

WP 2 - Development and Demonstration of plus energy multi-storey apartment buildings in four climatic zones

D.2.1 REPORT ON DESIGN PLUS ENERGY NEIGHBOURHOODS IN EACH OF THE FOUR CLIMATIC TYPES

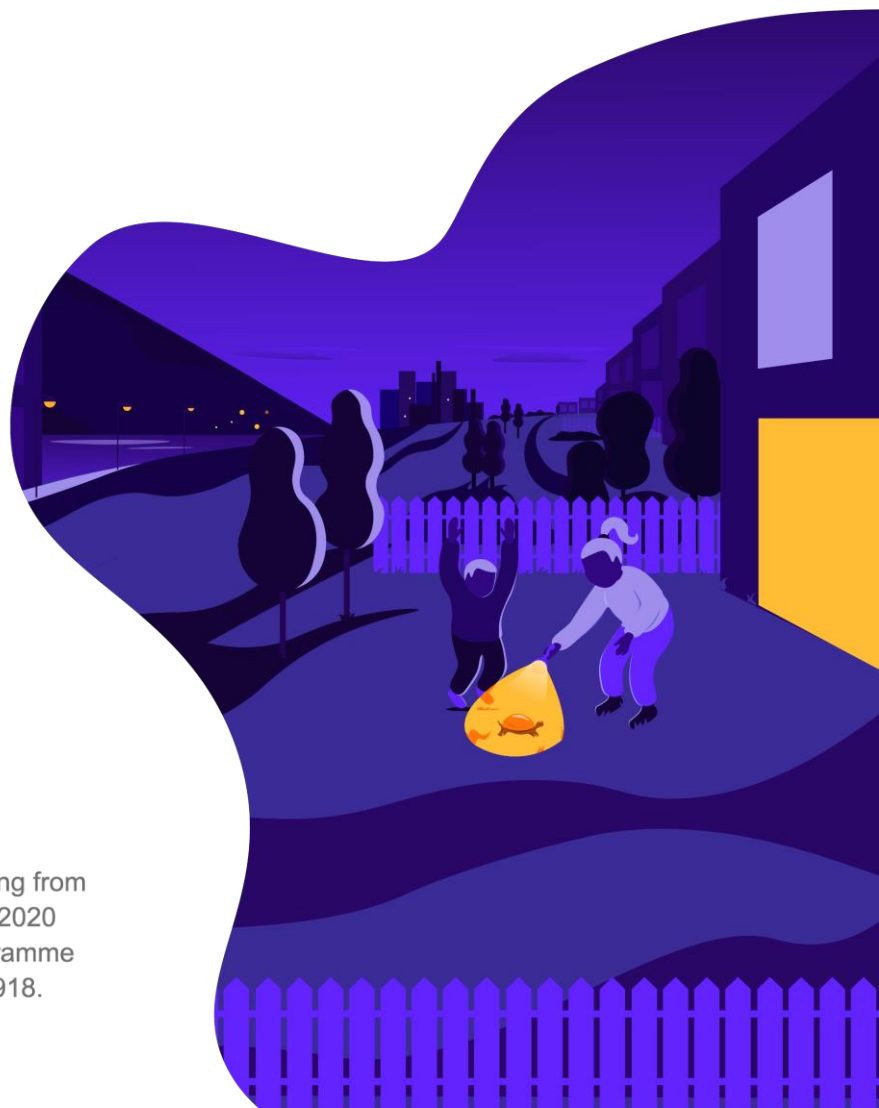
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Executive Summary

The main scope of this report is to describe the design process behind the development of the four different demonstration projects with insight in the effort devoted by the project partners in ensuring a positive energy balance and fulfilling Sustainable Plus Energy Neighbourhoods' targets. The report addresses both quantitative and qualitative variables and includes analyses developed in the first stages of the design process, including choices regarding materials, constructions, and technical systems of buildings and neighbourhoods.

Delivery of 2.1 corresponds to Task 2.1, entitled 'Integrated design and construction' and lasting from month 1 to month 18. In this task, the demonstration projects were developed towards sustainable plus energy neighbourhoods by applying methods of Integrated Energy Design (IED). The work includes the creation of scenarios for current and future climates, energy and power costs, energy flexibility, and user behaviour.

The performance of the plus energy neighbourhoods was predicted using dynamic simulation tools able to model parameters related to indoor climate, energy, power, and greenhouse gas emissions. Present conditions and future scenarios were simulated with combinations of state-of-the-art materials, components, technologies, and smart control systems. Design options and future scenarios were built taking into account the climatic context, user behaviour patterns, and the regulatory framework of each demonstration project. For evaluating and comparing results of different boundary conditions, the numerical framework and selected Key Performance Indicators developed as part of the joint evaluation framework - D3.1, were used as a framework for the evaluation of the different demonstration projects.

The performance analyses conducted show that after adjustments and applying solutions identified through integrated design approaches, the four demonstration projects will be able to fulfil SPEN targets in a wide range of conditions. This will ensure that all the four projects will deliver a positive contribution in terms of energy to the grid, while ensuring high quality indoor comfort and a healthy social environment to inhabitants.

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1. Roles and Responsibilities

Name	Role	Responsibility
NTNU	Task 2.1 leader. Coordinator of Deliverable contents and edition; Contributor and chapter editor	Definitions and limitations, Templates for describing Part A and Part B; Content's review. Edition of Deliverable; Coordination
SINTEF	Contributor	Demo project description and analyses
IREC	Contributor and reviewer	Excel for numerical framework used for the analyses; DEMO project description and analyses
TNO	Contributor	Demo project description and analyses
ABUD	Contributor	Demo project description and analyses

2. Introduction

On the 25th of September 2015, countries within the United Nations (UN) adopted an ambitious set of targets “aiming to end poverty and protect the planet while ensuring prosperity for all” [1]. In the new agenda, including seventeen targets to fulfil within a time framework of 15 years, smart technologies are pointed out as fundamental tools for re-harmonizing natural and built environment, while cities are described as the arena where a healthy relationship between man and nature should be restored [2].

The UN report projects that more than 68% of the world’s population will be living in urban areas by 2050 [3]. This represents a challenge but also an opportunity to transform cities into catalyst for a positive shift. Each neighbourhood in the city should become the opportunity to implement environmental solutions, addressing concerns related to a more sustainable development of social environment, transport, economic framework, and living quality.

As defined in syn.ikia, a Sustainable Plus Energy Neighbourhoods - SPEN – should reduce its direct and indirect energy use towards zero over the lifetime and ensure that the use of renewable energy sources is maximized. In addition, SPENs should produce more energy from renewable sources than they consume, while ensuring good indoor environmental quality and efficiently cover the building energy needs. Energy carriers within the geographical boundary of the neighbourhood should therefore include not only buildings, but also renewable energy and storage systems.

This report describes the effort devoted throughout the design process of the four demonstration projects to minimize their environmental impact, while ensuring architectural quality and good indoor comfort.

3. Objectives

A Sustainable Plus Energy Neighbourhood includes a discrete number of buildings with associated infrastructure, located within a confined geographical area. Infrastructure systems include renewable energy systems, accumulation tanks for buffering energy, and a digital platform which in syn.ikia is entitled Digital Cloud Hub. The digital platform will manage the energy exchange between energy carriers in the neighbourhood in a way to ensure the highest possible contribution to the energy grid.

A SPEN will necessarily be a highly energy efficient neighbourhood, where the surplus of energy is produced thanks to the integration of renewable energy sources. Energy flexibility is highly incentivised with the purpose of minimizing dependence on the energy grid. Direct consumption of electricity before being sent to the grid would moreover allow to minimize environmental impact of transport systems..

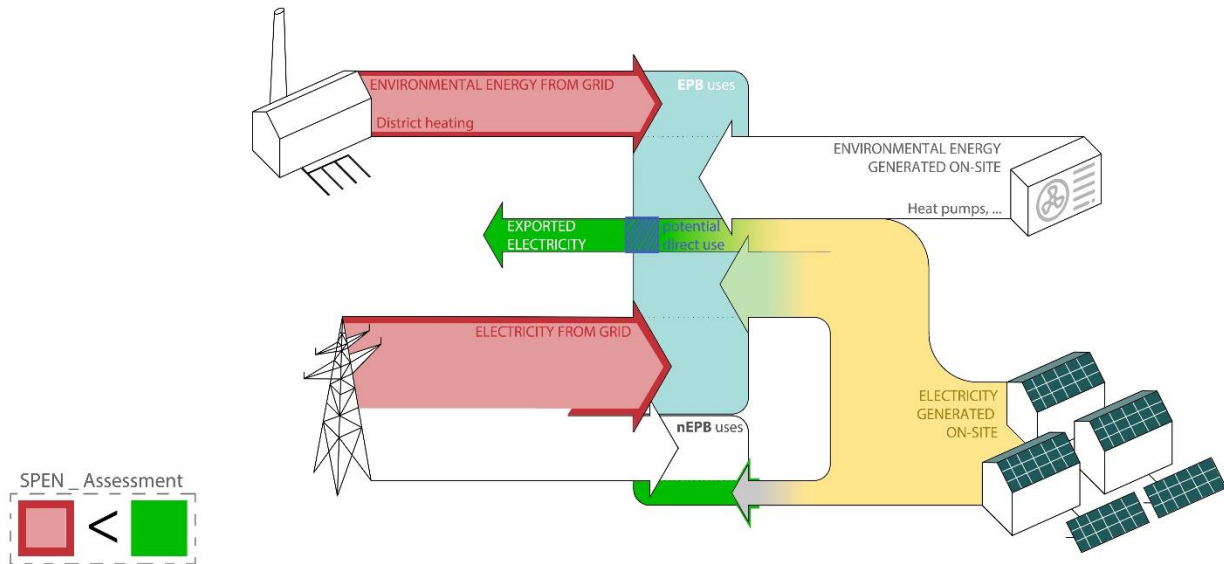


Figure 1. Graphical illustration of the assessment boundary and the energy flows of a SPEN

To ensure a high level of energy efficiency and a positive energy balance, the energy demand and the energy generation from the different energy sources need to be modelled throughout the design process. The energy balance is calculated taking into account all building operational energy uses; space and domestic hot water heating, space cooling, ventilation, and lighting, but excluding household appliances (plug loads). The calculation of the energy performance follows EN ISO 52000-1:2017. As illustrated in Figure 1, exported electricity to the grid and used for non EPB uses should be higher than the energy demand for EPB uses.

The ultimate purpose of energy flexibility and sharing within the neighbourhood boundaries, is that of ensuring minimal dependence on the grid and, more important, on its non-renewable energy component. Primary energy factors will be used in this report when evaluating the overall impact of the neighbourhood's energy demand.

The work developed in this report relies on the main Key Performance Indicators (KPIs) for Environmental and Energy performance as defined in syn.ikia's Evaluation framework report[4].

4. Description of the Deliverable

The syn.ikia project aims to design, build, and monitor the four demonstration projects within the timeframe of four years. In order to reach such an ambitious goal, the concepts and targets for the design and development of the neighbourhood were defined already from the start of the project. Technical solutions were also framed and aligned with the project concept and scope. Within the defined framework, in dialogue with contractors and developers, the project partners evaluated those solutions that could be considered as viable within the framework of the four demonstration projects.

The D2.1 report includes:

- Chapters 5, 6 and 7: A short description of methodological approaches for Integrated Energy Design of Sustainable Plus energy Neighborhoods (IED^N) followed by a description of the joint frameworks used for the evaluation of environmental and energy performance analyses and future scenarios.
- Chapter 8: Descriptions of environmental and energy performance analyses for each of the demonstration projects, including a general description of the project architecture, the strategies applied to fulfill SPEN targets, and a detailed description of simulation inputs, tools, and outputs. The environmental and energy performance analyses aimed to ensure that SPEN targets are fulfilled in present conditions.
- Chapter 9: Descriptions of scenario planning analyses for each of the demonstration projects, including how the scenarios have been built to ensure that the projects are robust enough to fulfill SPEN targets in a series of different boundary conditions regarding climate change, user behavior and energy and power costs.
- Chapter 10: The overall conclusions of the report are summed up, along with an outline of the further work with the syn.ikia demonstration projects.

5. Integrated Energy design at neighbourhood scale

Integrated Energy Design – IED - aims to ensure that technical concerns related to environmental and energy performance of the building are addressed from the early stages of the design process when form, construction, and technical system can still be adjusted in a way to serve the project targets. IED implies that more time is spent in the early stages of the design process to evaluate the performance of alternative design options and their impact on a series of parameters used as evaluation criteria. However, the increased time spent in the early phases is gained back by a more efficient process in the later design and construction phases.

The IED process was described, tested, and developed with the research Centre for Zero Emission Buildings [5]. Here, it was emphasized that an IED team working at building scale should include competences in the use of simulation tools able to give feedback on the effects of implementing alternative passive strategies such as utilisation of natural ventilation, daylight and thermal mass, and active systems such as HVAC and renewable energy systems integration.

The IED process' framework was used as a starting point for drafting the structure of an integrated energy design process at neighbourhood scale, abbreviated to IED^N. A first version of the IED^N process was developed as a result of a workshop where the four demonstration projects were discussed together with several syn.ikia partners. This resulted in a 7 step IED^N process as described below.

The further development of the demo projects in syn.ikia will provide new insight and experience for revising the IED^N process. However, for now, the draft 7-step IED^N design process was used as a template to describe the actual processes in the neighbourhood demonstration projects in Spain, the Netherlands, and Norway, to see how well it covered what had actually happened in the real projects. Feedback provided by the project partners will serve as basis the further development of the IED^N methodology towards the final deliverable D2.9 in M44. T

When working at a neighbourhood scale, the integrated energy design processes will consider not only quantitative parameters related to the environmental and energy performance of buildings in the neighbourhood, but also qualitative variables related to social environment or economic framework. An IED^N will therefore compromise numerical results provided by different kinds of simulation tools along with qualitative concerns related to aesthetics, social needs, and economic framework, among others.

The 7-step IED^N process that the demo project developers were asked to test and give feedback on includes:

Step 1. IED^N design team.

From day one, select a multi-disciplinary design team that is skilled in energy/environmental issues and motivated for close cooperation and openness.

When compared to IED at building scale, an IED^N process will involve a larger number of professionals and span over a longer time horizon. The design team will include professionals able to handle concerns related to outdoor environmental conditions and their relation to buildings' performance, their possible energy exchange, quality of outdoor areas, and social qualities.

A multi-disciplinary team would generally include the developer, a contractor contributing with "hands-on" experience and a pragmatic view to cost-effective solutions, an architecture firm, a landscape architect, and an energy/environment consultant. The team should be open to continuously revising the energy and environmental solutions throughout the development of the project. In some cases, a construction consultant for feasibility studies related to foundation and terrain, and other consultants related to fire, building physics, traffic, geology, daylight etc. could provide a valid support to the project. Material suppliers (such as solar panel suppliers) could also be included as valid support for the optimization of the project architecture in relation to specific issues (renewable energy generation, etc.). Finally, user participation/input is important to implement the needs of the community and neighbours and to reduce the "noise" and resistance later in the project.

Step 2. Boundary conditions and ambitions.

Analyse the boundary conditions of the project. Which stakeholders are/should be involved? What are the stakeholders' needs and demands? Clarify the project ambition and formulate a set of specific goals for the project. Make scenarios for future developments.

In syn.ikia, the main project targets were the positive energy balance of the neighbourhood, cost effectiveness, and ensuring apartments characterized by high quality in terms of indoor comfort and spatial qualities. Specific key performance indicators were developed for measuring the achievement of these targets.

Step 3. Quality assurance.

Make a quality assurance program and a quality control plan for follow-ups throughout the project phases.

The quality assurance should of course be based on current laws and regulations, but also on the specific goals of the project and the project partners' experiences. The quality assurance program and the quality control plan should be visited throughout the project stages, and special checkpoints should be made at key stages of the design and implementation phases. It will be important to prioritize the quality measures to find the most suitable that will give most value to the final project.

Step 4. IED^N kick-off workshop.

Arrange a kick-off workshop to make sure that all stakeholders and team members have a common understanding of the project and its goals.

Step 5. Design team workshops, methods and tools used.

