840
Nh, Berkhout	5.5	6.6	7.7	2350	2570	3510
Gr, Winschoten, Nieuw Beerta	5.4	6.5	7.6	2350	2570	3510
Z, Vlissingen	5.5	6.5	7.5	2350	2570	3510
Gr, Groningen, Eelde	5.2	6.3	7.5	2350	2350	3510
Fle, Marknesse	5.1	6.2	7.4	2350	2350	3150
Zh, Voorschoten	5.0	6.1	7.3	2350	2350	3150
D, Hoogeveen	5.1	6.2	7.3	2350	2350	3150
Nh, Amsterdam, Schiphol	5.4	6.3	7.3	2350	2350	3150
U, Lopik, Cabauw	5.1	6.2	7.3	2350	2350	3150
Fle, Lelystad	5.1	6.1	7.2	2350	2350	3150
Gld, Beesd, Herwijnen	5.0	6.1	7.2	2350	2350	3150
O, Heino	5.0	6.0	7.1	2350	2350	3150
Gld, Groenlo, Hupsel	4.9	6.0	7.1	2350	2350	3150
Zh, Rotterdam	5.0	6.0	7.0	2350	2350	3150
Z, Westdorpe	4.9	5.9	7.0	2350	2350	3150
Nb, Woensdrecht	4.1	5.4	6.7	2350	2350	2670
Nb, Volkel	4.5	5.6	6.7	2350	2350	2670
Nb, Gilze-Rijen	4.5	5.5	6.6	2350	2350	2670
U, Utrecht, De Bilt	4.4	5.5	6.6	2350	2350	2670
Gld, Arnhem, Deelen	4.4	5.5	6.6	2350	2350	2670
L, Maastricht	4.5	5.5	6.5	2350	2350	2670
O, Enschede (Twente)	4.2	5.3	6.5	2350	2350	2670
L, Ell	4.4	5.4	6.5	2350	2350	2670
Nb, Eindhoven	4.5	5.4	6.4	2350	2350	2670
L, Arcen	4.0	5.2	6.4	2350	2350	2670

Appendix D

Composed dataset example for weather station Amsterdam – average temperature 2011-2020 (°C) (tab 1)

Composed dataset example for weather station Amsterdam – minimum temperature 2011-2020 (°C) (tab 2)

Composed dataset example for weather station Amsterdam – maximum temperature 2011-2020 (°C) (tab 3)

Composed dataset example for weather station Amsterdam – average windspeed 2011-2020 (m/s)
(tab 4)

Composed dataset example for weather station Amsterdam – minimum windspeed 2011-2020 (m/s)
(tab 5)

Composed dataset example for weather station Amsterdam – maximum windspeed 2011-2020 (m/s)
(tab 6)

Composed dataset example for weather station Amsterdam – average radiation 2011-2020 (J/cm2) (tab 7)

Composed dataset example for weather station Amsterdam – minimum radiation 2011-2020 (J/cm2) (tab 8)

Composed dataset example for weather station Amsterdam – maximum radiation 2011-2020 (J/cm2) (tab 9)

All included in the external excel file: 'Dataset Amsterdam'

Appendix E

Prints from the tool:

1. **Parameter input sheet**

2. **Editable assumption sheet**

3. **Dashboard (dynamic, although static print)**

4. **Infographic and energy flows (dynamic, although static print)**

PLAN PARAMETERS

GENERAL PROJECT AND PLAN INFORMATION

Projectname	...xxtestxx...
Date	DD-MM-YYYY
Version	V0.1
Location (4-digit postal code)	1200
Weather data set	Nh, Amsterdam, Schiphol
data scenario (average/max/min)	Average
Modelling of predefined dwelling types?	No

PRIVATE DOMAIN

ID	B-1	B-2	B-3	B-4	B-5
~~Predefined types~~	~~Detached dwelling~~	~~Semi-detached~~	~~Terraced house (between~~	~~Detached dwelling~~	~~Apartment (gallery)~~
Name	Test1	Test2	Test3	Test4	Test5
South facade orientation (°, relative to south)	0	40	100	230	330
Quanitity	10	5	5	10	15
User profiles	Profile 1	Profile 2	Profile 1	Profile 1	Profile 2
Occupation (persons)	3	4	2	4	4
Rc wall (m2K/W)	6	7	8	7	8
Rc roof (m2K/W)	9	7	8	7	6
Rc floor (m2K/W)	7	7	7	7	7
Surface wall (m2)	150	270	90	170	270
Surface roof (m2)	120	150	45	150	150
Surface floor /foothprint (m2)	120	150	45	150	150
Living area (m2) (BVO)	120	250	45	180	250
Volume (m3)	360	620	130	520	620
Area window - south (m2)	15	20	5	20	25
Area window - west (m2)	10	10	3	15	20
Area window - north (m2)	10	5	2	5	5
Area window - east (m2)	15	5	2	10	10
Uw (W/m2K)	0.5	0.5	0.5	0.5	0.5
G-value	0.45	0.45	0.45	0.45	0.45
Area doors (m2)	5	6	2	5	8
U doors (W/m2K)	0.8	0.8	0.8	0.8	0.8
Comfort - heated indoor temperature (°C)	20	20	20	20	20
Comfort - maximum desired indoor temperature (°C)	26	26	26	26	26
Shading control	Yes	Yes	Yes	Yes	Yes
G-value shade impact	0.15	0.15	0.15	0.15	0.15
Primary Heating System (PHS)	Bodem warmtepomp, GSHP	Bodem warmtepomp, GSHP	L/W warmtepomp, ASHP	L/W warmtepomp, ASHP	L/W warmtepomp, ASHP
Thermal storage interaction for space heating	No	No	No	No	No
Cooling system/technology	Airco	Bodem warmtepomp, GSHP	Airco	L/W warmtepomp, ASHP	No cooling
DHW system	Bodem warmtepomp, GSHP	Bodem warmtepomp, GSHP	Elektrische CV	L/W warmtepomp, ASHP	L/W warmtepomp, ASHP
Heat recovery rate ventilation (%)	45%	45%	45%	45%	45%
Dynamic ventilation	Yes	Yes	Yes	Yes	No
Ventilation rate (m3/h/m2)	0.0009	0.0009	0.0009	0.0009	0.0009
Aerial PV output (W/m2)	~~225~~	225	225	225	225
PV surface (m2)	0	35	15	35	45
Performance ratio (PV system)	~~0.8~~	0.8	0.8	0.8	0.8

PV orientation (°,relative to south)	~~0~~	90	180	10	10
PV angle (°)	~~30~~	30	35	30	25
Aerial PV output (W/m2)	~~225~~	~~225~~	~~225~~	~~225~~	~~225~~
PV surface (m2)	0	0	0	0	0
Performance ratio (PV system)	~~0.8~~	~~0.8~~	~~0.8~~	~~0.8~~	~~0.8~~
PV orientation (°, relative to south)	~~40~~	~~90~~	~~180~~	~~40~~	~~40~~
PV angle (°)	~~60~~	~~30~~	~~30~~	~~30~~	~~30~~
Internal gain factor (W/m2) BVO	6	6	6	6	6
Presence of Thermal Collectors (and type)	Thermal collector - predefined	Thermal collector - predefined	No thermal collectors	Thermal collector - predefined	Thermal collector - predefined
n0	0.719	0.719	0	0.719	0.719
a1	4.3	4.3	0	4.3	4.3
a2	0.006	0.006	0	0.006	0.006
Aperture surface (m2 - per panel)	2.36	2.36	0	2.36	2.36
U-value (w/m2/K)	4	4	0	4	4
flow (kg/s)	0.02	0.02	0	0.02	0.02
#PVT panels	2	5	10	3	6
PVT surface	4.72	11.8	0	7.08	14.16
Orientation (°,relative to south)	0	40	90	230	330
Angle (°)	35	25	15	30	15

PUBLIC DOMAIN

Photovoltaic energy potential

ID	PV - 1	PV - 2	PV - 3	PV - 4	PV - 5
Aerial PV output (W/m2)	225	225	225	225	225
PV surface (m2)	20	0	0	0	0
Performance ratio (PV system)	0.8	0.8	0.8	0.8	0.8
PV orientation (°,relative to south)	20	0	0	0	0
PV angle (°)	25	20	20	20	20

Wind energy potential

ID	W - 1	W - 2	W - 3	W - 4	W - 5
Number of turbines (#)	1	0	0	0	0
Approx. Axle height (m)	10				
Capacity (per turbine) (kW)	10	0	3	3	3

Electric Storage

ID	S-1
Type of storage	Battery
Efficiency	90%
Self-discharge rate	0.1%
Capacity	3000 kWh
Oversupply as feed-in to grid?	Yes

> not editable, will do automatically

Thermal Storage

ID	T-1
Present	Yes
Type of storage	Water
Capacity (L)	30000
U-value (W/m2K)	0.087
Surface tank (m2)	100
Setpoint temperature	30.0 °C
Maximum temperature	90.0 °C
Residual heat (e.g. industry)	0.0 Wh

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY ARCADIS Design & Consultancy for natural and built assets

COP values	Heating	Cooling	Dhw
Lucht-water warmtepomp (ASHP, lucht/water)		3.5	
Bodemwarmtepomp (GSHP. Bodem/water)	*Calculated*	4.5	*Calculated*
Grondwater warmtepomp (WSHP, water/water)		3.5	
Airco	4	5	/
Elektrische CV	1	/	1
No cooling	1	0	/