Facilitate close cooperation between stakeholders (e.g. landowner, municipality, energy- and utility companies) and members of the design team (e.g. urban planners, architects, engineers) through a series of workshops during the project design phase. Apply appropriate methods and tools for continuous performance prediction and evaluation of design options.

Step 6. Document QA. Update the Quality Control Plan and document the energy and environmental performance at critical points (milestones) during the design.

Step 7. Contracting. Make contracts that encourage integrated design and construction.

How the syn.ikia demo projects addressed these steps will be further elaborated in the deliverable D.2.9.

6. Framework for environmental and energy performance analysis

Environmental and energy performance analyses were carried out for the different syn.ikia demo projects with the purpose of ensuring a positive energy balance and good indoor climate. Design options were built, taking into account the climatic context and regulatory framework of each demonstration project. For each alternative design option, the quantities shown in Table 1 were calculated and collected in the appendix.

Table 1. Example of energy quantities extracted for every design option.

SYN.IKIA proposed design worst case scenario. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	19,64	1,32	1,10	1,16	1,06	1,95	2,44	2,68	2,73	1,79	1,09	1,12	1,21
non EPB uses	kWh/m ²	29,25	2,49	2,23	2,51	2,39	2,49	2,44	2,41	2,47	2,44	2,47	2,43	2,47
EPB used electricity	kWh/m ²	11,29	0,67	0,63	0,74	0,76	1,22	1,39	1,52	1,46	1,01	0,69	0,58	0,61
Energy produced on-site	kWh/m ²	35,43	1,59	1,94	2,69	3,41	4,38	4,31	4,65	3,99	3,08	2,48	1,52	1,38
Environmental energy	kWh/m ²	10,18	1,29	0,96	0,81	0,75	0,78	0,75	0,75	0,77	0,75	0,77	0,78	1,03
Exported electricity	kWh/m ²	24,14	0,92	1,31	1,96	2,65	3,15	2,92	3,13	2,53	2,07	1,79	0,93	0,77
Exported for non EPB uses	kWh/m ²	13,35	0,75	1,10	1,08	1,52	1,53	1,42	1,27	1,14	1,17	1,01	0,76	0,60
Grid exported	kWh/m ²	10,79	0,17	0,21	0,88	1,13	1,63	1,50	1,86	1,39	0,90	0,78	0,17	0,17
Grid delivered, (EPB uses)	kWh/m ²	8,35	0,65	0,47	0,42	0,30	0,72	1,04	1,16	1,27	0,78	0,40	0,53	0,60
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-5,64	-0,10	-0,30	-0,55	-0,84	-0,87	-0,67	-0,70	-0,45	-0,46	-0,50	-0,14	-0,06

In order to analyse and better compare results of alternative design options and future scenarios, a diagram including “Energy generated on site”, “EPB uses”, “EPB used electricity”, and “Exported electricity for non EPB uses” was used throughout the report¹, see Figure 2. These quantities are fundamental for characterizing the energy performance of the neighbourhood and identify the best design option.

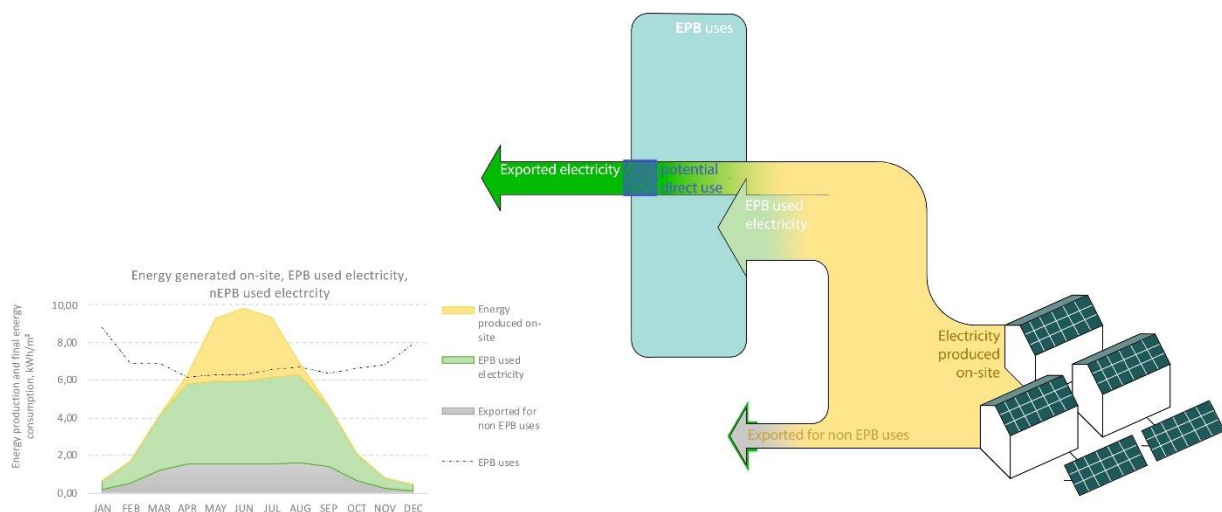


Figure 2. A representation of the diagrams used as reference for the comparison and evaluation of the alternative design options. The graph to the left shows the final energy balance following the syn.ikia assessment boundary (including EPB uses heating, cooling, DHW and lighting): Energy produced on-site (yellow area), EPB uses (dotted line, EPB used electricity from on-site production (green area) and energy exported for non-EPB uses (grey area).

Primary energy factors, as shown in Table 2, were collected for each demo project to calculate the renewable and non-renewable energy consumption of each demonstration project, following the

¹ EPB refers to the Energy Performance of Buildings Directive.

methodology described in the syn.ikia report on the evaluation framework [4]: “In the framework of syn.ikia, weighting factors for exported energy should be selected based on the resources avoided from the external grid, which is equivalent to “Step B” stated in ISO-52000. This means that for example the values of the delivered and exported weighting factors for electricity are considered to be equal”.

Table 2. Example of primary energy factors of energy sources in the neighbourhood, f_{ren} is the renewable primary energy factor, while f_{nren} is the non-renewable primary energy factor.

Primary energy source	f_{ren}	f_{nren}
Grid electricity	0.414	1.954
Produced PV electricity	1	0
Environmental heat	1	0

Yearly data of each design option were then collected in a summary table where results could be compared.

To describe the overall energy performance of a building / neighbourhood, two main indicators were selected: the non-renewable primary energy balance and the supply cover factor.

The non-renewable primary energy balance takes into consideration all types of energy consumed and produced by the system, and the exchange with the energy networks, and sums up all delivered and exported energy for all energy carries into a single indicator with the corresponding non-renewable primary energy weighting factors (unit: kWh/(m² y)). If non-renewable primary energy balance is lower than zero, it means that it is a plus energy neighbourhood.

The supply cover factor – or self-consumption - is the relation between the energy produced on-site and directly used, and the total on-site produced energy. As shown in Figure 3, the supply cover factor is the ratio between the self-consumed part (area C) and the total energy generation (area B+C). In ISO-52000, this factor is named ‘production matching fraction’ (unit: dimensionless).

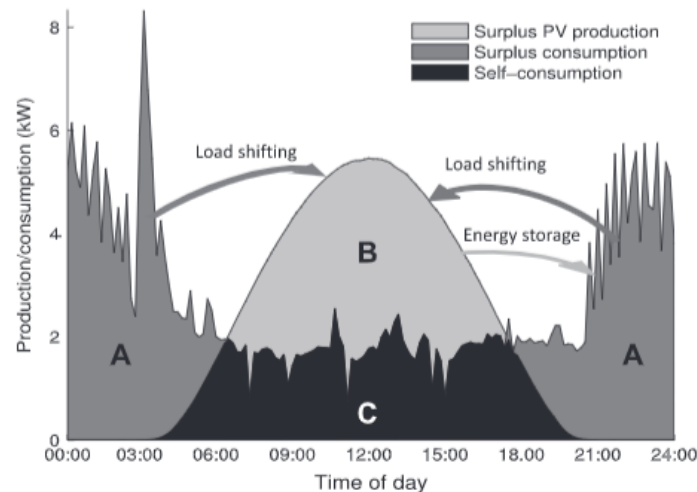


Figure 3. Schematic outline of daily net load (A + C), net generation (B + C) and absolute supply cover factor (C) in a building with on-site PV. It also indicates the function of the two main options (load shifting and energy storage) for increasing matching between on-site production and energy consumption [6].

To estimate the indoor environment comfort, Predicted Mean Votes (PMV) were calculated according to the theory of Fanger [7], or according to the adaptive comfort theory [8] when mechanical cooling is not provided. The best design options were identified as the ones ensuring a positive energy balance, a high supply cover factor based on the use of renewables, and good indoor comfort.

Table 3. An example of summary of results, where the best option is identified with a light blue colour.

Main KPI	case 1	case 2	case 3	case 4	case 5	case 6	case 7	case 8	case 9
Heating Demand [kWh/m ²]	9.14	9.35	5.97	10..6	12..0	10.6	3.99	3.74	9.40
Cooling Demand [kWh/m ²]	0	0	0	42.7	12.7	14.7	0	0	0
DHW Demand [kWh/m ²]	25	25	25	25	25	25	25	25	25
Lighting	13	13	13..1	13	15	13	13	13	13
COP-Heating	1	1	1	1	1	1	1	1	3.5
COP-Cooling	1	1	1	1	1	1	1	1	1
COP-DHW	1	1	1	1	1	1	1	1	1
PV production	55.4	55.4	55.4	55..4	55.4	55.4	55..4	55.4	55.4
Total primary energy consumption	93.4	93.9	85.9	96.9	102.2	96.9	81.2	80.7	112.2
Non-renewable primary energy consumption	33.9	33.9	33.1	34.3	38.5	34.3	32.6	32.5	92.6
Supply cover factor	0.39	0.55	0.42	0.44	0.47	0.44	0.42	0.42	0.19
PMV>0.5 [% of time overheating]	0.40	0.37	0.40	0.31	0.31	0.09	0.40	0.40	0.40
Cost [MNOK]	5.06	5.13	5.12	-	5.11	5.09	5.16	-	5.09

Notes: DHWO: Domestic Hot Water, COP: Coefficient of performance, PV: Photovoltaics. All values are yearly values unless otherwise noted.

For the design option identified as the best, a detailed energy balance is visualized as shown in Figure 4.

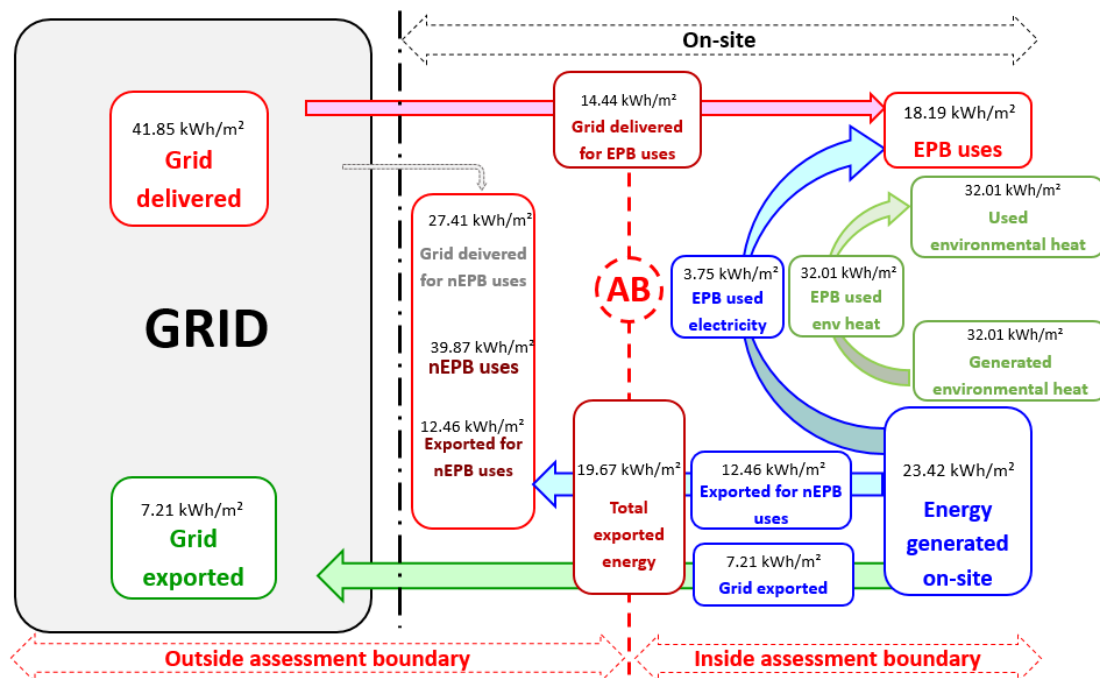


Figure 4. A detailed representation of the energy budget (credits: ISO 52000).

7. Framework for Scenario Planning

Scenario planning aims to identify “possible pathways towards a vision of the future” through a detailed analysis and understanding of present conditions and historic trends. On a general basis, scenario planning includes the following three steps:

Step 1. Analysis and understanding of present conditions and historic trends and events. In this first step, concerns regarding future scenarios are defined with the purposed of gathering data and separate certainties from uncertainties.

Step 2. Building future scenarios. Scenarios are built on the basis of data collected in the first step, identifying parameters and specific values that could be used as input for environmental and energy performance analyses.

Step 3. Analysing their impact on the project performance and possible targets' achievement. Analyse how demo projects would respond under identified conditions, evaluating the impact of the different scenarios on the key performance indicators. This third step includes also concerns related to the analysis' methodology and its reliability. The demo project is tested in relation to different scenarios using simulation tools. Measures are taken with the purpose of ensuring robustness and fulfilment of SPEN requirements.

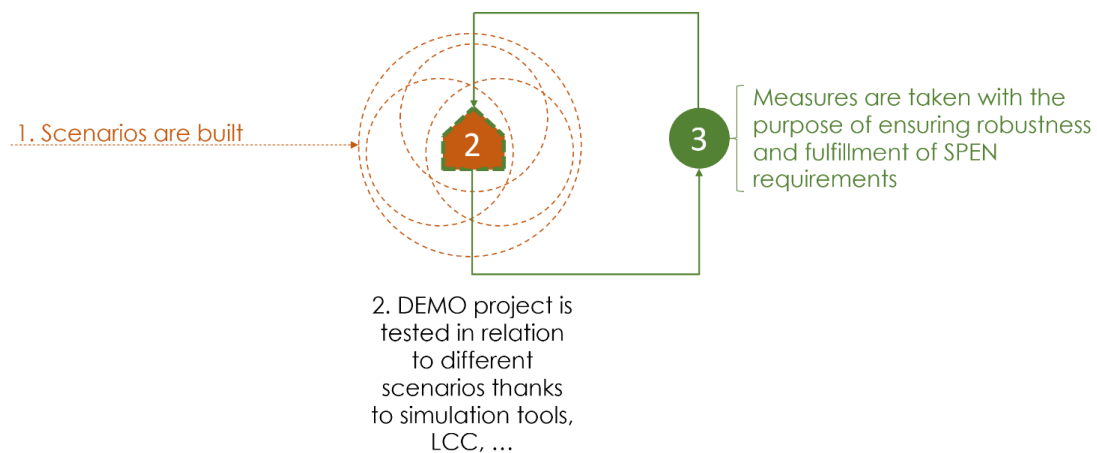


Figure 5. A diagrammatic representation of the three steps for scenario planning in syn.ikia.

In syn.ikia, both favourable and adverse future scenarios were built and analysed with the aim to ensure robustness of the demo projects in terms of energy performance. The ultimate intention was therefore to check if the energy balance would still be favourable given a series of different boundary conditions. Concerns related to variability of the following three different factors that could affect the environmental and energy performance of the neighbourhoods were addressed:

Cl _ Climate change

Ub _ User behaviour

Epc _ Energy and power cost in relation to flexibility

Climate Change

The IPCC panel described the following possible storylines related to climate change [9]:

1. The A1 storyline and scenario family describe a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies.
2. The A2 storyline and scenario family describe a very heterogeneous world where local identities are preserved, economy is locally oriented, and global population still increases according to today's patterns.
3. The B1 storyline and scenario describe a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

4. The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2. intermediate levels of economic development. and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

In the analysis and understanding of environmental and energy performance of the demonstration projects, scenarios A2 and B1 were considered as maximum and minimum impact in terms of global warming.