> Editable

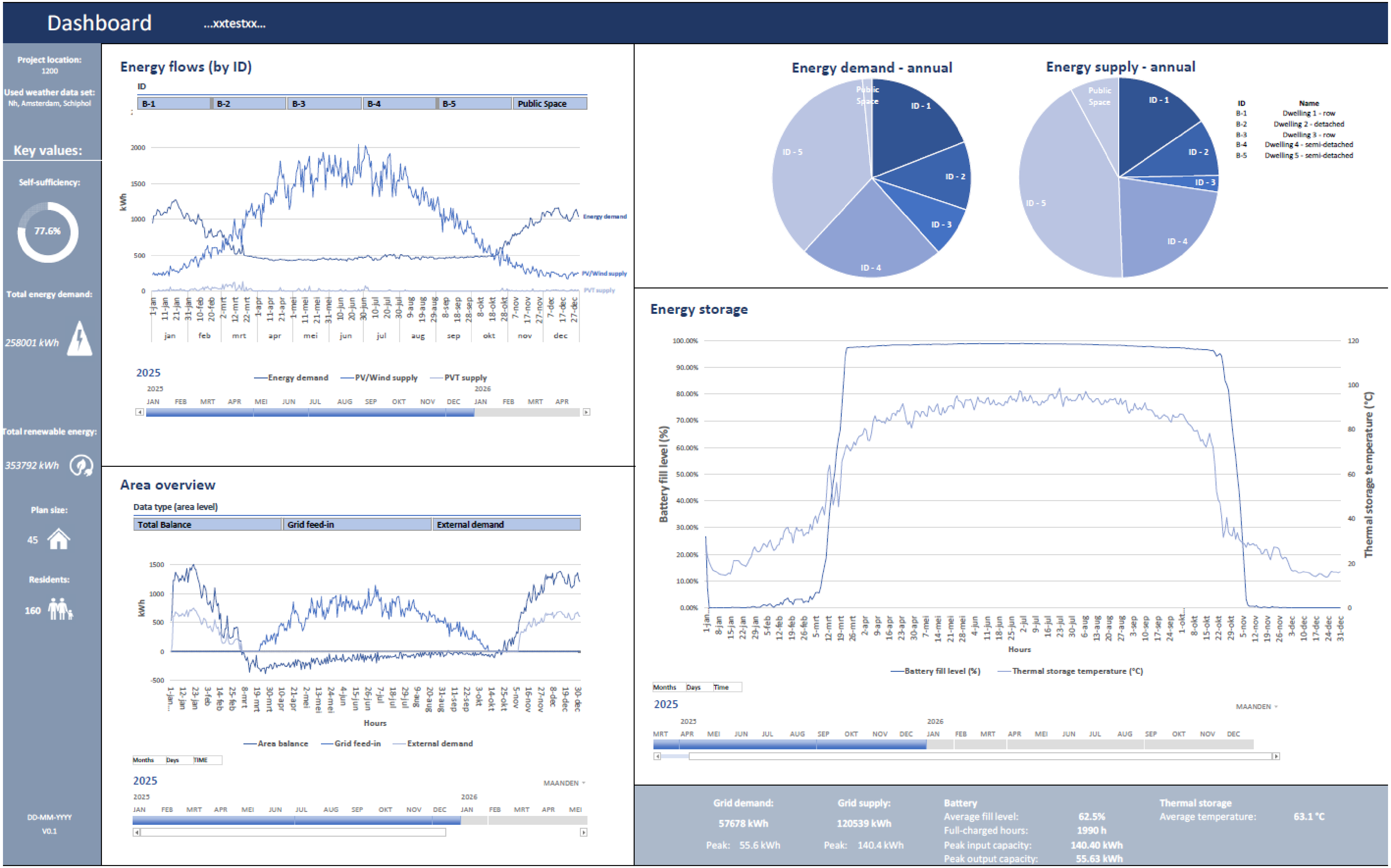
Domestic electricity consumption		
Base consumption household:	1310	kwh/annually
incremental consumption per additional person:	500	kwh/annually

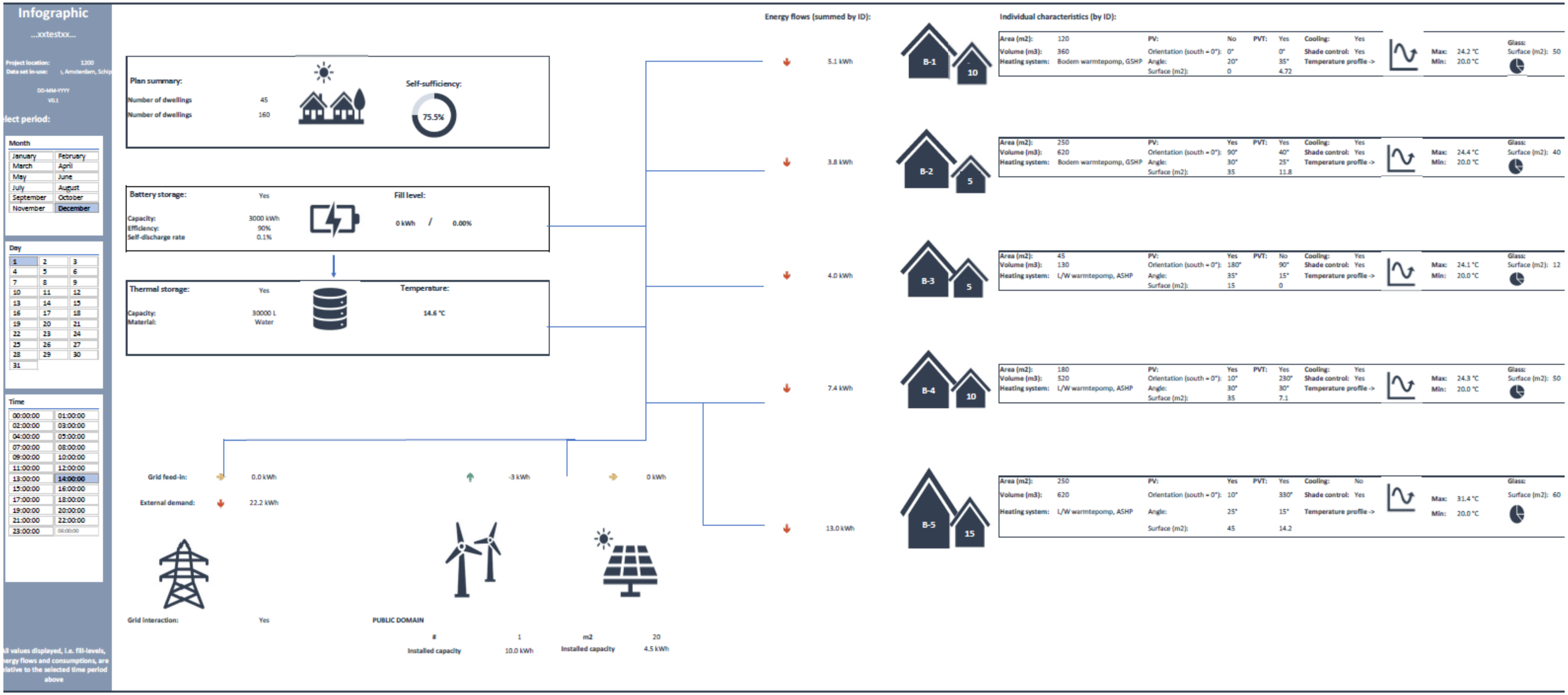
Domestic hot water	
Temperature start	13
Temperature desired	50
Daily consumption per person per day (L/pp/day)	71

	PVT - predefined	PVT - own values	NO - PVT
n0	0.719	0.705	0
a1	4.3	4.1	0
a2	0.006	0.005	0
Apenture surface (m2 - per panel)	2.36	2.36	0
U-value (w/m2/K)	4	4.1	0
flow (kg/s)	0.02	0.018	0

Shade control / blinds	
Threshold for activation by Q (kwh/m2)	0.35

Threshold fill-level battery before conversion (kWh)	2500
Initial fill level battery (kWh)	1000
Thermal storage start temperature (°C)	43.5
Efficiency thermal storage -> heating system	95%
Efficiency thermal storage -> DHW	95%
Public electric energy demand per dwelling in plan area	79.5 kWh


Dashboard
...xxtestxx...
Project location:
1200
Used weather data set:
Nh, Amsterdam, Schiphol
Key values:
Self-sufficiency:
77.6%
Total energy demand:
258001 kWh
Total renewable energy:
353792 kWh
Plan size:
45
Residents:
160
DD-MM-YYYY
V0.1
Energy flows (by ID)
ID
B-1
B-2
B-3
B-4
B-5
Public Space
kWh
Energy demand
PV/Wind supply
PVT supply
2025
Energy demand
PV/Wind supply
PVT supply
Area overview
Data type (area level)
Total Balance
Grid feed-in
External demand
kWh
Hours
Area balance
Grid feed-in
External demand
Months
Days
TIME
2025
MAANDEN
Energy demand - annual
Energy supply - annual
ID - 1
ID - 2
ID - 3
ID - 4
ID - 5
Public Space
ID
Name
B-1
Dwelling 1 - row
B-2
Dwelling 2 - detached
B-3
Dwelling 3 - row
B-4
Dwelling 4 - semi-detached
B-5
Dwelling 5 - semi-detached
Energy storage
Battery fill level (%)
Thermal storage temperature (°C)
Hours
Battery fill level (%)
Thermal storage temperature (°C)
Months
Days
Time
2025
MAANDEN
Grid demand:
57678 kWh
Peak: 55.6 kWh
Grid supply:
120539 kWh
Peak: 140.4 kWh
Battery
Average fill level: 62.5%
Full-charged hours: 1990 h
Peak input capacity: 140.40 kWh
Peak output capacity: 55.63 kWh
Thermal storage
Average temperature: 63.1 °C


Infographic
...xxtestxx...
Project location:
Data set in-use:
DD-MM-YYYY
V0.1
lect period:
Month
January
February
March
April
May
June
July
August
September
October
November
December
Day
Time
Plan summary:
Number of dwellings 45
Number of dwellings 160
Self-sufficiency:
75.5%
Battery storage: Yes
Capacity: 3000 kWh
Efficiency: 90%
Self-discharge rate 0.1%
Fill level:
0 kWh / 0.00%
Thermal storage: Yes
Capacity: 30000 L
Material: Water
Temperature:
14.6 °C
Energy flows (summed by ID):
5.1 kWh
3.8 kWh
4.0 kWh
7.4 kWh
13.0 kWh
Individual characteristics (by ID):
B-1
10
B-2
5
B-3
5
B-4
10
B-5
15
Grid feed-in: 0.0 kWh
External demand: 22.2 kWh
-3 kWh
0 kWh
Grid interaction: Yes
PUBLIC DOMAIN
Installed capacity 10.0 kWh
Installed capacity 4.5 kWh

Appendix F

Dashboard

Deelgebied 3B West Betuwe

Project location:
4191

Used weather data set:
Gld, Beesd, Herwijnen

Key values:

Self-sufficiency: 59.3%

Total energy demand: 1328916 kWh

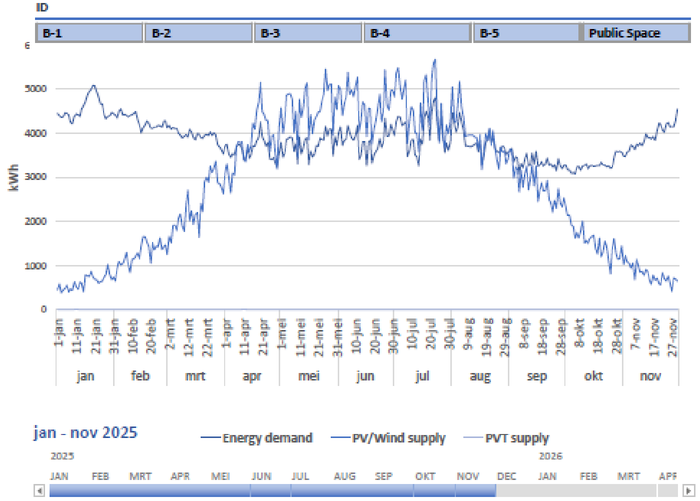
Total renewable energy: 957983 kWh

Plan size: 239

Residents: 645

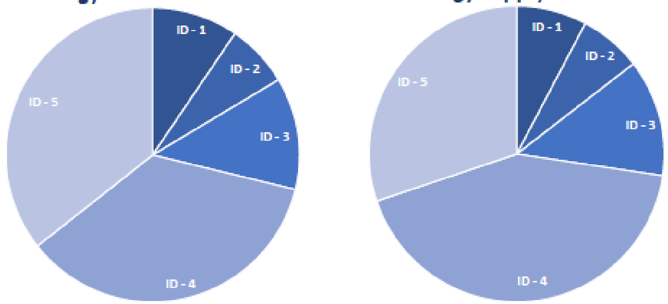
8-5-2023
V1

Energy flows (by ID)