User behaviour

Research about the interrelation between user behaviour and energy efficiency of buildings shows that users may significantly affect the building energy performance [10]. This is often related to the desire of the user to customize indoor comfort, but also to the need to interact with the outdoor environment as a response to indoor environmental stresses.

User behaviour is hard to predict in present conditions, and assumptions about future scenarios are even more difficult to build. User behaviour is moreover highly affected by cultural differences and climatic conditions that might suggest different actions related to indoor comfort and energy use.

After discussion with the project partners, two generic profiles have been described for the future conditions: 'the passive' and 'the active' user. These profiles have created on the basis of specific concerns related to climate conditions, national regulatory framework, and buildings' use cultures.

Energy flexibility and power cost

Future energy and power costs are dependent on national policies but are also affected by energy exchange agreements and the effective implementation of new renewable energy system capacities.

Because of large differences in what could be expected as future scenarios for energy and power cost in each country, the four different demonstration projects have customized separate future scenarios based on national analyses and projections.

In building scenarios related to energy and power cost, the partners have applied models based on energy exchange between buildings and taken into account flexible solutions that may increase the direct use of electricity within the neighbourhood's virtual boundaries

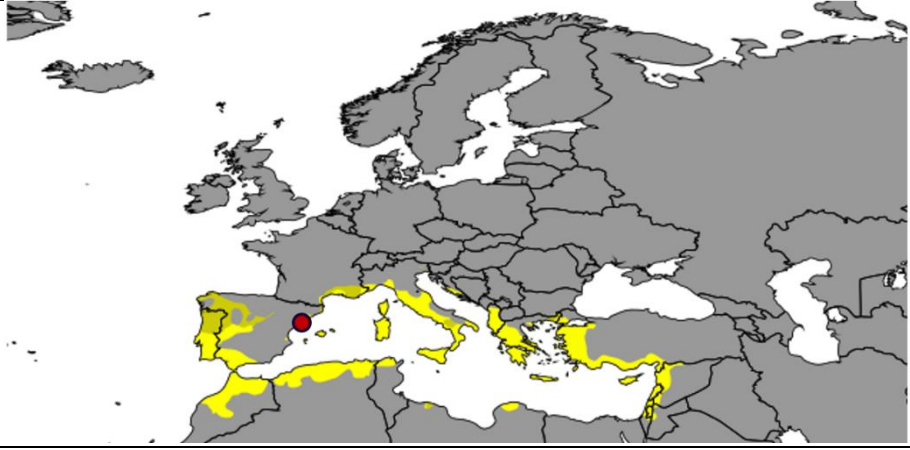
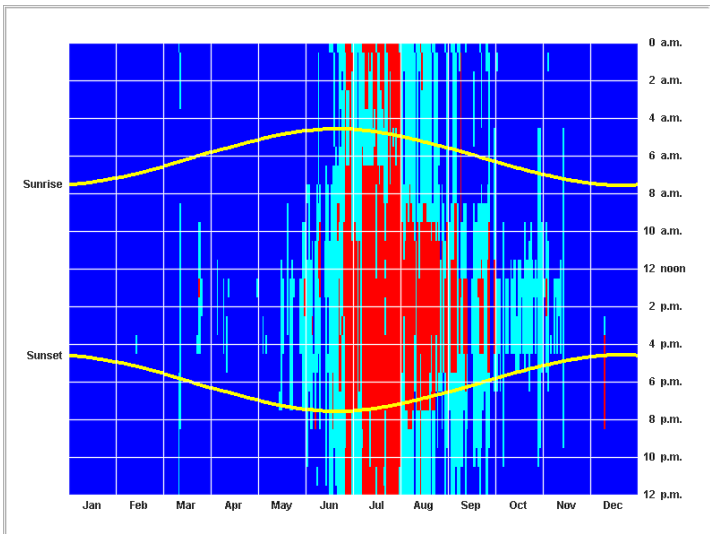
Optimistic and pessimistic scenarios

In order to evaluate the impact of possible future conditions on the neighbourhood's environmental and energy performance, the future scenarios Cl, Ub, Epc were modelled separately one after the other. Future conditions, however, will clearly be characterized by a combination of these factors. For this reason, two combined scenarios were also modelled, resulting from the combination of the most favourable and adverse conditions. The first scenario was defined as an optimistic one, while the second was considered to be a pessimistic one. The pessimistic scenario's modelling was developed in order to check the robustness of the project under what could be foreseen as being the most unfavourable conditions with respect to fulfilling the SPEN targets.

8. Environmental and energy performance analyses

This chapter contains the results of the environmental and energy performance analyses of the 4 demo projects. The scenario analysis of the demo projects follows in Chapter 12.

Mediterranean climate demonstration project

DEMO	Barcelona. Santa Coloma de Gramenet		
Key data	Program: Residential		
	Gross floor area: 2495 m ²		
	Heated floor area: 2154 m ²		
	Ambition: SPEN		
	Energy carriers	1	Electricity
Location	Barcelona, Spain		
	Lat: 41,39		
	Long: 2.16		
Climate	Mediterranean		
	HDD: 1438 hours		
	CDD: 75 hours		

Project scope and description

The project is located in Santa Coloma de Gramenet, a city located 4 km from Barcelona, and the demonstration area is placed in a neighbourhood that is involved in an urban regeneration process. The project aims to create open spaces in an existing neighbourhood, refurbishing the buildings of the area and improving habitability of the surrounding buildings. The demonstration site includes 38 dwellings, 2 commercial premises, and 38 parking spaces, from which the 38 dwellings are within the scope of syn.ikia.

Program and social dimension

The design includes the construction of 38 dwellings. All of them are composed of a living room, kitchen, two bedrooms, and one bathroom. The bedrooms are double and of similar area, which allows organizing the house for different family or social groups.

The purpose of the building is to provide housing to people that have economic difficulties to access a house in the open market. This fact has to be considered also to obtain low operating costs.

Environmental concept and ambition

The integrated energy design process of the building includes both passive and active energy saving solutions. From passive design, the building has undergone a process of testing different design parameters in which an optimal combination of building envelope solutions has been chosen, which goes further than the current regulatory framework. The selected technical system allows to cover the low thermal demands of the building with an innovative and highly efficient solution. Additionally, the building includes a photovoltaic installation to cover the electric needs of the building and to share the excess energy with the neighborhood. The integrated energy design process has been done based on a multicriteria analysis, considering energy, environmental, indoor comfort, and economic parameters.

Flexibility concept

The building has been designed considering that in the coming years it could be connected to a new District Heating (DH) system supplied with spring water that will be promoted by the City Council of Santa Coloma de Gramenet. The centralized heating solution of the building has been designed for two main goals. On the one hand, it has been designed to make the most of the photovoltaic electricity generated in the planned installation. On the other hand, it has been designed to make the future connection to the district heating system simple and with a minimum cost.

In order to guarantee the success and maximum use of the electrical generation installation, the building will be conveniently managed by an operator who will maintain and manage the turnover and as well as the efficiency of the overall plus energy building and the possible interaction and energy share with other buildings in the neighborhood. In this way, the constitution of an energy communities with other nearby buildings and entities is being considered.

Additionally, the HVAC and DHW systems will implement model predictive control to optimize the performance of the building and its interaction with the neighborhood, and to exploit the available energy flexibility at every moment of the day. Figure 6 shows the flexibility concept of the Mediterranean demo site, representing the different elements of the building and how will be operated (manual operation, schedule operation and by control signals).

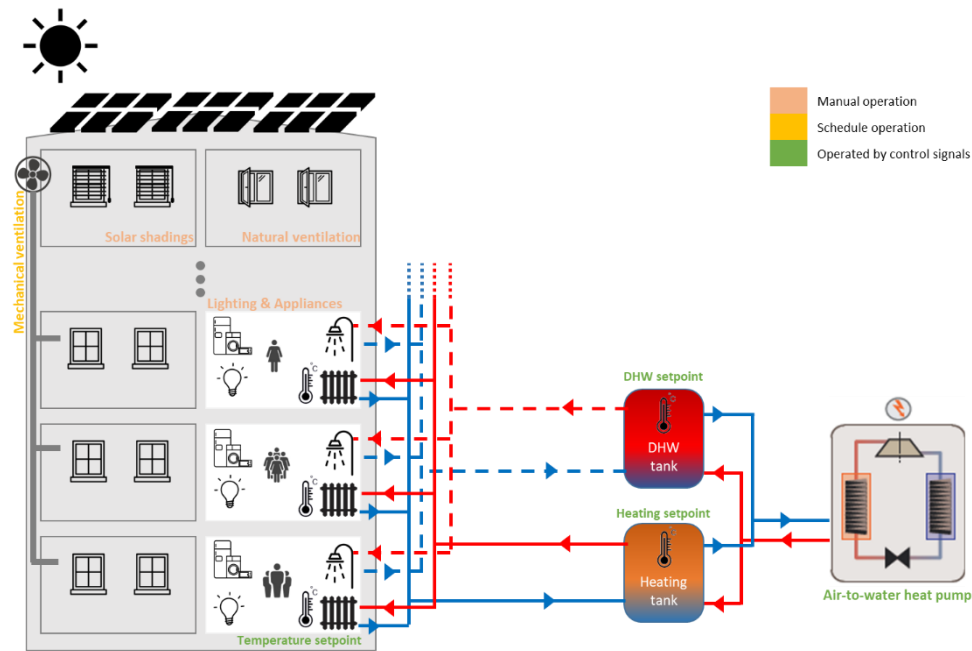


Figure 6. Scheme of the flexibility concept of the Mediterranean demo site. representing all the elements of the building according to their operation scheme: manual, schedule and by control signals.

Architecture and sustainability

The integrated project design includes the achieving the best possible balance between architecture and sustainability. Factors like thermal insulation, best percentage of openings depending on facade orientation, shading for sunlight control, absorptivity of materials, and color of façades, have been studied to optimize energy performance while achieving the best possible indoor environmental comfort and architectural quality.



Figure 7. Illustration of the demo project located in Santa Coloma de Gramenet.

Environmental and energy performance analyses

Regulatory framework and technical codes

For energy and environmental performance analysis, the demonstration site in Barcelona follows the technical requirements from the Spanish Building Code (CTE) [11]. Spain has been divided into 12 climate zones, from which the Barcelona demo site is in zone C2. The important requirements and the calculation criteria of CTE are presented in Table 4 and the primary energy conversion factors are shown in Table 5.

Model and tools

The energy simulations of the Barcelona demo site building are carried out with the transient system simulation tool TRNSYS 18 [12], using SketchUp as a 3D interface. The building model has been performed to provide energy and thermal comfort performance predictions. For the evaluation of local energy production from solar panels, the PV design and yield forecast software Archelios [13] is used. The PV production results obtained by Archelios have been introduced to the building model in order to calculate the energy balance of the building.

Table 4. Technical requirements and calculation criteria of the Spanish Building Code (CTE).

Technical requirements	Spanish Building Code (CTE)		
Envelope	External wall. U-value	< 0.49	W/(m ² K)
	Ground floor. U-value	< 0.70	W/(m ² K)
	Roof. U-value	< 0.40	W/(m ² K)
	Windows. U-value	< 2.10	W/(m ² K)
Infiltration and ventilation	Infiltration rate	0.57	h ⁻¹
	Night ventilation in summer	4	h ⁻¹
Internal gains	Occupancy: Sensible / Latent heat	Weekday 07h-15h 0.54 / 0.34 15h-23h 1.08 / 0.68 23h-07h 2.15 / 1.36 Weekend All day 2.15 / 1.36	W/m ²
	Lighting / electric equipment	07h-18h 1.32 / 1.32 18h-19h 2.20 / 2.20 19h-23h 4.40 / 4.40 23h-00h 2.20 / 2.20 00h-07h 0.44 / 0.44	W/m ²
Heating and cooling system	Operation time	Heating: October - June Cooling: June - September	-
	Heating set point	07h-23h 20°C 23h-07h 17°C	°C
	Cooling set point	07h-15h OFF 15h-23h 25°C 23h-07h 27°C	°C

Table 5. Primary energy weighting factors of Spain.

Primary energy source	fren	fnren
Grid electricity	0.414	1.954
Produced PV electricity	1	0
Environmental heat	1	0

The Barcelona demo site building is a residential complex which has 38 dwellings. The building has 2 blocks, the bigger one has its external side oriented north-west and the smaller one has its external side oriented

south-east. In between of the 2 blocks is an open courtyard and the entrance to the households are also provided from the courtyard side. The building has 7 floors organized as shown in Figure 8 and Table 6. In the north-west block, there is a ground floor that holds commercial areas and the upper 5 floors are residential households. In the south-east block, the first floor holds a common bicycle parking area and the upper 4 floors are residential households. The building has parking lots on 2 floors (ground floor and sub-ground floor). A typical dwelling of the building consists of 2 bedrooms, 1 bathroom, and one open kitchen/living room.



Figure 8. Architectural drawings of floor plan of the Barcelona demo site building's attic floor (left) and the elevation section (right). Detailed households are circled with orange.

Table 6. Building floors description

Floors	North-west block	Building model	South-east block	Building model
Sub-ground	Sub-ground floor – parking lot	No	Sub-ground floor – parking lot	No
Ground	Ground floor – Commercial area	Yes	Sub-ground floor – parking lot	Yes
1 st	Typical floor – residential floor	Yes	1 st floor – Bicycle parking	No
2 nd	Typical floor – residential floor	No	Typical floor – residential floor	No
3 rd	Typical floor – residential floor	No	Typical floor – residential floor	No
4 th	Typical floor – residential floor	Yes	Typical floor – residential floor	Yes
Attic	Attic floor – residential floor	Yes	Attic floor – residential floor	Yes

The 3D model of this building, Figure 9, has 32 zones, in general there is 1 zone per household, but for detailed comfort analysis there are 4 dwellings that each have 4 zones – one for each room. Two of the detailed dwellings are on the typical floor and two on the attic floor in order to observe critically behaving zones. Both floors have one dwelling from the north-west block and one from the south-east block (marked with orange circles in Figure 8 (left)) to monitor closely the effects of orientation. Additionally, from the 6 floors of the building, 3 of them have been simplified in the 3D model and are not completely included in the simulation model in order to speed up the computation time. Also, for the same reason, the sub ground parking floor has not been included in the simulation. The 3rd and 4th floors are added to serve shading objects in the simulation. In the final stage of the building performance evaluation, the results of a typical floor are aggregated over 2 floors for the north-west block, and over 3 floors for the south-east block, in order to obtain the thermal demands of the whole building. For model simplification purposes, the terraces of the building are added as shading objects. The floors included in the building model are detailed in Table 6. The surrounding buildings are added as shading objects (purple) to the model as shown Figure 9.

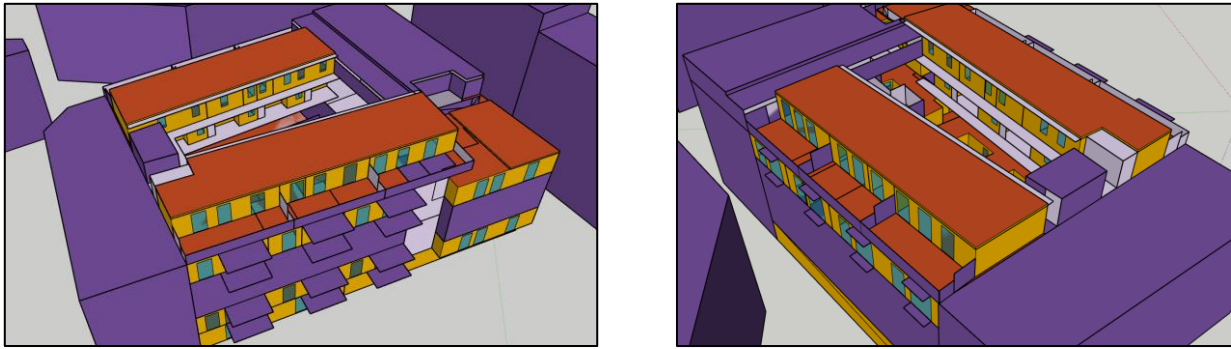


Figure 9. The 3D model. view from the north (left) and east (right).

Design options

The integrated design process of a building consists of testing multiple cases to determine the best fit to the building's location, use, and cost. For the Barcelona demo site, 8 alternatives are simulated and are summarized in Table 7. There are 5 categories of parameters that are modified along the 8 design options: envelope and infiltration, ventilation, solar shading, heating, cooling, DHW systems, and local photovoltaic production.

Case 0 is the starting point of the building design, where the building fits the Spanish regulation in terms of envelope. A centralized air-to-water heat pump is chosen to cover the heating and DHW demand of the whole building and a photovoltaic system is considered in the building. Case 1 and Case 2 are focused on the improvement of the passive design of the building, increasing the envelope insulation and optimizing the ventilation and solar shading strategies, taking in consideration an increase awareness of the users. Case 3 includes the optimal passive design (Case 1) and separates the heating and DHW storage and distribution systems, allowing to work at different temperatures in both circuits. Case 4 implements a reversible air-to-water heat pump to cover the cooling demand, which was covered by passive strategies in the other cases (natural ventilation and solar shadings). In Case 5, Case 6, and Case 7, based on Case 3 design options, different photovoltaic configurations were tested, changing the orientation and the number of panels.

Table 7. Part A simulation case descriptions of the Mediterranean demo site in the IED process. (CTE: Spanish building code. DHW: Domestic Hot Water. SE: South East orientation. W: West orientation. E/W: East and West orientation)

DEMO	Barcelona							
Categories	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Envelope & infiltration	CTE	Improved CTE	High insulated	Improved CTE	Improved CTE	Improved CTE	Improved CTE	Improved CTE
Ventilation	CTE	Optimized	Optimized	Optimized	Optimized	Optimized	Optimized	Optimized
Solar shading	CTE	Optimized	Optimized	Optimized	Optimized	Optimized	Optimized	Optimized
HVAC & DHW systems	2-pipes	2-pipes	2-pipes	4-pipes	4-pipes	4-pipes	4-pipes	4-pipes
	Heating DHW	Heating DHW	Heating DHW	Heating DHW	Heating Cooling DHW	Heating DHW	Heating DHW	Heating DHW
	CTE schedule	Optimized schedule	Optimized schedule	Optimized schedule	Optimized schedule	Optimized schedule	Optimized schedule	Optimized schedule
PV design	SE	SE	SE	SE	SE	W	E/W	SE-ZEB

Envelope and infiltration

There are three alternatives of the envelope considered: one version that follows the CTE criteria (Spanish building code), one with an envelope that improves the CTE performance, and one highly insulated version that far exceeds the CTE criteria. The characteristic details of the three alternative scenarios are presented in Tables 8, 9, and 10 for external walls, roofs and windows.

Table 8. External wall layout for the three different alternatives: CTE, Improved CTE, and High insulated

Characteristics		CTE	CTE improved	High insulated
Inside	Plasterboard. thickness	0.015 m	0.015 m	0.015 m
	Perforated brick. thickness	0.140 m	0.140 m	0.140 m
	Expanded Polystyrene (EPS). thickness	0.070 m	0.110 m	0.140 m
Outside	Mortar. thickness	0.008 m	0.008 m	0.008 m
U-value		0.402 W/m ² K	0.273 W/m ² K	0.220 W/m ² K

Table 9. Roof layout for the three different alternatives: CTE, Improved CTE, and High insulated

Characteristics		CTE	CTE improved	High insulated
Inside	Plasterboard. thickness	0.020 m	0.020 m	0.020 m
	Reticulated reinforced concrete slab. thickness	0.270 m	0.270 m	0.270 m
	Extruded polystyrene. thickness	0.080 m	0.100 m	0.150 m
	Sublayer of felt. thickness	0.001 m	0.001 m	0.001 m
	Mortar. thickness	0.020 m	0.020 m	0.020 m
Outside	Tile. thickness	0.05 m	0.05 m	0.05 m
U-value		0.397 W/m ² K	0.331 W/m ² K	0.234 W/m ² K

Table 10. Glazing properties for the three different alternatives: CTE, Improved CTE, and High insulated

Characteristics	CTE	CTE improved	High insulated
Frame	Thermal break Aluminum	Thermal break Aluminum	Thermal break Aluminum
U-value	1.69 W/m ² K	1.1 W/m ² K	1.1 W/m ² K
Glazing	4/12/4	4+4/16-Ar/5+5 Low-e	4+4/16-Ar/5+5 Low-e
SHGC	0.66	0.67	0.67

Regarding the infiltration characteristics, the CTE establishes a maximum infiltration rate of 0.57 h⁻¹. However, based on measurement data and literature review [14], it is possible to improve this value in high quality construction buildings. In the Barcelona demo case, there will be quality controls during the building process, such as blower door tests. It is therefore reasonable to consider an improved level of infiltration rate of 0.4 h⁻¹, which corresponds to approximately n₅₀=5 h⁻¹. Table 11 summarizes the infiltration rates used in each alternative design.

Table 11. Infiltration rate for the three different alternatives: CTE, Improved CTE, and High insulated

Characteristics	CTE	CTE improved	High insulated
Infiltration rate	0.57 h ⁻¹	0.4 h ⁻¹	0.4 h ⁻¹

Ventilation strategy

Two different ventilation strategies have been tested in the building design process. The first one is related to the CTE recommendations, that establish a night ventilation during summer months. However, as the objective is to achieve comfortable conditions in summer without a cooling system, an optimized ventilation strategy has been tested. The optimized ventilation strategy is based on the appropriate use of natural cross ventilation by the occupants, which is a typical strategy of vernacular architecture in Mediterranean

climates. The optimized ventilation strategy is activated when one of two conditions are happening, as is summarized in Table 12:

- The operative temperature (Top) of the household is between 24 and 28°C
- The operative temperature is exceeding 28°C and at the same time is exceeding the outdoor temperature (Tout).

Table 12. Ventilation strategy for the two alternatives: CTE and Optimized

Description	CTE	Optimized
Ventilation rate	4 h ⁻¹	4 h ⁻¹
Operation	June-September. Night ventilation: 00h - 07h	Top = 24 - 28°C Top > 28°C & Top > Tout

Solar shading

The shading controls are applied to the external facades of the building that are not facing the courtyard. Two operation strategies of the solar shading are defined: CTE and Optimized. The optimized solar shading strategy is part of the passive design of the building. The solar shading elements allow the occupants to practice a vernacular strategy to optimize their energy use and to take advantage of solar gains or protection from the sun, depending on the season. The solar shading strategy depends on temperature- and radiation-based controls. The solar shading is present when:

- The operative temperature is over 24°C and
- The solar radiation (Rs) level on the corresponding orientation is over 140 W/m².

The solar shading is removed when:

- The operative temperature is below 24°C or
- The solar radiation level on corresponding orientation is lower than 120 W/m².

Table 13. Solar shading strategy for the two alternatives: CTE and Optimized

Description	CTE	Optimized
Shading factor	0.92	0.7
Operation	June-September All day	<div>ON</div> <div>Top > 24.5 °C</div> <div>&</div> <div>Rs >140 W/m²</div> <div>OFF</div> <div>Top <24.5 °C</div> <div>or</div> <div>Rs <120 W/m²</div>

Heating, cooling, and DHW systems

The heating, cooling, and DHW systems include three air-to-water heat pumps. The technical information of the 3 heat pumps is presented in Table 14. Three alternative configurations are compared, as indicated in Table 15: 2-pipes Heating and DHW system, 4-pipes Heating and DHW system, and 4-pipes Heating, Cooling and DHW system. Figure 10 shows the distribution scheme of the 4-pipes system. In the scheme there are three air-to-water heat pumps where each outdoor unit is connected to two indoor units. After the indoor units, there is a collector to distribute the mass flow to the heating tank and the DHW tank. After the heating and DHW tanks, the flow is delivered to the households. **Error! Reference source not found.** Table 15 provides the working temperatures of the three configuration systems.

Table 14. Technical information of the air-to-water heat pumps.

Parameters	Heating	Cooling
COP (rated)	4.98	4.62
Capacity (rated)	50.40 kW	50.40 kW
Power (rated)	11.94 kW	10.91 kW

Table 15. Heat pump system tank configurations.

Configuration	2-pipes (H/DHW)	4-pipes (H/DHW)	4-pipes (H/C/DHW)
DHW tank set-point ($T_{\text{Tank,DHW}}$)	55°C		
DHW HP supply ($T_{\text{HP,DHW}}$)	60°C		
Heating tank set-point ($T_{\text{Tank,HEAT}}$)	55°C	Heating curve [40-30°C]	Heating curve [40-30°C]
Heating HP supply ($T_{\text{HP,HEAT}}$)	60°C	Heating curve + 5°C	Heating curve + 5°C
Cooling tank set-point ($T_{\text{Tank,COOL}}$)	-	-	17°C
Cooling HP supply ($T_{\text{HP,COOL}}$)	-	-	12°C

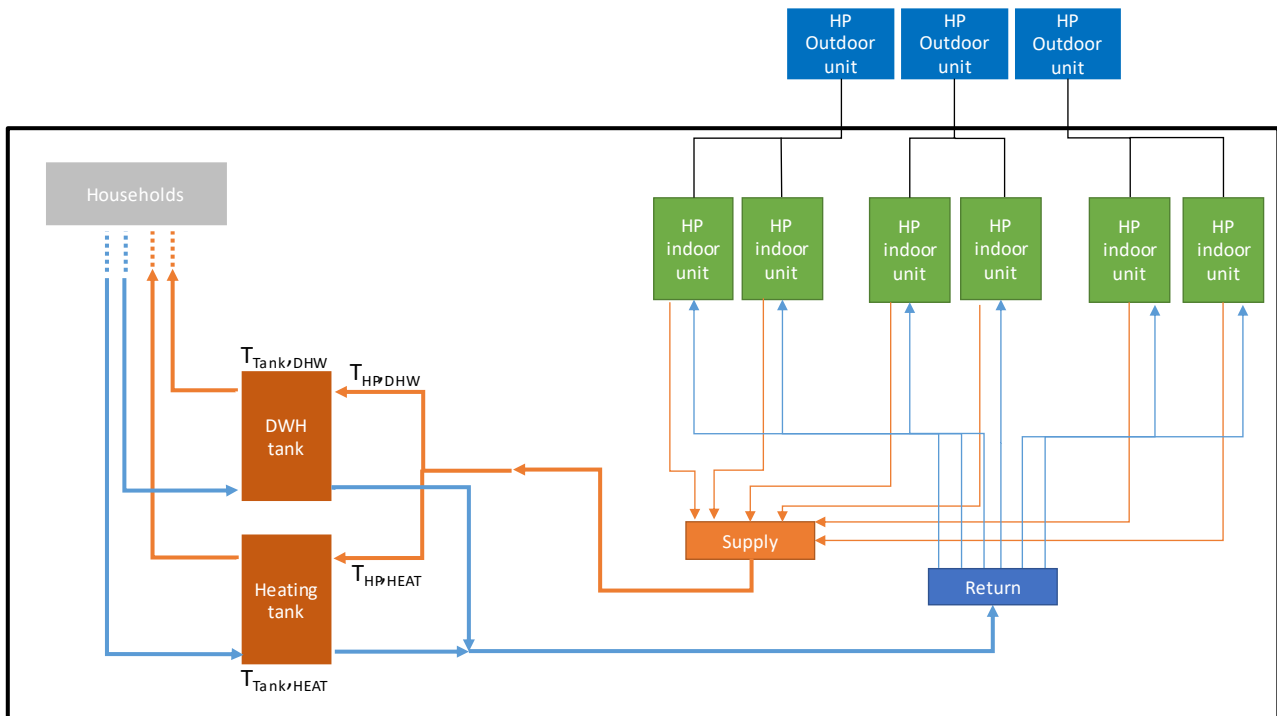


Figure 10. 4-pipes Heating and DHW configuration of the air-to-water heat pump system.

A last point related to the operation of the system at household level is the setpoint temperature defined for the heating and cooling system. Two operation conditions have been considered (Table 16): the one established by CTE, and the optimal one which is related to the actual behaviour of the inhabitants. The cooling setpoints are only used in Case 4, where the heat pump is reversible and provides cooling to the households.

Table 16. Heating and cooling setpoint temperature at household level.

Description	CTE schedule	Optimized schedule
Heating	07h-23h 20°C 23h-07h 17°C	07h-23h 21°C 23h-07h 17°C
Cooling	07h-15h OFF 15h-23h 25°C 23h-07h 27°C	07h-23h 26°C 23h-07h OFF

PV design

The Barcelona demo site building has local energy production from photovoltaic panels. which are placed both on the north-west and south-east block roofs. There are four PV design alternatives. where the orientation and the number of panels have been adapted accordingly. The last configuration, SE-ZEB, has the

objective to achieve a Zero Energy Building (ZEB), using the optimal orientation, SE, and reducing the number of PV panels to achieve the net zero energy balance close to zero. Table 17 and Figure 11 describes the characteristics of the four PV designs.

Table 17. Characteristics of the PV design alternatives: SE, W, E/W and SE-ZEB

Configuration	SE	W	E/W	SE-ZEB
Nº of panels per orientation	SE:119	W:119	W:59 E:60	SE:73
Slope [°]	30	30	30	30
Total power [kWp]	39.1	38.8	39.3	24.1
Annual production [kWh/panel]	410.6	375.7	328.7	448.4
Annual production [kWh]	48 862	44 717	39 113	32 731



Figure 11. PV panel design alternatives: SE, W, E/W, and SE-ZEB

Base case design: Case 0

The results of the base case are described in the following section. Table 18 shows the main characteristics of the base case, Case 0, which are related to the Spanish building code requirements.

Table 18: Characteristics of the base case design for the Mediterranean Demo

Parameter	Value	Description
External wall U-value	0.402 W/(m ² K)	Expanded Polystyrene: 0.070 m
Roof U-value	0.397 W/(m ² K)	Extruded polystyrene: 0.080 m
Window U-value & SHGC	1.69 W/(m ² K) & 0.66 [-]	Glazing: 4/12/4
Infiltration rate	0.57 h ⁻¹	-
Ventilation strategy	4.0 h ⁻¹ - Natural cross ventilation	June-September. Night ventilation: 00h - 07h
Solar shading strategy	Shading factor: 0.92	June-September. All day
Heating and DHW system	Air-to water HP with 2-pipes distribution system	
PV system	Total power: 39.1 kWp	SE oriented panels

Table 19 summarizes the main results of the final energy balance for the base case, considering the syn.ikia assessment boundary. The total needs of the building are around 60 kWh/m², 1/3 corresponds to EPB uses and 2/3 to nEPB uses. Most of the energy produced on-site is used by the nEPB uses, 63%, and only a 7% is used by the EPB uses. Total greenhouse gas emissions of the building are -0.88 kg_{CO2eq}/m². Figure 12 represents the final energy balance in terms of how much energy produced on-site is used by the EPB uses, by the nEPB uses and how much energy is exported to the grid.

Table 19. Annual and monthly final energy balance for the base case design, following the syn.ikia assessment boundary (Heating, DHW, and lighting).