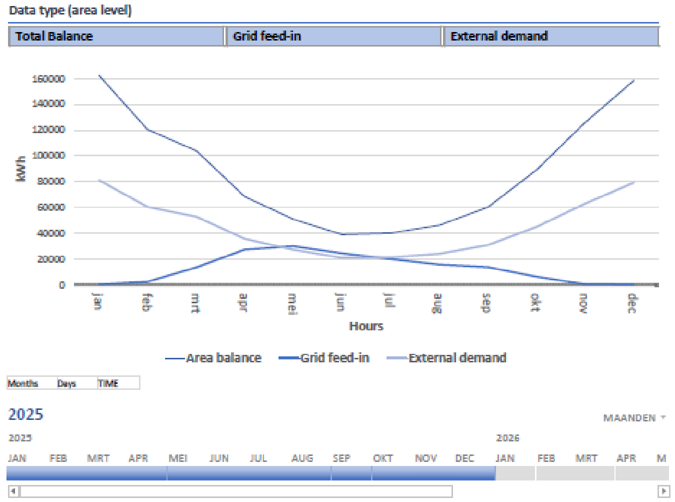
Energy demand - annual

Energy supply - annual

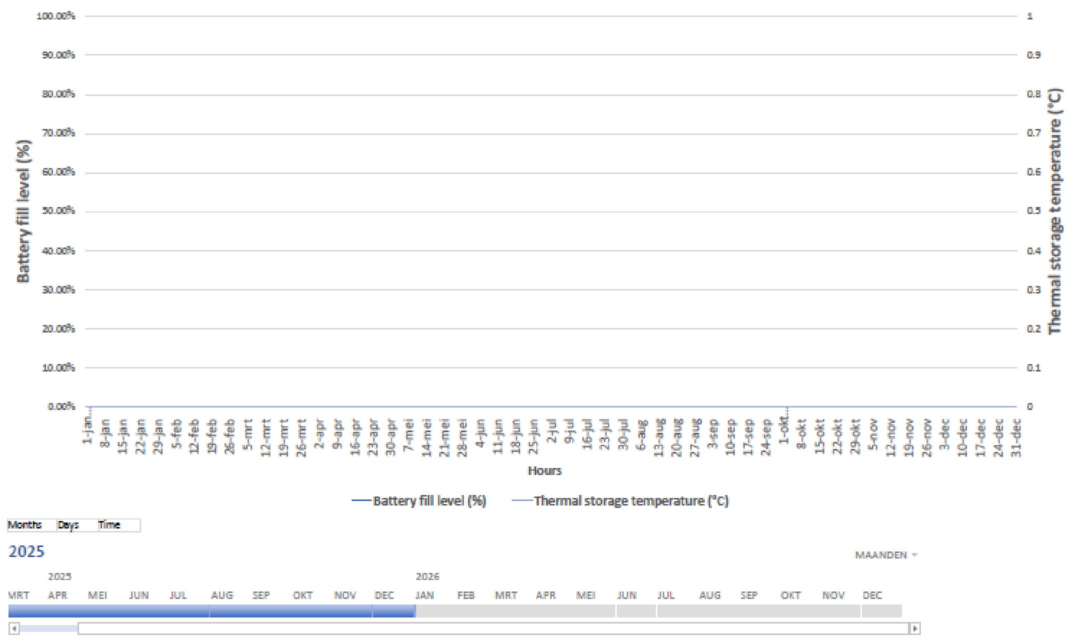


ID	Name
B-1	Semi-detached T1
B-2	Semi-detached T2
B-3	Semi-detached T3
B-4	Row/corner T1
B-5	Row/corner T2

Area overview



Energy storage



Grid demand: 540463 kWh
Peak: 190.0 kWh

Grid supply: 152577 kWh
Peak: 146.6 kWh

Battery
Average fill level: Not present
Full-charged hours: Not present
Peak input capacity: Not present
Peak output capacity: Not present

Thermal storage
Average temperature: 0.0 °C

Dashboard

Deelgebied 3B West Betuwe

Project location:
4191

Used weather data set:
Gld, Beesd, Herwijnen

Key values:

Self-sufficiency:

74.0%

Total energy demand:

1292085 kWh

Total renewable energy:

991042 kWh

Plan size:

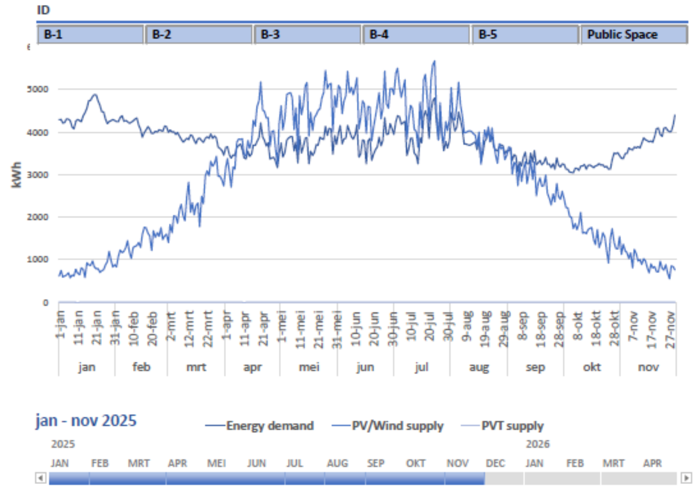
239

Residents:

645

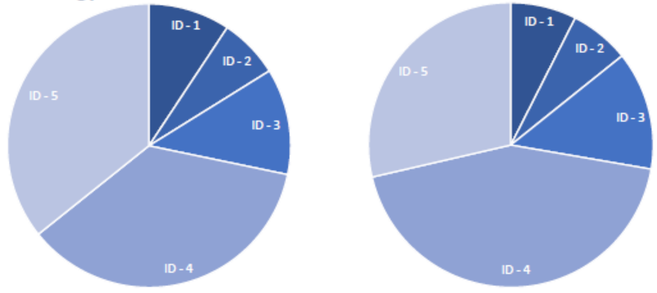
8-5-2023
V1

Energy flows (by ID)



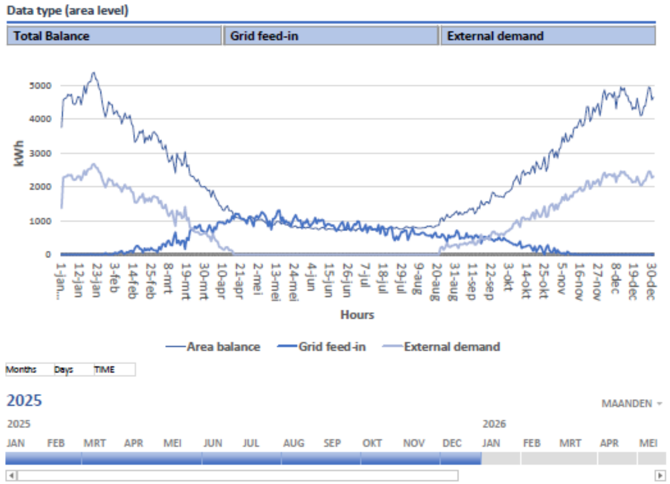
Energy demand - annual

Energy supply - annual

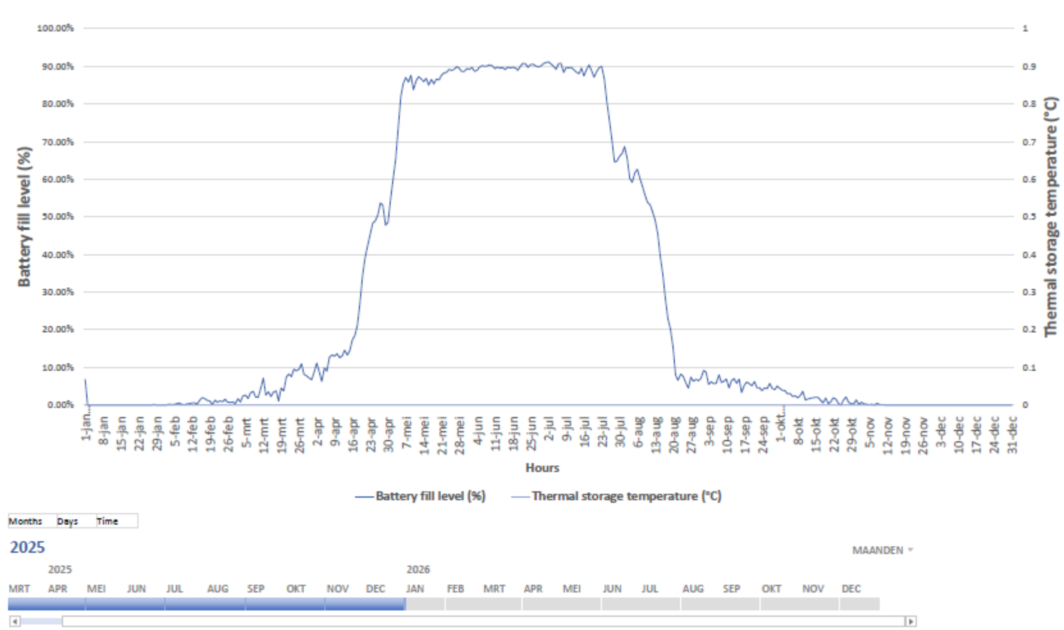


ID	Name
B-1	Semi-detached T1
B-2	Semi-detached T2
B-3	Semi-detached T3
B-4	Row/corner T1
B-5	Row/corner T2

Area overview



Energy storage



Grid demand:
336218 kWh
Peak: 179.6 kWh

Grid supply:
168777 kWh
Peak: 153.5 kWh

Battery

Average fill level:	27.8%
Full-charged hours:	316 h
Peak input capacity:	153.51 kWh
Peak output capacity:	179.55 kWh

Thermal storage
Average temperature: 0.0 °C

Appendix G

Dashboard

DV- Buitengoed Heiloo - left nr. 68-80

Project location: 1851

Used weather data set: Nh, Den Helder, De Kooy

Key values:

Self-sufficiency: 43.2%

Total energy demand: 61272 kWh

Total renewable energy: 27834 kWh

Plan size: 13

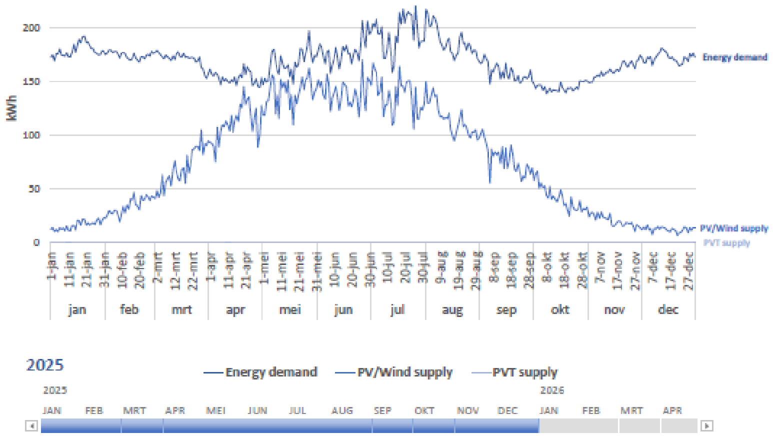
Residents: 34

14-5-2023

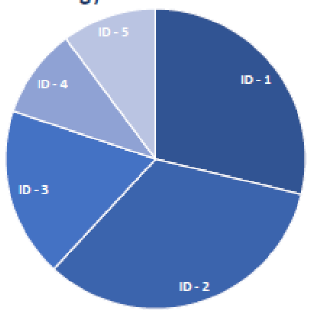
V1

Energy flows (by ID)

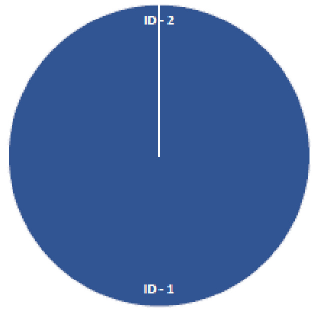
ID: B-1 | B-2 | B-3 | B-4 | B-5 | Public Space



Energy demand - annual

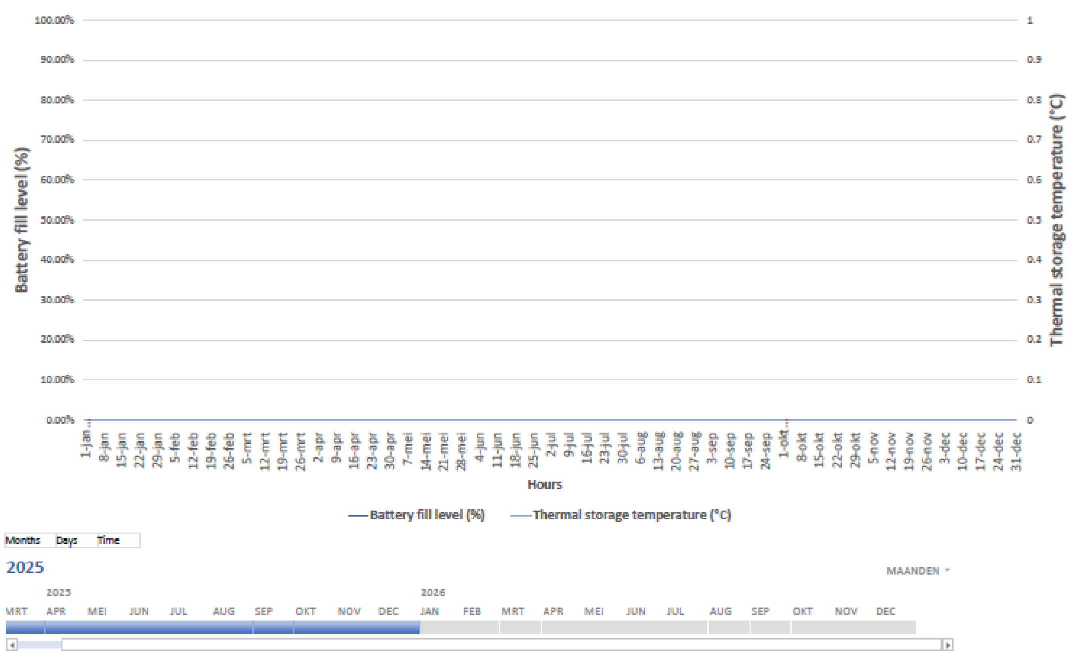


Energy supply - annual



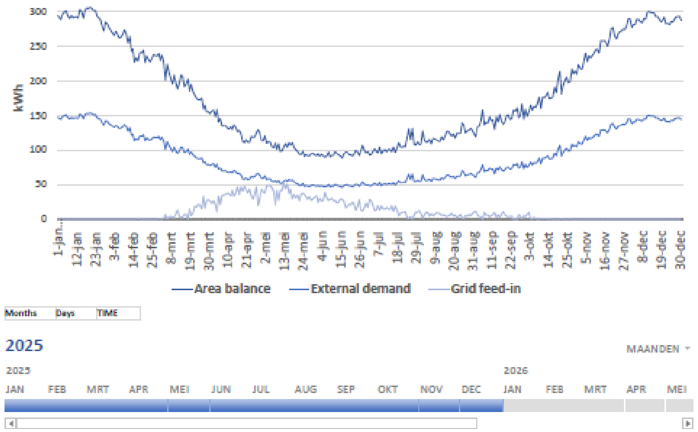
ID	Name
B-1	Type D (68 - 72)
B-2	Type E (73, 74, 77, 78)
B-3	Type F (75, 76)
B-4	Type G1 (80)
B-5	Type G2 (79)

Energy storage



Area overview

Data type (area level): Total Balance | Grid feed-in | External demand



Grid demand: 34780 kWh

Peak: 11.3 kWh

Grid supply: 1208 kWh

Peak: 4.0 kWh

Battery

Average fill level: Not present

Full-charged hours: Not present

Peak input capacity: Not present

Peak output capacity: Not present

Thermal storage

Average temperature: 0.0 °C

Dashboard

DV- Buitengoed Heiloo - left nr. 68-80

Project location:
1851

Used weather data set:
Nh, Den Helder, De Kooy

Key values:

Self-sufficiency:

67.5%

Total energy demand:

54757 kWh

Total renewable energy:

43226 kWh

Plan size:

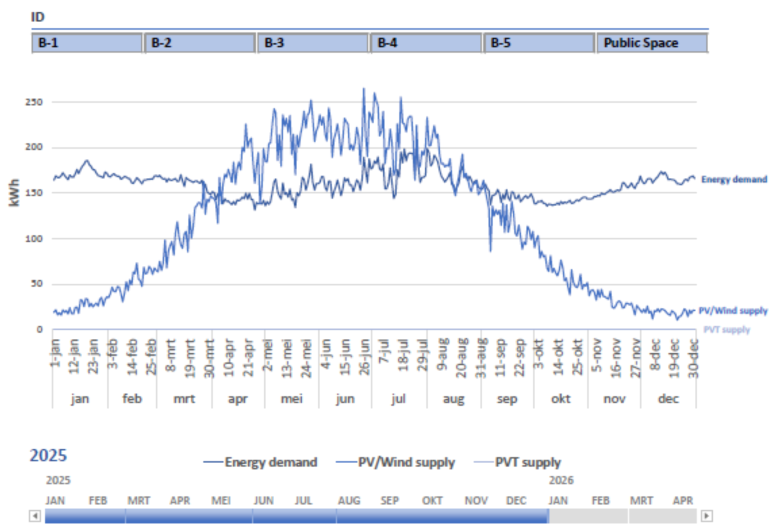
13

Residents:

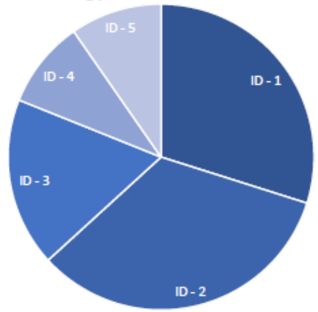
34

14-5-2023
V1

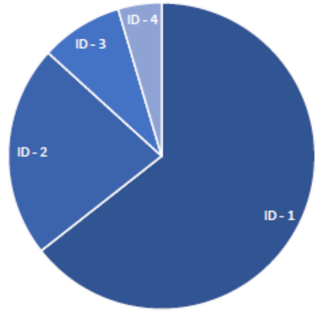
Energy flows (by ID)



Energy demand - annual

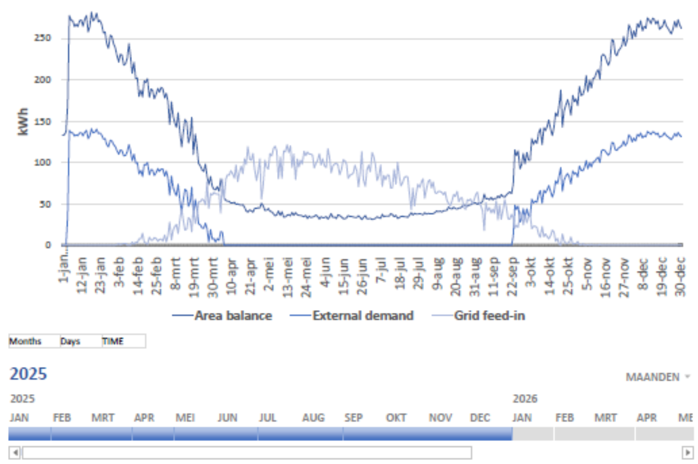


Energy supply - annual

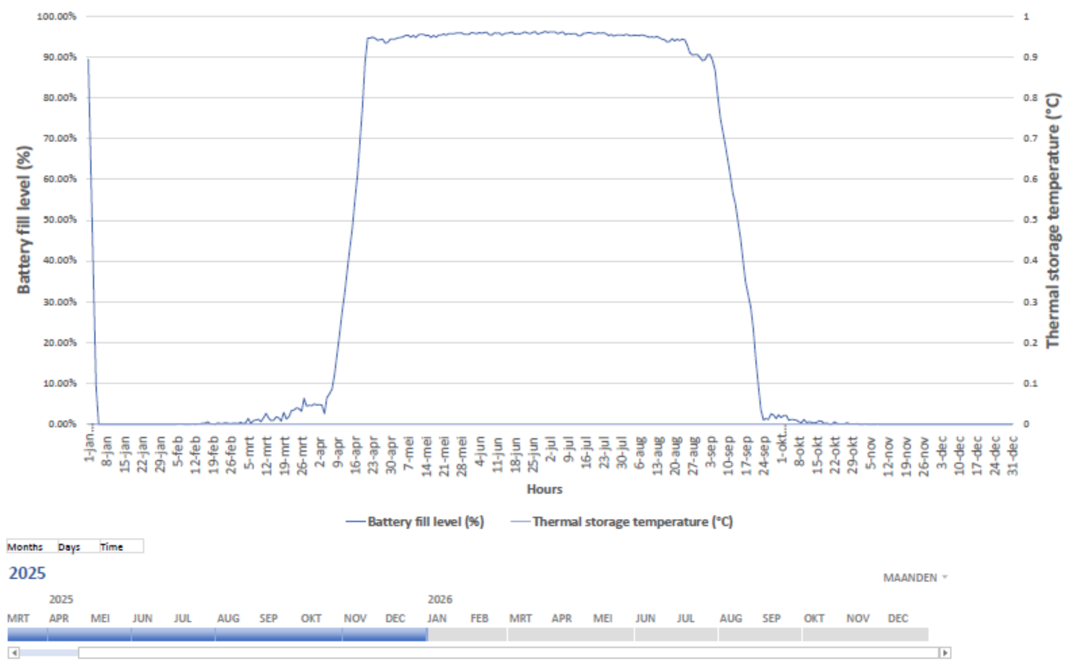


ID	Name
B-1	Type D (68 - 72)
B-2	Type E (73, 74, 77, 78)
B-3	Type F (75, 76)
B-4	Type G1 (80)
B-5	Type G2 (79)