Final energy - Electricity		YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EPB uses	kWh/m ²	20.96	4.30	3.05	1.97	1.16	1.01	0.79	0.63	0.57	0.80	0.96	1.65	4.07
non EPB uses	kWh/m ²	39.98	3.37	3.02	3.43	3.26	3.37	3.36	3.40	3.40	3.31	3.43	3.27	3.36
EPB used electricity produced on-site	kWh/m ²	1.76	0.33	0.36	0.23	0.08	0.07	0.05	0.04	0.03	0.05	0.06	0.16	0.32
Energy produced on-site	kWh/m ²	23.42	0.98	1.37	2.20	2.27	2.56	2.63	2.72	2.58	2.06	2.00	1.08	1.00
Environmental energy	kWh/m ²	25.34	4.71	3.45	2.31	1.39	1.41	1.26	0.97	0.85	1.17	1.26	1.91	4.63

Exported electricity	kWh/m ²	21.66	0.65	1.01	1.96	2.19	2.49	2.58	2.69	2.55	2.01	1.94	0.92	0.68
Exported for non EPB uses	kWh/m ²	14.69	0.56	0.87	1.27	1.45	1.54	1.67	1.60	1.65	1.41	1.31	0.80	0.57
Grid exported	kWh/m ²	6.97	0.10	0.13	0.69	0.75	0.95	0.91	1.09	0.90	0.60	0.63	0.12	0.11
Grid delivered. (EPB uses)	kWh/m ²	19.20	3.97	2.69	1.74	1.08	0.94	0.74	0.60	0.54	0.75	0.91	1.50	3.75
CO ₂ emission coefficient for delivered electricity		0.357												
CO ₂ emission coefficient for exported electricity		0.357												
Total greenhouse gas emissions	kgCO ₂ eq/m ²	-0.88	1.18	0.60	-0.08	-0.40	-0.55	-0.66	-0.75	-0.72	-0.45	-0.37	0.21	1.10

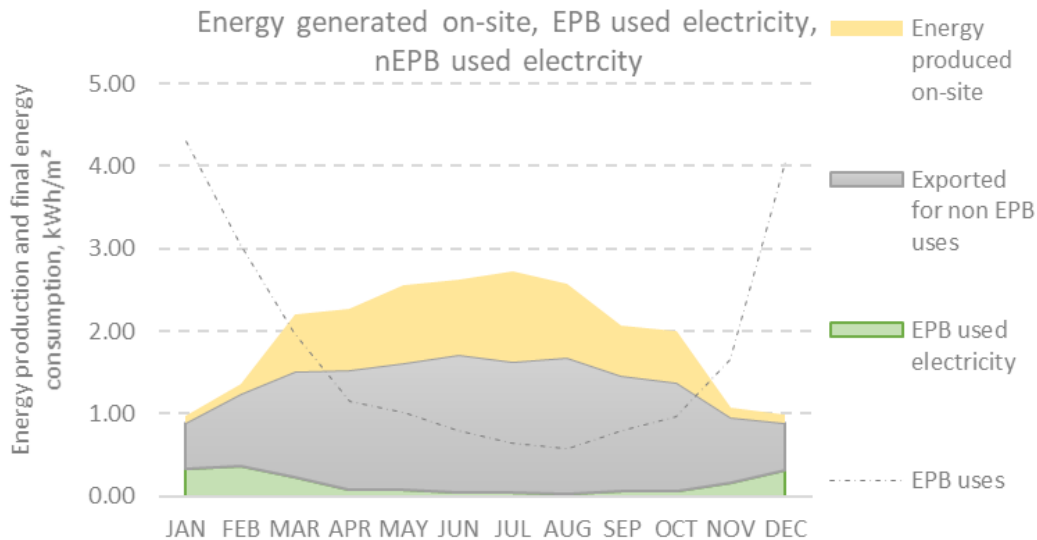


Figure 12. Final energy balance for the base case design following the syn.ikia assessment boundary (Heating, DHW and lighting): Energy produced on-site (yellow area), EPB uses (dotted line, EPB used electricity from on-site production (green area) and energy exported for nEPB uses (grey area).

Simulation results

The main results of the simulation are presented in Table 20. The table summarizes the main parameters that are changed from one case to another. and the main results in terms of energy balance. Information about the investment cost has been introduced in the design analysis. The investment costs have been detailed as following:

- Total investment cost: includes all the costs related to the construction of the building: materials and labour costs of all the elements of the building.
- Envelope cost: considers the costs related to façades, roofs, and windows. Structural and indoor elements are not included.
- HVAC system: takes in consideration the costs of the generation and distribution systems (heat pumps, storage tanks, distribution pumps, pipes and substation heat exchanger of each household), excluding the indoor household elements (radiators and thermostats).
- PV system cost: includes all the elements of the system: PV panels, inverters, and PV structure.

Regarding the heating needs. it is possible to observe that as the building envelope is improved. the heating demand is reduced. and that the reduction of the infiltration has a great impact on the demand (change implemented from Case 0 to Case 1). Additionally, the heating system improvement has an important impact on the results. Comparing the 2-pipes and 4-pipes systems, we can observe an improvement in the energy performance of the system (COP), increasing from 2.35 to 4.40 for heating, due to the lower working temperature of the DHW distribution system (details in **Error! Reference source not found.**).

To evaluate the cooling needs, the analysis should be done together with the annual overheating performance prediction. The main objective of the building design is to address the cooling needs through passive strategies: natural cross ventilation and solar shading. To verify the appropriate design of the passive strategies, the thermal comfort should be guaranteed, and to this aim, the annual overheating has been analysed. The annual overheating has been calculated based on the adaptive comfort model [8] which establishes that the comfortable temperature depends on the outdoor conditions and varies accordingly. Comparing the results, it is possible to observe how vernacular strategies and their appropriate use allows to reduce the annual overheating. Comparing Case 0 and Case 1, the overheating hours is reduced from 5.58% to 1.27% of the time, which is significantly lower than the limits established by CTE (<4%). Comparing Case 1 with Case 2, it shows that excessive insulation of the building could cause an increase in the overheating. However, in this case the difference is small. Finally, Case 4 incorporates a reversible heat pump to cover the cooling needs which reduces the overheating to almost zero.

To compare the different PV systems, Case 3, 5, 6 and 7 should be analysed. Case 3, 5, and 6 have the same number of PV panels, the differences are due to the variation in the orientation of the panels. Case 3 is the one with the best energy performance, presenting a higher PV production and small variations on the load cover factor (self-consumption). A final Case 7 has been performed to analyse the impact in terms of the costs of having a positive energy building or a net Zero Energy Building. In that case, the PV investment cost can be reduced by a 24%.

The variations in terms of total investment cost of the different alternatives are small, being lower than +/- 0.5% comparing the Case 3 with the other alternatives, except for the Case 0 where the difference is greater (-2%).

Table 20. Simulation results of Mediterranean demo site.

Main KPIs	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5	Case6	Case7
Heating demand [kWh/m ²]	15.85	9.85	8.57	9.85	9.85	9.85	9.85	9.85
Cooling demand [kWh/m ²]	-	-	-	-	9.54	-	-	
DHW demand [kWh/m ²]	24.04	24.04	24.04	24.04	24.04	24.04	24.04	24.04
Lighting [kWh/m ²]	3.03	3.03	3.03	3.03	3.03	3.03	3.03	3.03
COP – Heating	2.61	2.35	2.35	4.40	4.40	4.40	4.40	4.40
COP – Cooling	-	-	-	-	3.50	-	-	-
COP – DHW	2.96	2.96	2.96	2.96	2.96	2.96	2.96	2.96
PV production [kWh/m ²]	23.42	23.42	23.42	23.42	23.42	21.44	18.75	15.69
Total primary energy consumption [kWh/m ²]	42.94	31.67	29.27	28.23	36.92	39.64	43.31	38.81
Non-renewable primary energy consumption [kWh/m ²]	-4.81	-10.96	-12.26	-15.56	-8.39	-4.51	0.74	-0.45
Supply cover factor	0.134	0.112	0.107	0.108	0.163	0.110	0.129	0.116
Annual overheating [%]	5.58	1.27	1.41	1.27	0.24	1.27	1.27	1.27
Total investment cost [M€]	4.59	4.65	4.67	4.68	4.71	4.68	4.68	4.66
- Envelope	0.96	1.02	1.04	1.02	1.02	1.02	1.02	1.02
- HVAC system	0.28	0.28	0.28	0.31	0.33	0.31	0.31	0.31
- PV system	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.08

Detailed results of final design

The characteristics of the final design of the building are summarized in Table 21.

Table 21: Characteristics of the final design for the Mediterranean Demo

Parameter	Value	Description
External wall U-value	0.273 W/m ² K	Expanded Polystyrene: 0.110 m
Roof U-value	0.331 W/m ² K	Extruded polystyrene: 0.100 m
Window U-value & SHGC	1.1 W/m ² K & 0.67 [-]	Glazing: 4+4/16-Ar/5+5 Low-e
Infiltration rate	0.4 h ⁻¹	-
Ventilation strategy	4.0 h ⁻¹ - Natural cross ventilation	Control based on operative and outdoor temperature.
Solar shading strategy	Manual operation	Control based on operative temperature and solar radiation.
Heating and DHW system	Air-to water HP with 4-pipes distribution system	
PV system	Total power: 39.1 kWp	SE oriented panels

Figure 13 presents the monthly total energy performance of the building for the different energy uses: EPB and nEPB uses and the energy production on-site: electricity and environmental energy. The syn.ikia assessment boundary includes heating, DHW and lighting as Energy Performance of Building (EPB) uses, and appliances' energy use is counted as nEPB (not Energy Performance of Building). However, the CTE establishes that the EPB uses for residential buildings are only heating and DHW.

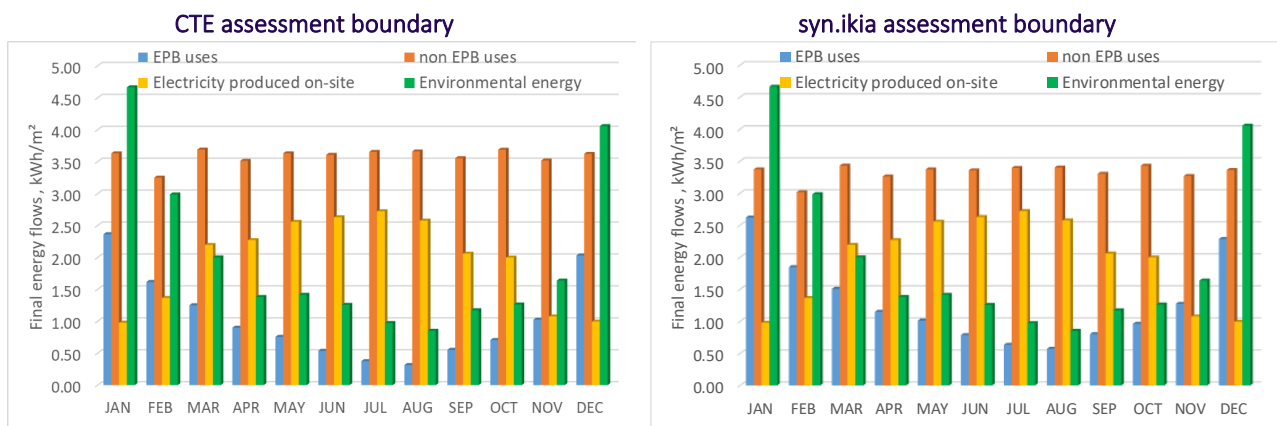


Figure 13. Total energy performance of the building by energy uses and energy production for the final design, considering the CTE (left) and syn.ikia (right) assessment boundaries.

Figure 14-left shows the Supply and Load Cover factors for three different assessment boundaries: Heating+DHW, Heating+DHW+Lighting, and ALL USES (EPB + nEPB uses). The Supply Cover factor is the relation between the energy generated on-site and directly used, and the total on-site generated energy. The Load Cover Factor relates the energy generated on-site and directly used to the total electric energy use. It can be observed that the indicators have an opposite behaviour; the Supply Cover Factor having higher values in winter and lower in summer, and the Load Cover Factor having lower values in winter and higher in summer. On the one hand, when the energy generated on-site is used by the building, the Supply Cover Factor tends to be higher. In this building, the supply cover factor is higher in winter because in summer there is a combination of two effects that decreases this indicator: higher PV production and lower energy demand. When the energy demand is lower, the Load Cover Factor becomes higher, meaning that a greater fraction of the demand is covered by on-site energy generation. This trend is the same for the different assessment boundaries, however, for ALL USES, the supply and load cover factor achieve higher values than in the other two assessments.

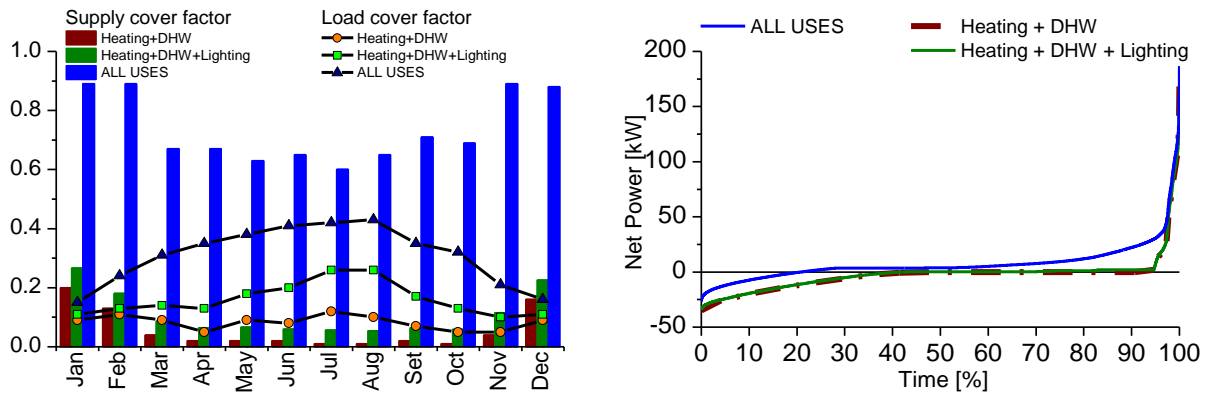


Figure 14. Supply and Load Cover factors for different assessment boundaries: CTE, syn.ikia, and ALL USES (left) and Net energy duration curve of the different assessment boundaries. Positive values represent delivered energy, negative is exported energy (right).

Figure 14-right represents the net energy duration curve, considering different assessment boundaries and calculated for each time step: Heating + DHW (CTE), Heating + DHW + Lighting (syn.ikia), and ALL USES (EPB + nEPB uses). The net energy duration curve provides an overview of the annual performance of a building in terms of exported and delivered energy. In the ALL USES assessment boundary, where all the building uses are considered as EPB uses, energy is exported from the assessment boundary only 20% of the year, while in case of syn.ikia it is 41%, and for CTE it is 45%.

Figure 15 is the final energy diagram where all the energy flows are represented inside and outside the assessment boundary. The electricity and the environmental heat generated on-site are represented, as well as the fractions of the EPB uses and the nEPB uses, and the exported energy to the grid. It is possible to see which are the sources of energy that cover the EPB uses, and which fractions come from the grid or from on-site production. The results show that a greater fraction of the EPB uses is covered by electricity delivered by the grid and that the PV production is mostly exported to cover the nEPB uses, which covers around the half of the nEPB needs. Table 22 provides the annual and monthly values of the final energy balance.

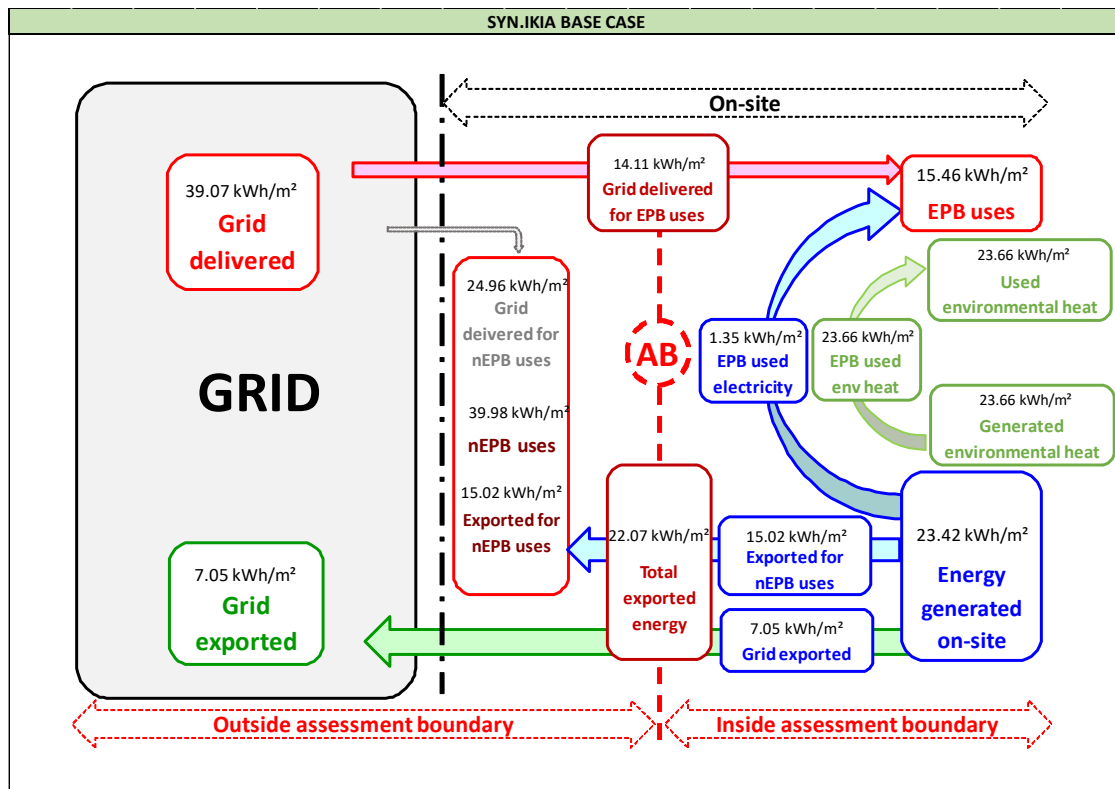


Figure 15. Energy balance of final design for the Mediterranean demo site.