Area overview



Energy storage



Grid demand: 17814 kWh
Peak: 10.9 kWh

Grid supply: 15707 kWh
Peak: 15.1 kWh

Battery

Average fill level:	40.6%
Full-charged hours:	730 h
Peak input capacity:	15.14 kWh
Peak output capacity:	10.86 kWh

Thermal storage
Average temperature: 0.0 °C

Appendix H

Dashboard

Buitengoed Heiloo - Phase 1 (type analysis without type A an

Project location:
1851

Used weather data set:
Nh, Den Helder, De Kooy

Key values:

Self-sufficiency:
48.5%

Total energy demand:
167863 kWh

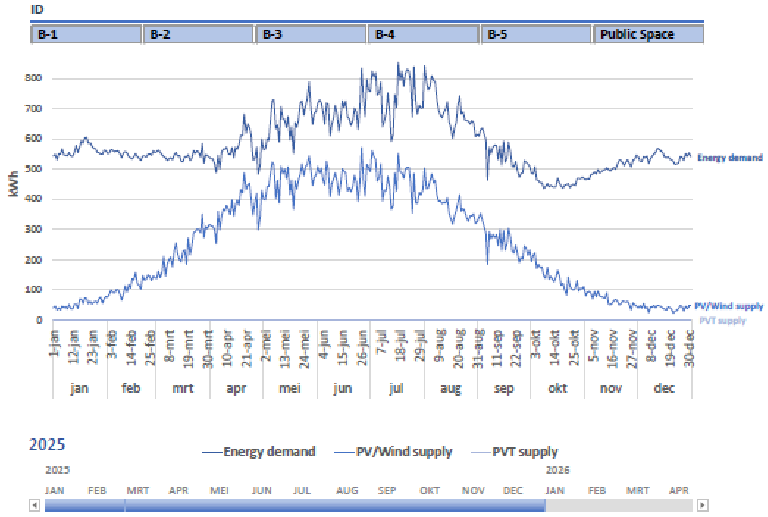
Total renewable energy:
93464 kWh

Plan size:
40

Residents:
106

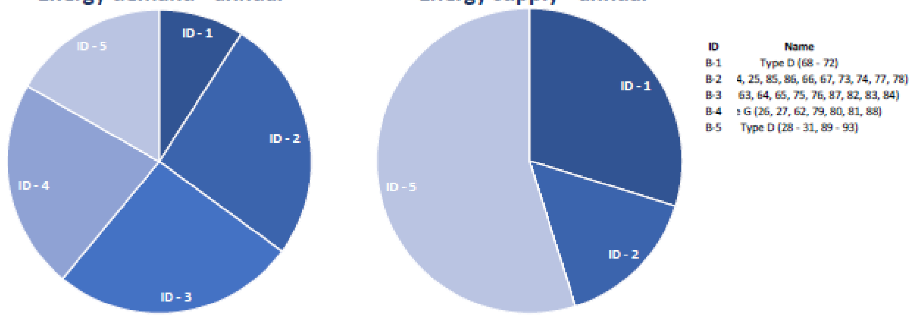
14-5-2023
V1

Energy flows (by ID)

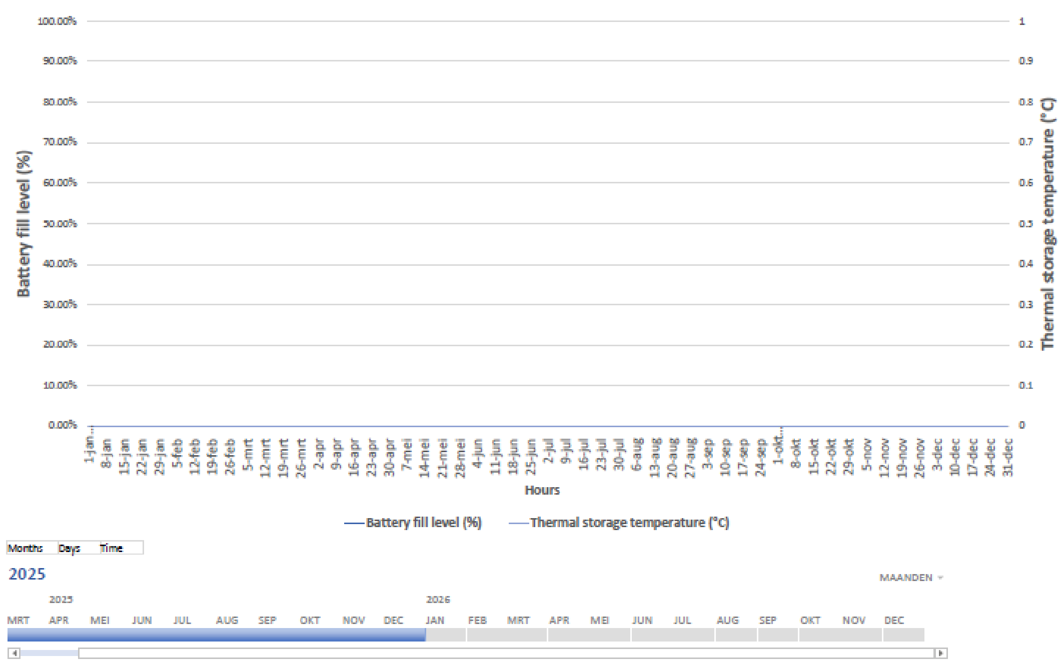


Energy demand - annual

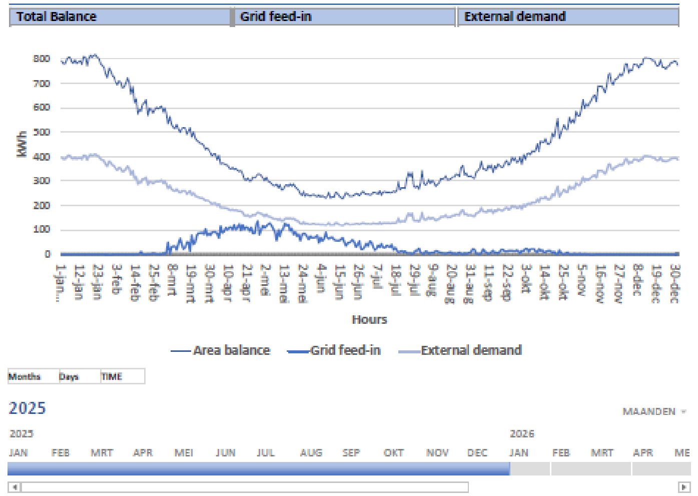
Energy supply - annual



Energy storage



Area overview



Grid demand:	Grid supply:	Battery		Thermal storage	
86485 kWh	10877 kWh	Average fill level:	Not present	Average temperature:	0.0 °C
Peak: 31.0 kWh	Peak: 17.4 kWh	Full-charged hours:	Not present		
		Peak input capacity:	Not present		
		Peak output capacity:	Not present		

Dashboard

DV- Buitengoed Heiloo - Phase 1 (typ

Combi A

Project location: 1851

Used weather data set: Nh, Den Helder, De Kooy

Key values:

Self-sufficiency: 82.4%

Total energy demand: 147073 kWh

Total renewable energy: 152214 kWh

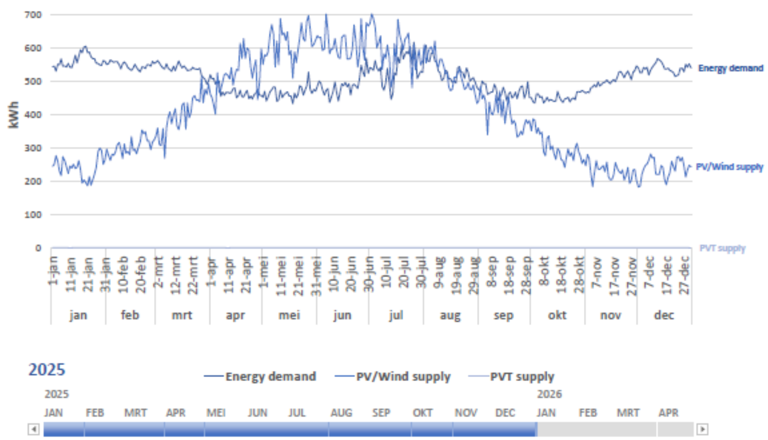
Plan size: 40

Residents: 106

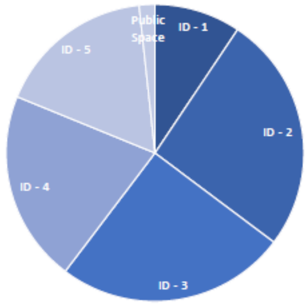
25-5-2023
V1

Energy flows (by ID)

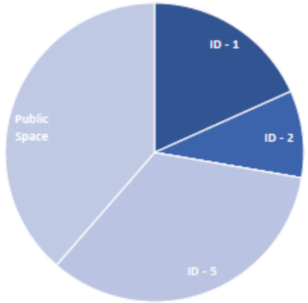
ID: B-1 | B-2 | B-3 | B-4 | B-5 | Public Space