Table 22. Annual and monthly final energy balance for the final design. following the syn.ikia assessment boundary.

Final energy - Electricity														
		YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EPB uses	kWh/m ²	15.46	2.62	1.85	1.51	1.15	1.01	0.79	0.63	0.57	0.80	0.96	1.27	2.29
non EPB uses	kWh/m ²	39.98	3.37	3.02	3.43	3.26	3.37	3.36	3.40	3.40	3.31	3.43	3.27	3.36
EPB used electricity produced on-site	kWh/m ²	1.35	0.26	0.25	0.13	0.07	0.07	0.05	0.04	0.03	0.05	0.06	0.12	0.22
Energy produced on-site	kWh/m ²	23.42	0.98	1.37	2.20	2.27	2.56	2.63	2.72	2.58	2.06	2.00	1.08	1.00
Environmental energy	kWh/m ²	23.66	4.66	2.99	2.00	1.38	1.41	1.26	0.97	0.85	1.17	1.26	1.64	4.06
Exported electricity	kWh/m ²	22.07	0.72	1.12	2.06	2.20	2.49	2.58	2.69	2.55	2.01	1.94	0.95	0.77
Exported for non EPB uses	kWh/m ²	15.02	0.61	0.97	1.35	1.45	1.54	1.67	1.60	1.65	1.41	1.31	0.83	0.65
Grid exported	kWh/m ²	7.05	0.10	0.15	0.71	0.75	0.95	0.91	1.09	0.90	0.60	0.63	0.12	0.12
Grid delivered. (EPB uses)	kWh/m ²	14.11	2.36	1.60	1.38	1.07	0.95	0.74	0.60	0.54	0.75	0.91	1.15	2.06
CO ₂ emission coefficient for delivered electricity		0.357												
CO ₂ emission coefficient for exported electricity		0.357												
Total greenhouse gas emissions	kgCO ₂ eq/m ²	-2.84	0.59	0.17	-0.25	-0.40	-0.55	-0.66	-0.75	-0.72	-0.45	-0.37	0.07	0.46

Primary energy balance results

Table 23 summarizes the hypothesis established for the different primary energy balances presented in the following section: assessment boundary, supply cover factor, and k_{exp} . k_{exp} defines how the exported energy should be considered in the primary energy balance: If $k_{exp}=1$, it means that the exported energy is considered as a “benefit” and this “benefit” reduces the primary energy use of the building by the amount of energy (both renewable and non-renewable) that due to the export of energy is avoided to be generated by the grid (the conversion factor of exported energy is equal to the conversion factor of the grid delivered energy). If $k_{exp}=0$, it means that the exported energy is not considered as a benefit and in that case, the conversion factor of exported energy is different from the grid delivered and depends on the on-site generation source, in this case PV. For more details about the primary energy balance calculation, see references [15] and [16]. The primary energy conversion factors are presented in Table 5.

Table 23. Primary energy balance calculation hypothesis.

Primary Energy balance hypothesis	Assessment boundary	Supply cover factor	k_{exp}
CTE	Heating+DHW	1	0
syn.ikia	Heating+DHW+Lighting	Actual	1

Figure 16 presents the EPB uses that are directly covered by the local energy generation, for each primary energy balance. It is dependent on the EPB uses considered in the assessment boundary and its correspondent supply cover factors; 1 for the CTE balance, and actual values for the syn.ikia balance. In the syn.ikia case, the EPB unweighted final energy use shows the same trend that the results presented in the previous section. However, the results for the CTE balance changes completely due to the supply cover factor hypothesis, which is set to 1. It means that all the on-site PV production is used by the EPB and nEPB needs, independently on the simultaneity of the generation and demand.

Figure 17-left shows the weighted exported total primary energy for the different balances and shows how the exported energy is accounted for in the different primary energy balances. The graphs present the “net benefit” in terms of total weighted exported primary energy and is the result of unweighted exported energy and the corresponding total grid exporting weighting factor. As in the CTE case, the exported energy is not accounted as “benefit” in the primary energy calculation, there is no weighted export of energy. The syn.ikia

balance presents higher values of weighted exported total primary energy in summer months, mainly due to higher PV production and lower EPB uses, in comparison to the winter period.

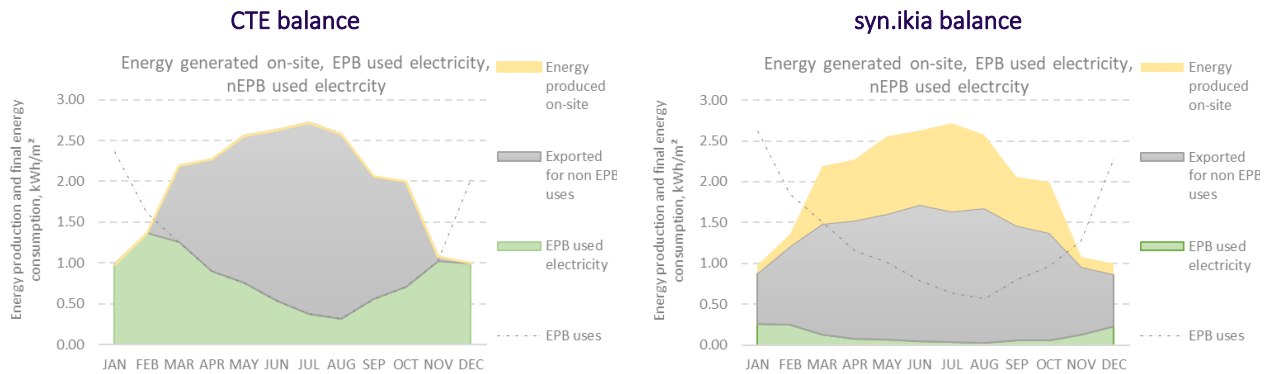


Figure 16. EPB used unweighted final energy consumption of the different Primary Energy balance hypotheses and the PV generation: CTE balance (left) and syn.ikia balance (right).

The annual results of total and non-renewable primary energy of the two balance hypotheses are presented in Figure 17-right. Even though the performance of the building is the same in both cases, the primary energy varies in great degree, showing a negative value only in the syn.ikia balance (non-renewable primary energy, PE_{ren} , is negative). The CTE balance cannot provide a negative value per definition, as the exported energy is not counted as a benefit. However, comparing the results of the CTE and syn.ikia balances, it can be concluded that in both cases a high energy performance has been achieved with the current design, even though the PEB can be visualised with a negative value (≤ 0) only when using the syn.ikia hypothesis. The CTE defines nZEB consumption limits of non-renewable and total primary energy which are 32 kWh/(m²yr) and 64 kWh/(m²yr) respectively, which the Case3 building design achieves.

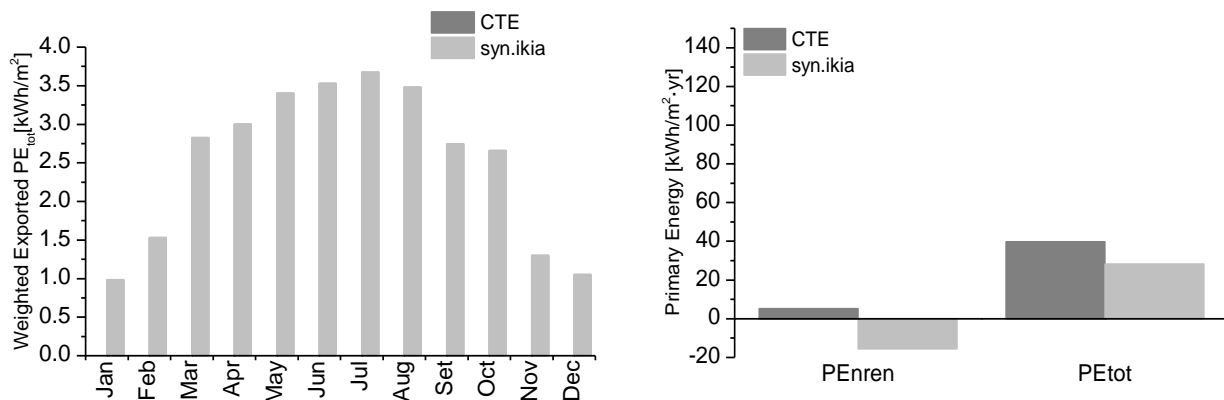
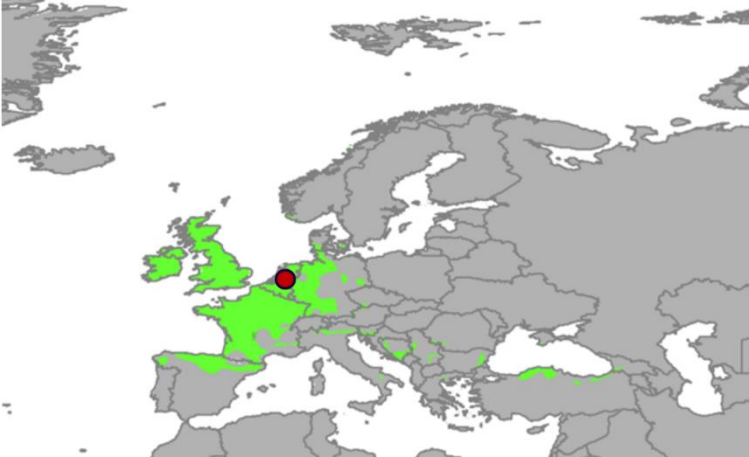
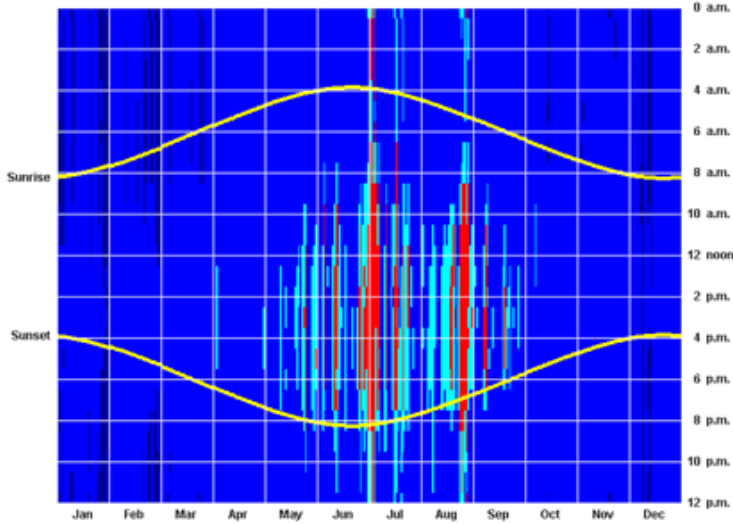


Figure 17. Left: Weighted exported total primary energy of different primary energy balance hypotheses. Right: Annual primary energy balance for the different primary energy balance hypothesis: CTE and syn.ikia.

DEMO	Apartment building in Uden (Netherlands)		
Key data	Program: Residential		
	Usable floor area: 2394 m ²		
	Heated floor area: 2360 m ²		
	Ambition: SPEN		
	Energy carriers	1	Electricity
Location	Uden, the Netherlands		
	Lat: 51°39'20.2"N		
	Long: 5°37'46.5"E		
Climate	Marine		
	HDD: 2814 hours		
	CDD: 20 hours		
	<div><div>DRY BULB TEMP</div><div>(degrees C)</div><div><div>5%</div><div>■</div><div>< 0</div></div><div><div>85%</div><div>■</div><div>0 - 20</div></div><div><div>6%</div><div>■</div><div>20 - 24</div></div><div><div>3%</div><div>■</div><div>24 - 38</div></div><div><div>0%</div><div>■</div><div>> 38</div></div></div>		

Project scope and description

The Dutch Demonstration case is a new residential development in a mid-sized town named Uden. It is located nearby sports locations and an industrial park. The 'Loopkantstraat' is in-between the residential and business area of Uden. The development consists of an apartment complex which includes 39 apartments spread over 3 floors. The total plot area for this development is 3 860 m² with a usable floor area of 2 394 m². PV panels of neighbouring buildings and electrical vehicle charging points in the neighbourhood are taken into account to optimize the energy flexibility at neighbourhood level.

Program and social dimension

The building development is a follow-up from the “Social Beautiful” concept which was developed in collaboration between Labyrint (Support in sheltered housing), Area (housing company), the municipality of Uden, and Hendriks Coppelmans (developer). The concept aims to provide an answer to changes in various policy areas and the changing demands of society. A suitable location for this initiative was found at the location at Loopkantstraat 3 in Uden. Currently this land is owned by Hendriks Coppelmans. In this development, Area will become the owner of the land, develop the building complex, and rent out 15 of the apartments to Labyrint. The other 24 apartments will be rented out as regular social housing.

The Social Beautiful concept consists of the following elements:

1. Living, working, and community services are brought together in one location. A multifunctional residential and service centre is being realized at the location.
2. Housing is shaped by the realization of financially accessible homes suitable for the target group. The housing design is tailored to the target group. it may also include sheltered / protected living.
3. Work takes place at the location or from the same location. The work has a social function within the neighbourhood. Wage-related work must contribute to providing structure in the daily activities of the residents.
4. Neighbourhood management is organized from the location in the surrounding neighbourhood. A service package is provided from the residential and service centre that contributes to the ability of neighbourhood residents to live independently for longer, to strengthen the social network, and to improve the quality of life and safety in the neighbourhood.
5. The houses are suitable for use at all times for regular rental. Communal facilities must be realized within the contours of a regular apartment.

The objective is to offer a suitable living and working situation to a group of vulnerable citizens. In this way they become a fully-fledged part of society. They not only make use of the facilities themselves, but also give substance to the level of facilities in the municipality. Due to the integrated approach, they experience a greater sense of well-being and security.

Environmental concept and ambition

The ambition level for energy performance is plus energy use for the building related energy uses. Per January 2021, the design is finalized. The design consists of:

Passive systems:

- Good insulation (high thermal resistance (R_c))
 - Façade: $R_c = 6.1 \text{ m}^2\text{K/W}$
 - Roof: $R_c = 8.1 \text{ m}^2\text{K/W}$
 - Floor: $R_c = 5.1 \text{ m}^2\text{K/W}$
- Airtight building ($q_{v,10}$ value $< 0.3 \text{ dm}^3/\text{s}/\text{m}^2$ at 10 Pa)²
- Triple glazing ($U_w = 1.0 \text{ W}/\text{m}^2\text{K}$)
- Doors ($U = 1.2 \text{ W}/\text{m}^2\text{K}$)

Active systems:

- Individual ground source heat pumps for space heating. space cooling and domestic hot water in each apartment
- Floor heating and cooling

² Air tightness of a building, indicated by $q_{v,10}$, means the air volume flow (q_v) that arises through the cracks and seams that are located between the various building parts in the building envelope at a pressure difference of 10 Pa. Divided by the usable floor surface of a building the specific $q_{v,10}$ is obtained ($\text{dm}^3/\text{s}/\text{m}^2$ at 10 Pa).

- Mechanical exhaust ventilation with CO₂ sensor
- PV on the roof

The calculated EPC-value is -0.03³.

Flexibility concept

The energy flexibility concept of the Dutch demo project is shown in Figure 18.