Energy demand - annual

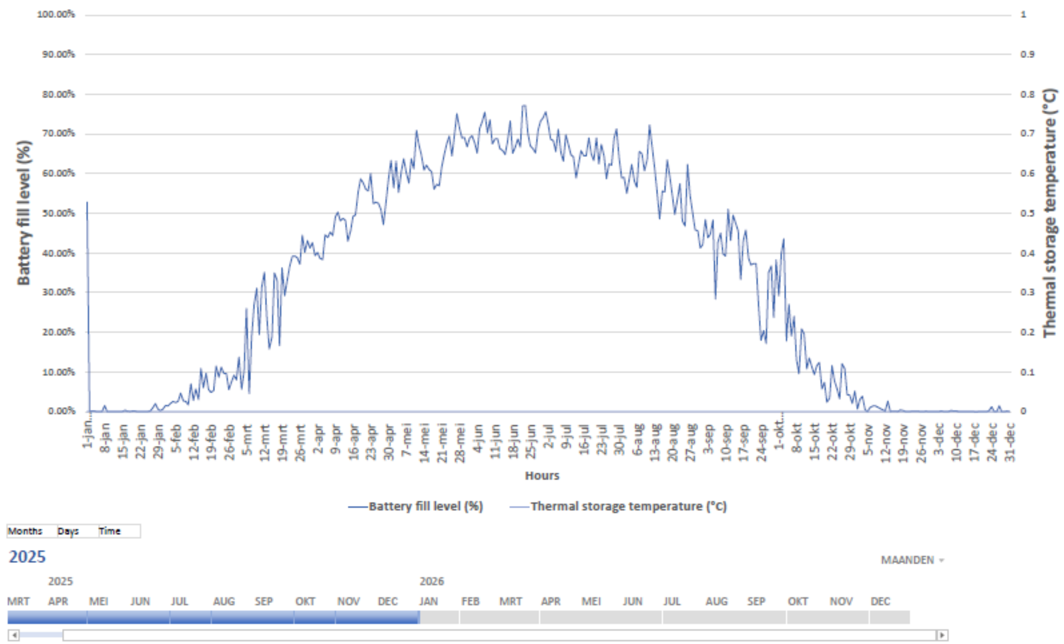


Energy supply - annual



ID	Name
B-1	Type D (68 - 72)
B-2	4, 25, 85, 86, 66, 67, 73, 74, 77, 78)
B-3	63, 64, 65, 75, 76, 87, 82, 83, 84)
B-4	±G (26, 27, 62, 79, 80, 81, 88)
B-5	Type D (28 - 31, 89 - 93)

Energy storage



Grid demand: 25835 kWh — Peak: 27.1 kWh

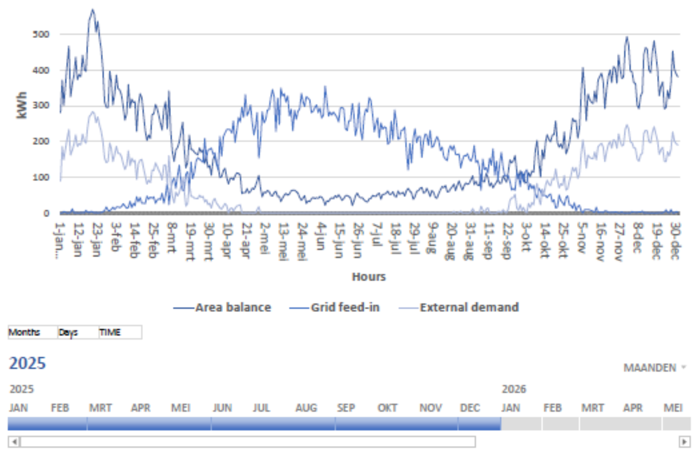
Grid supply: 46326 kWh — Peak: 42.2 kWh

Battery
Average fill level: 32.9%
Full-charged hours: 1308 h
Peak input capacity: 42.22 kWh
Peak output capacity: 27.10 kWh

Thermal storage
Average temperature: 0.0 °C

Area overview

Data type (area level): Total Balance | Grid feed-in | External demand



Dashboard

DV- Buitengoed Heiloo - Phase 1 (tyr

Combi B

Project location: 1851

Used weather data set: Nh, Den Helder, De Kooy

Key values:

Self-sufficiency: 82.3%

Total energy demand: 126888 kWh

Total renewable energy: 152214 kWh

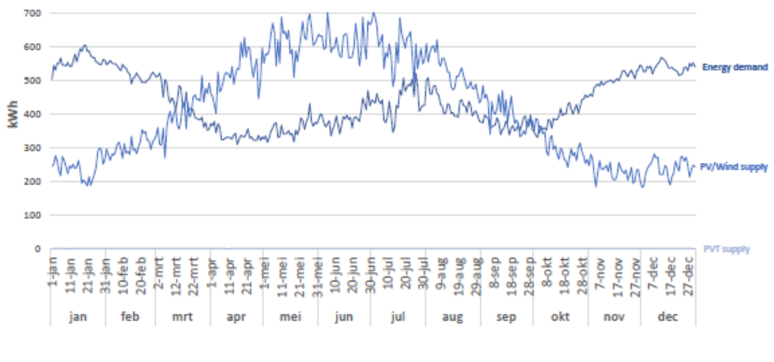
Plan size: 40

Residents: 106

25-5-2023
V1

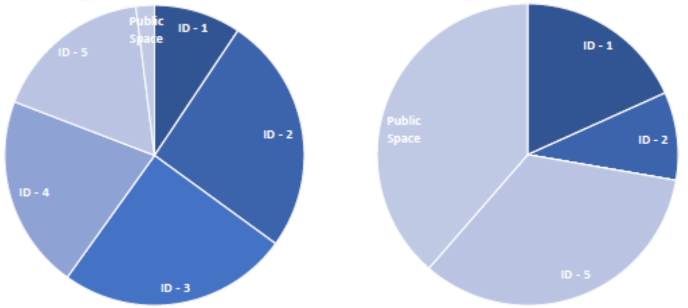
Energy flows (by ID)

ID: B-1 | B-2 | B-3 | B-4 | B-5 | Public Space



Energy demand - annual

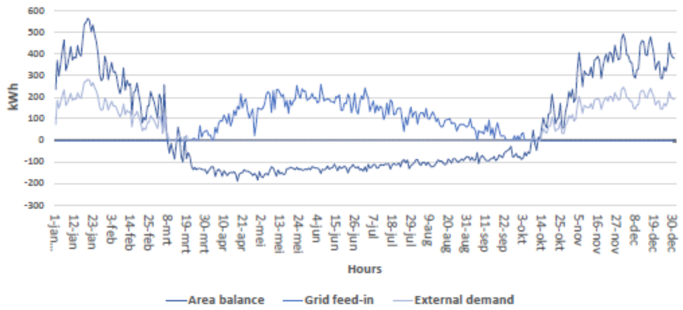
Energy supply - annual



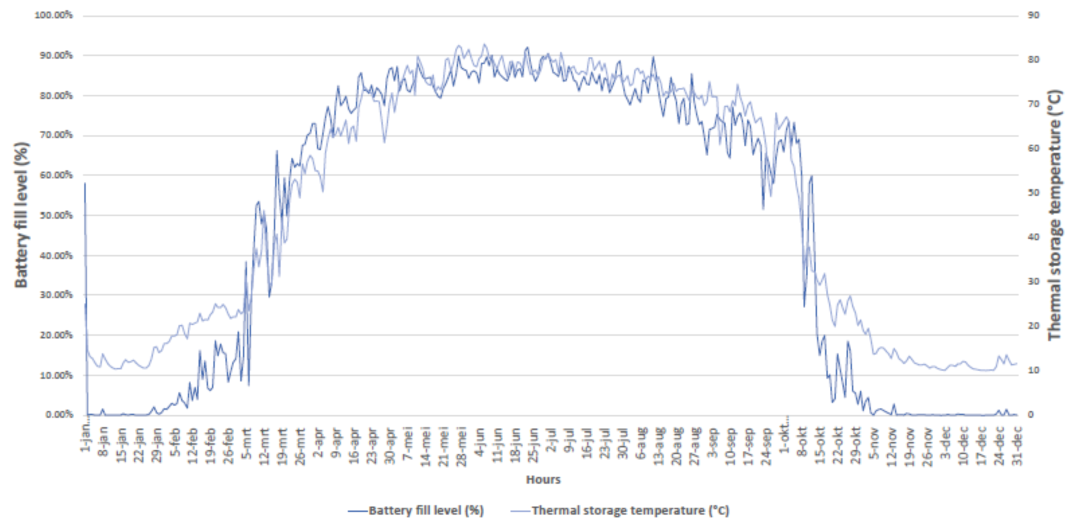
ID	Name
B-1	Type D (68 - 72)
B-2	4, 25, 85, 86, 66, 67, 73, 74, 77, 78)
B-3	63, 64, 65, 75, 76, 87, 82, 83, 84)
B-4	e G (26, 27, 62, 79, 80, 81, 88)
B-5	Type D (28 - 31, 89 - 93)

Area overview

Data type (area level): Total Balance | Grid feed-in | External demand



Energy storage



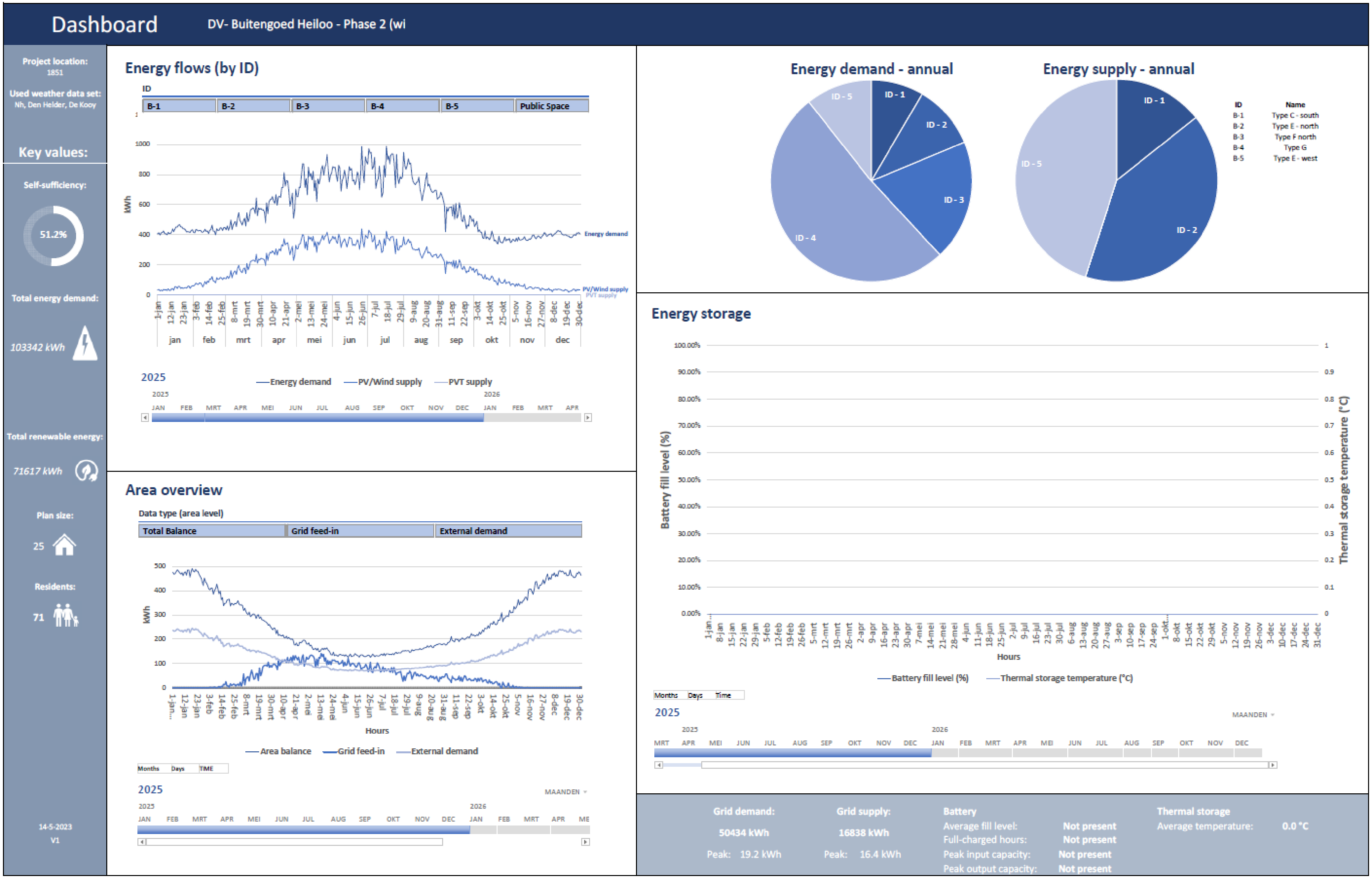
Grid demand: 22473 kWh
Peak: 27.1 kWh

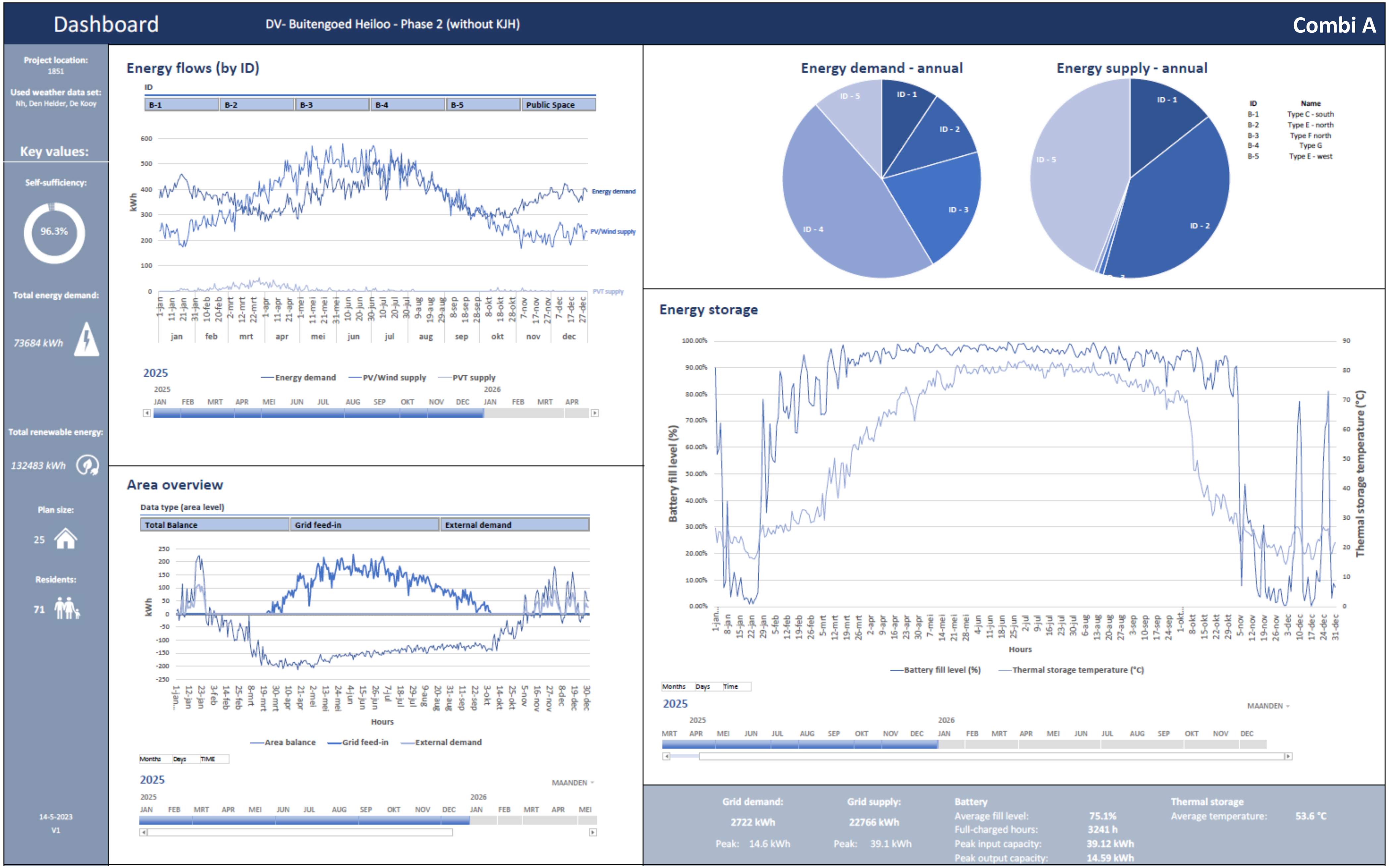
Grid supply: 23161 kWh
Peak: 46.1 kWh

Battery
Average fill level: 47.8%
Full-charged hours: 1902 h
Peak input capacity: 46.09 kWh
Peak output capacity: 27.10 kWh

Thermal storage
Average temperature: 47.8 °C

Appendix I


Dashboard
DV- Buitengoed Heiloo - Phase 2 (wi
Project location:
1851
Used weather data set:
Nh, Den Helder, De Kooy
Key values:
Self-sufficiency:
51.2%
Total energy demand:
103342 kWh
Total renewable energy:
71617 kWh
Plan size:
25
Residents:
71
14-5-2023
V1
Energy flows (by ID)
ID
B-1
B-2
B-3
B-4
B-5
Public Space
kWh
Energy demand
PV/Wind supply
PVT supply
2025
Energy demand - annual
Energy supply - annual
ID - 1
ID - 2
ID - 3
ID - 4
ID - 5
ID
Name
B-1 Type C - south
B-2 Type E - north
B-3 Type F north
B-4 Type G
B-5 Type E - west
Area overview
Data type (area level)
Total Balance
Grid feed-in
External demand
Hours
Area balance
Grid feed-in
External demand
Energy storage
Battery fill level (%)
Thermal storage temperature (°C)
Hours
Grid demand:
50434 kWh
Peak: 19.2 kWh
Grid supply:
16838 kWh
Peak: 16.4 kWh
Battery
Average fill level: Not present
Full-charged hours: Not present
Peak input capacity: Not present
Peak output capacity: Not present
Thermal storage
Average temperature: 0.0 °C


Dashboard
DV- Buitengoed Heiloo - Phase 2 (without KJH)
Combi A
Project location:
1851
Used weather data set:
Nh, Den Helder, De Kooy
Key values:
Self-sufficiency:
96.3%
Total energy demand:
73684 kWh
Total renewable energy:
132483 kWh
Plan size:
25
Residents:
71
14-5-2023
V1
Energy flows (by ID)
ID
B-1
B-2
B-3
B-4
B-5
Public Space
Energy demand
PV/Wind supply
PVT supply
2025
Energy demand - annual
Energy supply - annual
ID - 1
ID - 2
ID - 3
ID - 4
ID - 5
ID
Name
B-1 Type C - south
B-2 Type E - north
B-3 Type F north
B-4 Type G
B-5 Type E - west
Area overview
Data type (area level)
Total Balance
Grid feed-in
External demand
Hours
Area balance
Grid feed-in
External demand
2025
Energy storage
Battery fill level (%)
Thermal storage temperature (°C)
Hours
2025
Grid demand:
2722 kWh
Peak: 14.6 kWh
Grid supply:
22766 kWh
Peak: 39.1 kWh
Battery
Average fill level: 75.1%
Full-charged hours: 3241 h
Peak input capacity: 39.12 kWh
Peak output capacity: 14.59 kWh
Thermal storage
Average temperature: 53.6 °C

Dashboard

DV- Buitengoed Heiloo - Phase 2 (without KJH)

Combi B

Project location: 1851

Used weather data set: Nh, Den Helder, De Kooy

Key values:

Self-sufficiency: 95.6%

Total energy demand: 85746 kWh

Total renewable energy: 172699 kWh

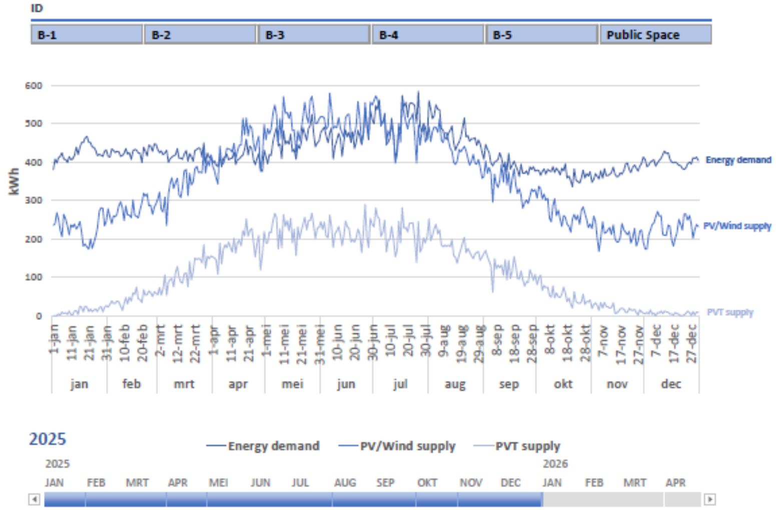
Plan size: 25

Residents: 71

14-5-2023

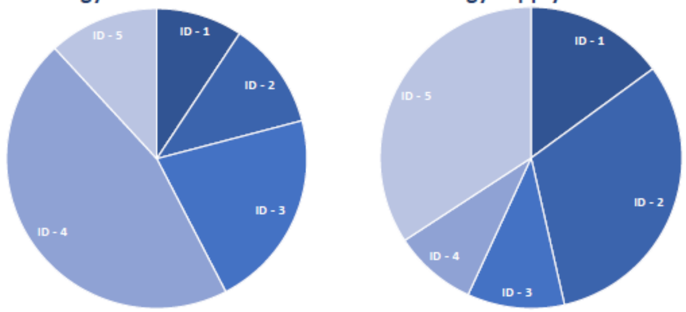
V1

Energy flows (by ID)