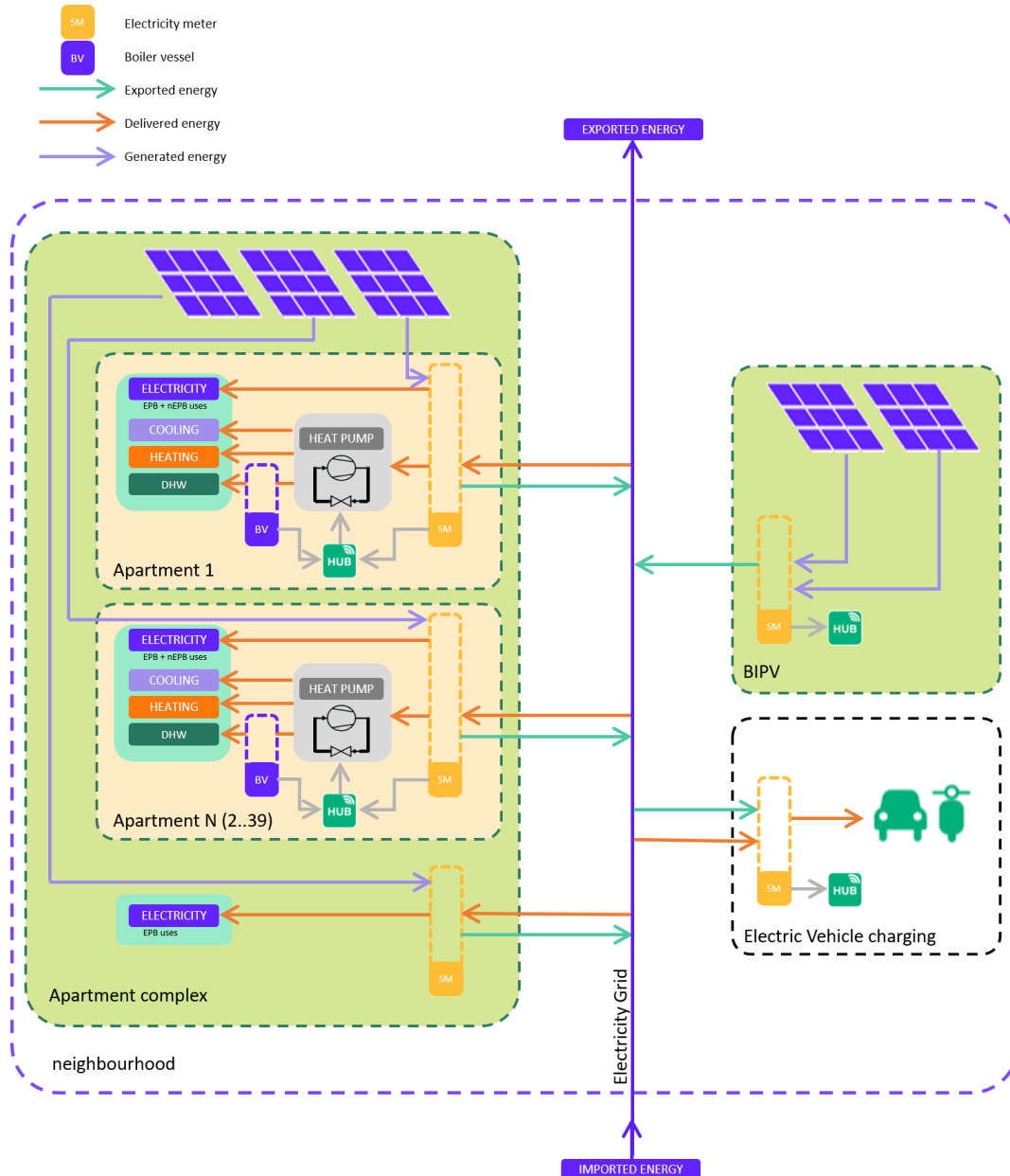


Figure 18. Map of the flexibility concept showing energy carriers and exchange vectors

Flexibility measures are planned to optimize the use of on-site PV production as much as possible for own use. For instance, this could be achieved by optimizing the use of the heat pump, either for filling the hot water vessel or for space heating, in situations when the PV panels produce electricity. The flexibility concept

³ The Energy Performance Coefficient (EPC) is the ratio between the calculated energy consumption and the reference energy consumption for the building. The reference energy consumption depends on several aspects (e.g. floor area, heat loss area). The method for calculating the energy consumption is described in NTA 8800, which replaces NEN 7120 from 1 January 2021. The EPC must comply with the limit value set in Dutch regulations (Bouwbesluit 2012).

consists of using the energy generated by PV in the apartments or in neighbouring apartments/buildings in the most effective way by:

- Increasing the building mass temperature via the floor heating system in each apartment using the individual ground source heat pump.
- Increasing the temperature of the individual storage vessels for domestic hot water in each apartment using the individual ground source heat pump.
- Taking into account charging of electric vehicles.

Architecture and sustainability

The project will follow the standards of the Dutch building code with additional housing standards including the Near zero energy building and the use of sustainable materials. The urban development plan for this initiative has been drawn up through an extensive participation process with local residents and other parties involved. The building block on Loopkantstraat is positioned in line with the façades on Loopkantstraat and is also parallel to the road.

The verge between the Loopkantstraat and the residential complex will have a green connection, so that the continuous image of the Loopkantstraat with a wide green verge on the south side with the building masses behind it. Furthermore, outdoor spaces are provided on this side of the complex in the form of an indoor balcony (loggia) and some balconies located outside the facade.

The building volume will increase from two storeys to three storeys with a height accent on the corner of the streets Loopkantstraat and President Kennedylaan. The building volume on President Kennedylaan also consists of three storeys and slopes south to two storeys at the head of the building, with the building line following the direction of the road. By lowering the building block on the corner, it will be connected to the building mass of the adjacent neighbouring plot on President Kennedylaan. Layering is applied to the facade through the application of different materials: bricks, facade cladding, and green façades provide cooling and green experience.

The residential units are switchable and stackable and can therefore be used anywhere. This makes it easy to form complexes, complete with a gallery, lift or patio.



Figure 19. Architectural impression of the demo project in Uden.



Figure 20: Plan of the ground floor of the demo project in Uden.



Figure 21: Facades and sections of the demo project in Uden.

Energy and environmental performance analyses

Regulatory framework and technical codes

According to the Dutch building regulation, all newly built buildings have to comply with the energy performance requirements as described in the Bouwbesluit (2012). For residential buildings, the overall Energy Performance Coefficient (EPC) must be lower than 0.4.

All requirements regarding the energy performance of buildings as described in the Bouwbesluit (2012) are given in the table below.

Table 24. Key design parameters from applicable Dutch regulations

Standard	Criteria	Value
Bouwbesluit (2012)	Energy Performance Coefficient (EPC)	≤ 0.4
	Air tightness	$\leq 0.2 \text{ m}^3/\text{s}$
	U-values:	
	Roof	$\leq 0.16 \text{ W}/(\text{m}^2\text{K})$ ($R_c \geq 6.0 \text{ m}^2\text{K}/\text{W}$)
	Outer wall	$\leq 0.21 \text{ W}/(\text{m}^2\text{K})$ ($R_c \geq 4.5 \text{ m}^2\text{K}/\text{W}$)
	Floor	$\leq 0.26 \text{ W}/(\text{m}^2\text{K})$ ($R_c \geq 3.5 \text{ m}^2\text{K}/\text{W}$)
	Windows, doors, and frames	$\leq 2.2 \text{ W}/(\text{m}^2\text{K})$ (individual components) $\leq 1.65 \text{ W}/(\text{m}^2\text{K})$ (average value over all components in the building)

Simulation Model

The Dutch building regulation requires to calculate the Energy Performance Coefficient of the building according to NEN 7120, to prove that the building complies with the EPC requirements. In the design phase, the simulation tool TRNSYS 18 was used to evaluate different design options. In the TRNSYS model, some other assumptions (e.g. indoor temperature) are used than in the EPC calculation. Furthermore, the EPC calculation is a monthly one zone method, while TRNSYS is a dynamic multizone model.

Simulation tools

The designs are evaluated using the energy simulation software package TRNSYS 18. The energy use for domestic hot water production is calculated separately using the calculation procedure in the Dutch EPB standard (NEN 7120).

Table 25. Characteristics of the base case design for the Dutch demo project.

DEMO	Apartment building in Uden (Netherlands)	
Envelope	Walls	0.16 W/(m ² K) (Rc=6.1 m ² K/W)
	Floor	0.20 W/(m ² K) (Rc=4.8 m ² K/W)
	Roof	0.12 W/(m ² K) (Rc=8.1 m ² K/W)
	Windows	U=1.0 W/(m ² K)
		ZTA=0.53 (see footnote ⁴)
		LTA=0.73 (light transmission)
	Glass to wall ratio	37 %
	Infiltration rate	0.3 ACH
Ventilation	Air exchange rate	1.4 m ³ /(hm ²)
Internal gains	Occupancy, lighting, fans, and appliances	8.6 W/m ²
	Operation time (hours/days/weeks)	16/7/52
Heating set point	night/day/evening	19/20/21 °C
Cooling set point		23 °C
Heating system	Ground source heat pump (Itho Daalderop WPU 35 5G)	SCOP = 5.7
Cooling system	Ground source heat pump (Itho Daalderop WPU 35 5G)	SCOP = 5.0
Domestic hot water system	Ground source heat pump (Itho Daalderop WPU 35 5G) + storage vessel WPV150	SCOP = 3.6
Heat recovery	N/A	
Specific fan power		0.8 kW/m ³ /s

Note: SCOP: Seasonal Coefficient of Performance

Base case and design options

The base case design consists of:

- Ground source heat pumps for space heating, cooling, and domestic hot water in each apartment (capacity 3.3 kW, SCOP 5.7 for heating, 3.6 for DHW, and 5.0 for cooling)
- Domestic hot water vessel (150 litre boiler) in each apartment that is filled during the night from 3:00 to 5:00.
- Floor heating (supply temperature 35-40°C)
- Floor cooling (supply temperature 18°C)
- Mechanical exhaust ventilation with CO₂ sensor (air change rate depends on CO₂ level)
- PV on the roof (195 panels, 310 Wp/panel, orientation S and SWW)

The energy performance of this design calculated with TRNSYS is summarized in the table and figure below.

⁴ ZTA stands for Solar Admittance Factor and indicates the ratio between the incoming solar heat and the total solar radiation on the window. Instead of ZTA nowadays the g-value is more common used. The difference is that ZTA is determined for an angle of incidence of 45 degrees, while the g-value applies for 90 degrees (or in other words, perpendicular to the window).

Table 26. Energy performance of the base case.

DESCRIPTION		YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
SYN.IKIA BASE CASE. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	23.18	3.33	2.60	2.06	1.58	1.27	1.34	1.33	1.35	1.25	1.62	2.35	3.10
non EPB uses	kWh/m ²	48.62	4.01	4.08	4.04	4.04	4.08	4.02	4.09	4.01	4.06	4.07	4.03	4.09
EPB used electricity	kWh/m ²	3.12	0.25	0.28	0.29	0.32	0.26	0.33	0.31	0.27	0.19	0.23	0.21	0.18
Energy produced on-site	kWh/m ²	24.45	0.59	1.07	1.47	3.06	3.37	3.55	3.40	3.12	2.14	1.47	0.70	0.51
Environmental energy	kWh/m ²	48.74	10.16	6.71	4.14	1.90	1.82	1.88	1.82	1.88	1.83	1.99	5.55	9.07
Exported electricity	kWh/m ²	21.33	0.35	0.78	1.18	2.74	3.10	3.23	3.09	2.86	1.94	1.24	0.49	0.33
Exported for non EPB uses	kWh/m ²	21.33	0.35	0.78	1.18	2.74	3.10	3.23	3.09	2.86	1.94	1.24	0.49	0.33
Grid exported	kWh/m ²	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grid delivered, (EPB uses)	kWh/m ²	20.06	3.08	2.31	1.77	1.26	1.01	1.02	1.02	1.08	1.06	1.38	2.13	2.93
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-0.43	0.93	0.52	0.20	-0.50	-0.71	-0.75	-0.70	-0.60	-0.30	0.05	0.56	0.88

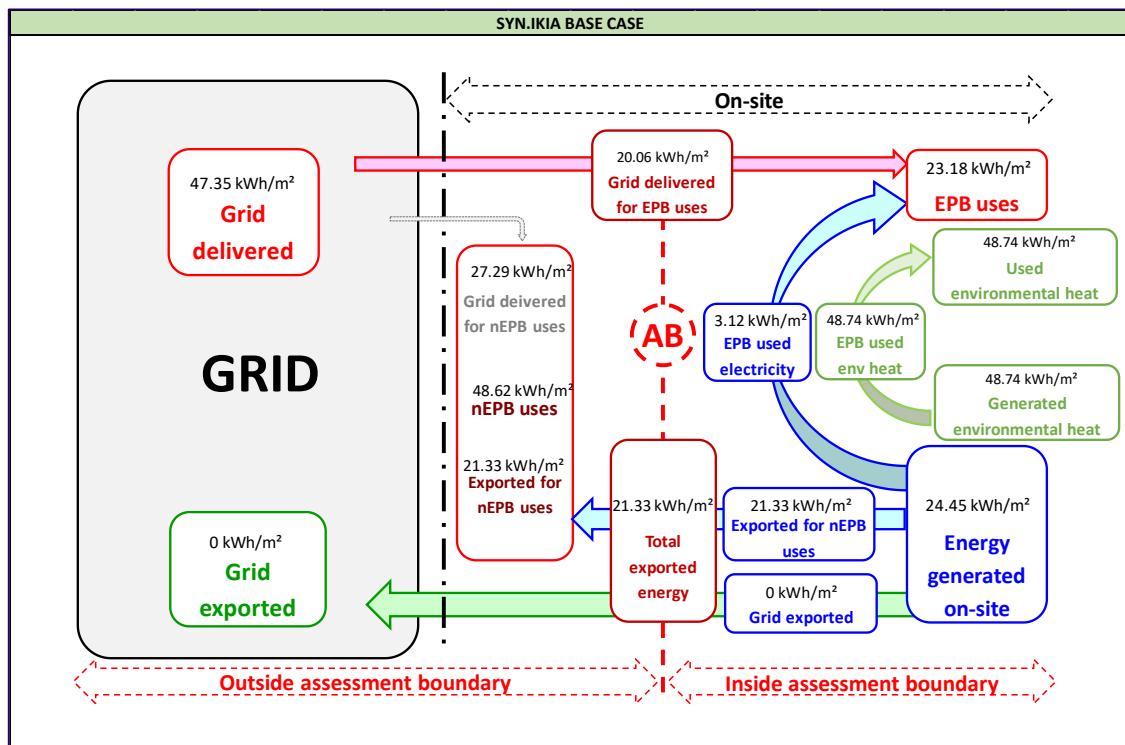


Figure 22. Energy balance of the base case.

Design options

For the Dutch demo case, the following design options have been simulated:

- Case 1: The hot water vessel for domestic hot water preparation (DHW boiler) is filled during the day from 12:00 to 14:00 (instead of during the night)
- Case 2: Air source heat pump in each apartment (instead of ground source heat pump), capacity 3.3 kW. SCOP 3.5 for heating, SCOP 2.1 for DHW, SCOP 7.5 for cooling
 - o COP's are calculated based upon the occurring ambient temperature
 - o DHW boiler filled during the day from 12:00 to 14:00
- Case 3: Air source heat pump (same as case 2) in combination with solar shading (instead of ground source heat pump)
 - o External solar shading on each orientation of the building
 - o 90% shading when total solar load on window ≥ 250 W/m²
 - o COP's are calculated based upon the occurring ambient temperature
 - o DHW boiler filled during the day from 12:00 to 14:00
- Case 4: Radiators instead of floor heating

- Water temperatures radiators 40-45°C (5 degrees higher compared to floor heating as a result of the assumed dimensions for the radiators)
- Due to these higher water temperatures a somewhat lower COP of the heat pump occurs
- Heating setpoint during the night 15°C instead of 19°C in case of floor heating
- DHW boiler filled during the day from 12:00 to 14:00
- Case 5: Heat recovery ventilation system instead of mechanical exhaust ventilation
 - Heat recovery of 80% during heating season. otherwise bypass of the heat recovery
 - Ventilation level average 18.5 dm³/s per apartment. Less than mechanical exhaust system in base case (25 dm³/s). due to the better ventilation efficiency.
 - Effective fan power 60 W per apartment instead of 20 W in case of mechanical exhaust system
 - DHW boiler filled during the day from 12:00 to 14:00

Simulation results

In the table below, the results for each case are summarized.