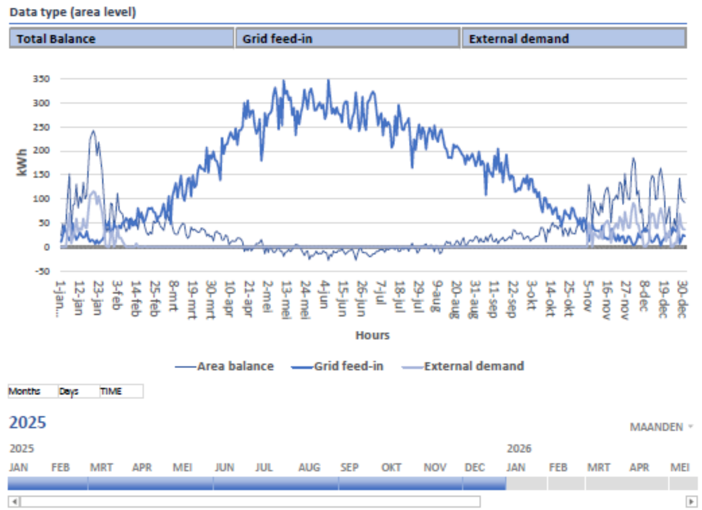
Energy demand - annual

Energy supply - annual

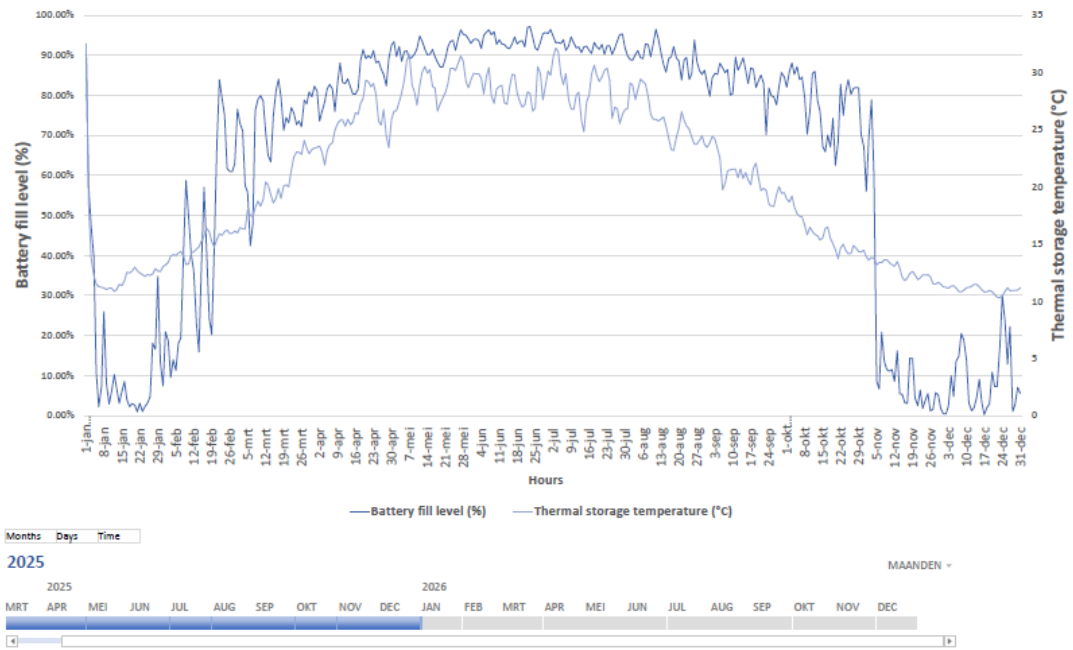


ID	Name
B-1	Type C - south
B-2	Type E - north
B-3	Type F north
B-4	Type G
B-5	Type E - west

Area overview



Energy storage



Grid demand: 3774 kWh
Peak: 15.2 kWh

Grid supply: 54030 kWh
Peak: 37.9 kWh

Battery
Average fill level: 63.9%
Full-charged hours: 2398 h
Peak input capacity: 37.87 kWh
Peak output capacity: 15.24 kWh

Thermal storage
Average temperature: 20.5 °C

Appendix J

Dashboard

DV- Buitengoed Heiloo - left nr. 68-80

Project location: 1851

Used weather data set: Nh, Den Helder, De Kooy

Key values:

Self-sufficiency: 100.0%

Total energy demand: 43690 kWh

Total renewable energy: 57581 kWh

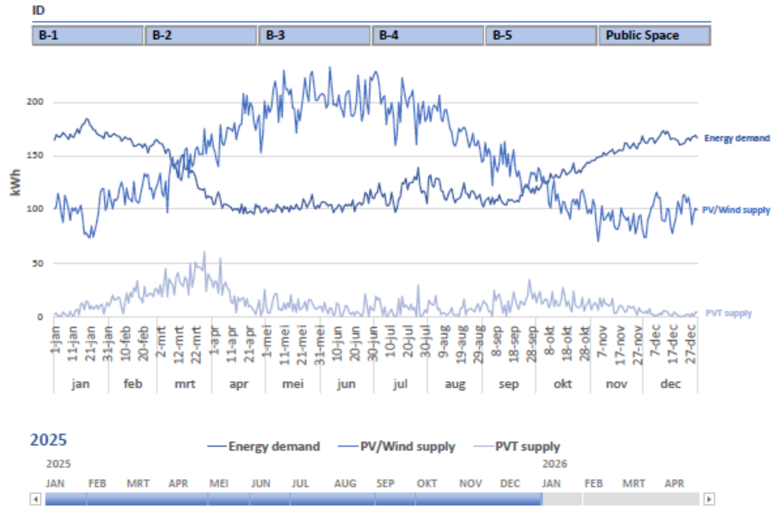
Plan size: 13

Residents: 34

14-5-2023

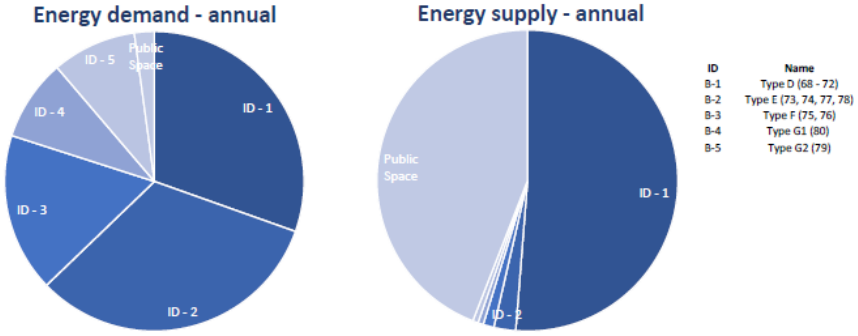
V1

Energy flows (by ID)

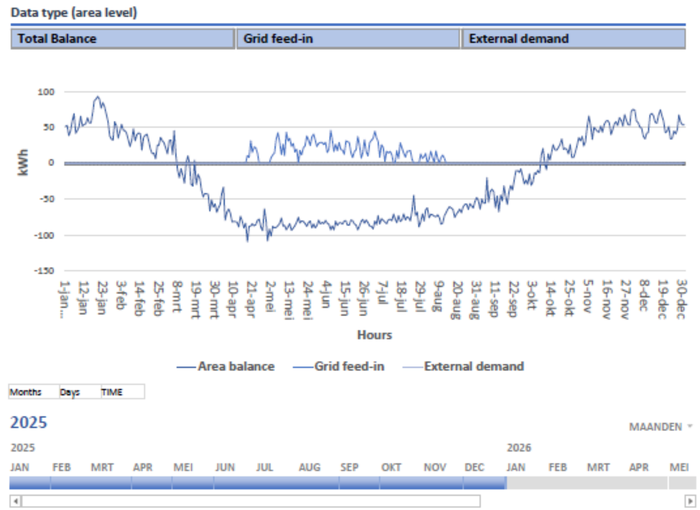


Energy demand - annual

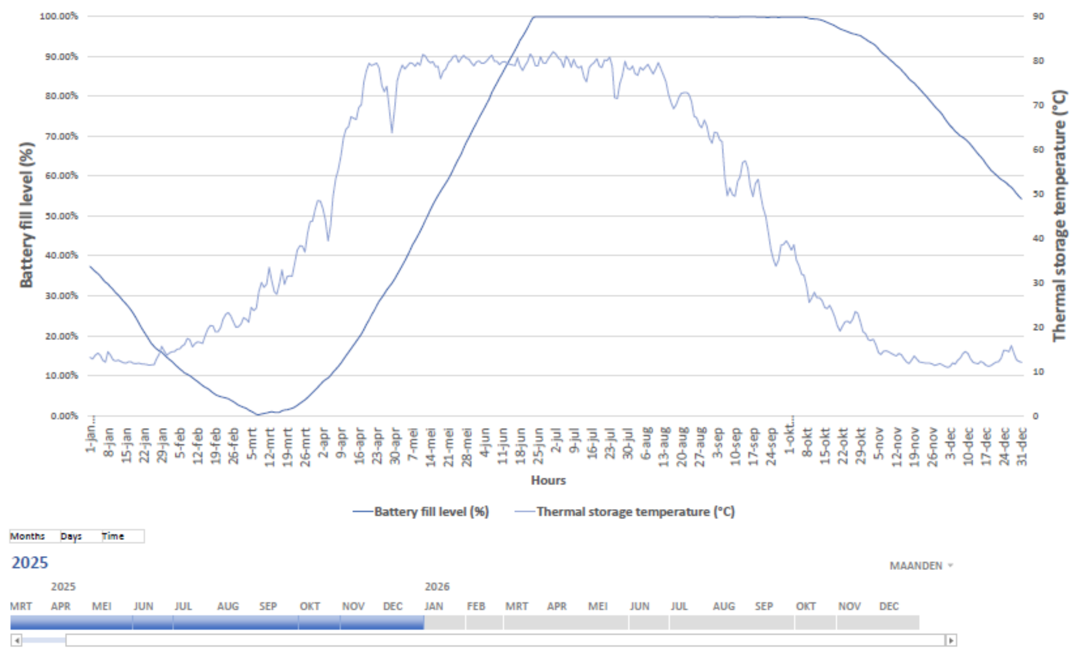
Energy supply - annual



Area overview



Energy storage



Grid demand:	Grid supply:	Battery		Thermal storage	
0 kWh	2081 kWh	Average fill level:	62.5%	Average temperature:	45.1 °C
Peak: 0.0 kWh	Peak: 14.9 kWh	Full-charged hours:	937 h		
		Peak input capacity:	15.57 kWh		
		Peak output capacity:	9.01 kWh		