Table 27. Simulation results of the Dutch demo site.

Main KPIs	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
Heating demand [kWh/m ²]	32.3	32.3	32.3	36.5	30.2	8.9
Cooling demand [kWh/m ²]	40.8	40.8	40.8	23.1	39.6	53.2
DHW demand [kWh/m ²]	30.6	30.6	30.6	30.6	30.6	30.6
Lighting [kWh/m ²]	5.2	5.2	5.2	5.2	5.2	5.2
COP – Heating	5.7	5.7	3.5	3.5	5.4	5.7
COP – Cooling	50	50	7.5	7.5	50	50
COP – DHW	3.6	3.6	2.1	2.1	3.6	3.6
PV production [kWh/m ²]	24.5	24.5	24.5	24.5	24.5	24.5
Total primary energy consumption [kWh/m ²]	82.4	82.4	93.4	94.7	80.2	66.2
Non-renewable primary energy consumption [kWh/m ²] (A)	33.6	33.6	54.3	52.6	33.5	36.8
Renewable primary energy delivered by PV [kWh/m ²] (B)	35.5	35.5	35.5	35.5	35.5	35.5
Non-renewable primary energy consumption [kWh/m ²] (A minus B)	-1.84	-1.84	18.8	17.1	-1.99	1.36
Imported EPB uses [kWh/m ²]	20.1	15.6	27.0	26.7	14.8	15.9
Exported EPB uses [kWh/m ²]	21.3	16.8	13.9	14.8	16.1	15.0
Environmental use [kWh/m ²]	48.7	48.7	39.0	42.0	46.7	29.4
Environmental return [kWh/m ²]	41.6	41.6	46.3	26.2	40.4	54.2
Supply cover factor ¹	0.13	0.33	0.28	0.26	0.36	0.37
PMV>0.5 [%] ²	11.0	11.0	11.0	1.7	3.4	18.5

Notes:

¹ Supply cover factor is the percentage of the EPB uses that is delivered by PV as located on the own building plot

² Overheating with the period from 8 to 23 hours

The primary energy factors in the table below are obtained from the Dutch standards to calculate the renewable and non-renewable primary energy consumption.

Table 28. Primary energy factors used in the calculations.

Primary energy conversion factors				
		Fp_ren	Fp_nren	Fp_tot
Electricity	Grid	0	1.45	1.45
Electricity	PV	1.45	0	1.45
Environment heat	ENV	1	0	1

Discussion of results

The TRNSYS simulations are performed with time steps of 15 minutes. During each time step, the energy flows are evaluated, for instance, to what extent the on-site PV production can be used in the apartments, or needs to be exported. Based on this, the supply cover factor is determined, which indicates the percentage of the EPB uses that is delivered by the on-site PV production.

For a good understanding of table 27, it is important to note that in the base case situation (case 0) the domestic hot water boiler is filled during the night (from 3:00 to 5:00), while in all other cases the boiler is filled during the day only (from 12:00 to 14:00).

From table 27 it can be derived that in the base case situation (case 0), the environmental energy use and environmental return energy from and to the ground source shows an acceptable balance. The amount of imported electricity for EPB uses drops significantly in case the domestic hot water buffer is filled during the day (case 1). This is because the matching between on-site PV production and the electricity consumption increases. Related to this, also less electricity will be exported. The part of the EPB uses that is delivered via the on-site PV production, increases from 0.13 (case 0) to 0.33 (case 1).

When using an air source heat pump (case 2), due to the lower SCOP values for heating, cooling and domestic hot water preparation, the imported electricity for EPB uses increases compared to the base case (case 0). In combination with solar shading (case 3), the cooling demand clearly decreases compared to the base case. Nevertheless, the imported electricity for EPB uses, due to the lower SCOP values, stays higher compared to the base case. This happens despite the fact that the domestic hot water boiler is filled during the day instead of during the night.

The situation with radiators (case 4) instead of floor heating shows a decrease of the imported electricity for EPB uses compared to the base case (case 0). The reason for that is the decrease in both the heating and the cooling demand. It is noted however, that using radiators for cooling is less desirable, due to the risk of condensation.

Using a heat recovery ventilation system (case 5) leads to a clear drop in the heating demand compared to the other cases. Therefore, the electricity use for heating decreases, however this decrease is limited because of the high SCOP value of the ground source heat pump (SCOP is 5.7). The electricity use of the heat recovery system itself (60W per apartment) is higher than the electricity use of the mechanical exhaust system (20W per apartment). Furthermore, the cooling demand increases, because the ventilation is less in case of the heat recovery system. Overall, this leads to a small increase of the imported electricity for EPB uses compared to the base case in which the hot water boiler is filled during the day (case 1). To improve this, a heat recovery system with less energy use for the fans is needed. Due to the decrease in the heating demand and increase of the cooling demand, the imbalance of the ground source increases, which is less favourable.

Table 27 shows that the total primary energy consumption in case of a heat recovery ventilation system is significantly lower compared to the other cases. However, this is also caused by the fact that the renewable environmental energy use is taken into account. The non-renewable primary energy consumption in case of a heat recovery ventilation system is even somewhat higher compared to the other cases, except the cases with an air source heat pump (case 2 and case 3). This is caused by the lower SCOP values of the air source heat pump.

The figures concerning overheating ($PMV > 0.5$, see table 27) show a tendency that is expected. Overheating occurs less when using solar shading (case 3) or radiators (case 4). Floor heating results in more overheating (case 1 to case 3), while in combination with a heat recovery ventilation system the overheating further increases.

Detailed results of final design

Based upon the performed simulations, the base case situation in which the domestic hot water boiler is filled during the day (case 1), is considered to be a good design; the imported electricity for EPB uses is low, the supply cover factor is high, and the ground source is in balance. The energy performance is summarized in the table and figures below. The results show that it is a net zero energy building (for EPB uses): on a yearly basis the EPB uses (23.18 kWh/m²) are less than the energy generated on-site (24.45 kWh/m²).

Table 29. Energy performance of the final design.

DESCRIPTION		YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
SYN.IKIA FINAL DESIGN. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	23.18	3.31	2.62	2.03	1.61	1.27	1.32	1.35	1.33	1.28	1.60	2.36	3.10
non EPB uses	kWh/m ²	48.62	4.01	4.08	4.04	4.04	4.08	4.02	4.09	4.01	4.06	4.07	4.03	4.09
EPB used electricity	kWh/m ²	7.61	0.39	0.51	0.62	0.86	0.83	0.88	0.89	0.83	0.60	0.55	0.36	0.29
Energy produced on-site	kWh/m ²	24.45	0.59	1.07	1.47	3.06	3.37	3.55	3.40	3.12	2.14	1.47	0.70	0.51
Environmental energy	kWh/m ²	48.74	10.10	6.77	4.07	1.96	1.82	1.82	1.88	1.82	1.89	1.96	5.58	9.07
Exported electricity	kWh/m ²	16.84	0.21	0.55	0.85	2.21	2.54	2.67	2.51	2.29	1.54	0.92	0.34	0.22
Exported for non EPB uses	kWh/m ²	16.84	0.21	0.55	0.85	2.21	2.54	2.67	2.51	2.29	1.54	0.92	0.34	0.22
Grid exported	kWh/m ²	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grid delivered, (EPB uses)	kWh/m ²	15.58	2.92	2.11	1.41	0.75	0.45	0.44	0.46	0.50	0.68	1.05	2.00	2.82
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-0.43	0.92	0.53	0.19	-0.49	-0.71	-0.76	-0.70	-0.61	-0.29	0.04	0.56	0.88

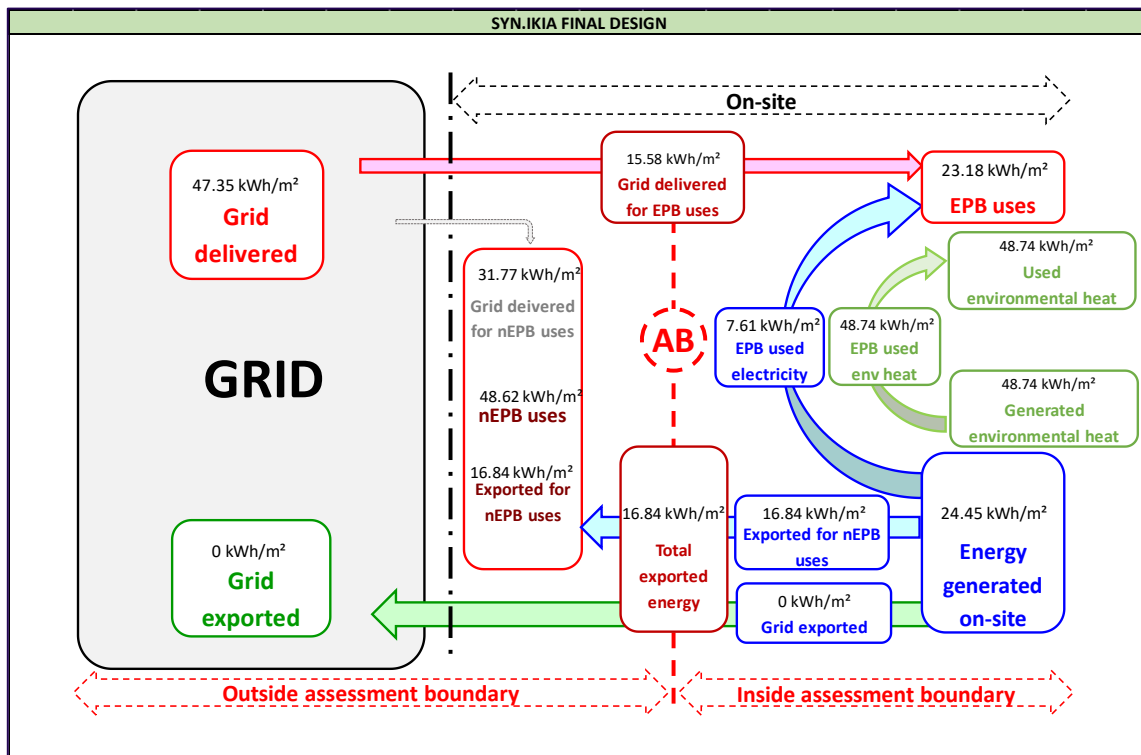


Figure 23. Energy balance of the final design.

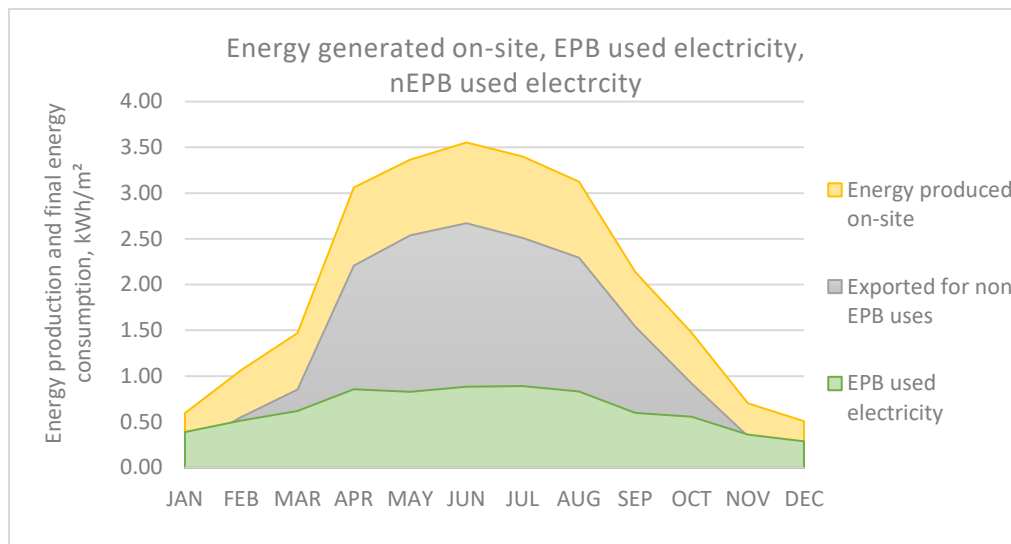
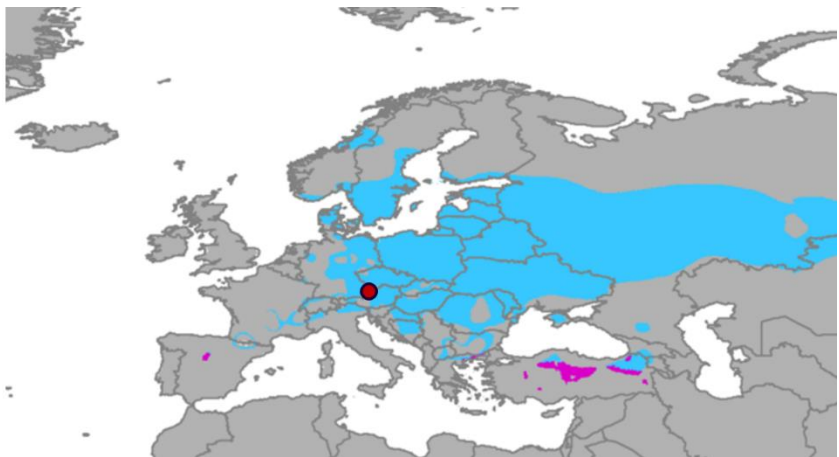
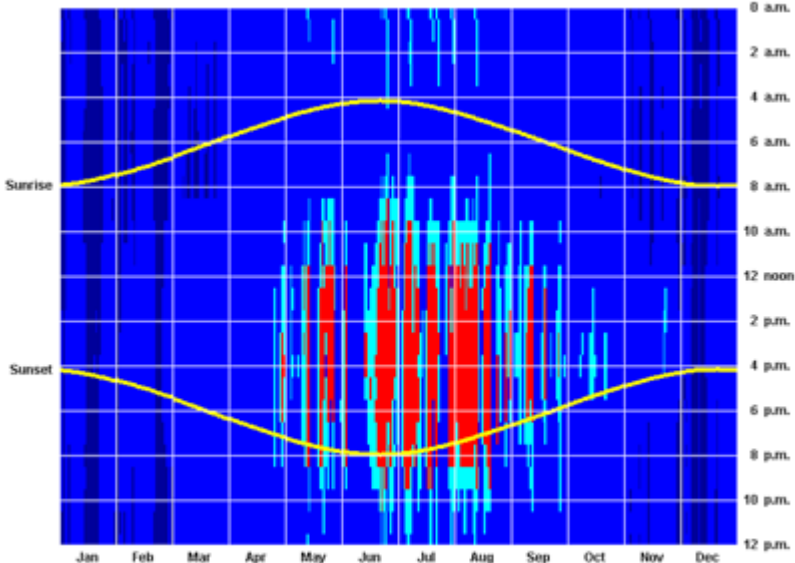


Figure 24. Energy generated on-site (PV), EPB used electricity, and exported electricity for nEPB uses per month.

DEMO	GEWIN Gneis		
Key data	Program: 16 Multi residential buildings, 1 Kindergarten, Rooms in the base zone for the social aid and service organization "Caritas"		
	Floor area: 24 798 m ²		
	Heated floor area: 22 000 m ²		
	Ambition: SPEN		
	Energy carriers	1	Electricity
		2	District heating
Location	Salzburg, Austria		
	Lat: 47°85'56.2" N		
	Long:13°35'37.9" E		
Climate	Continental		
	HDD: 3211 hours		
	CDD: 2 hours		

Project scope and description

The Austrian demo is a new residential development in Salzburg. It is a greenfield development located on the outskirts of the city in a quiet area with mostly multifamily houses.



Figure 25. Site layout for the GEWIN Gneis project.

Program and social dimension

The 17 buildings on the plot consists of mostly multi-residential dwellings. Half of the dwellings will be social housing units, the other half will be sold at a certain fixed price. There will also be a Kindergarten and a base zone that will be managed from the social aid and service organization “Caritas”.

The project is developed by “Heimat Österreich” together with the City of Salzburg and many other contributors. In addition to achieving the syn.ikia goals, the project aims to achieve the Austrian ‘klimaaktiv certification’ [17] and many other project specific goals that are fixed in a quality agreement.

The plot includes a green field with 1-3 storey buildings in the direct vicinity. In the neighbourhood there is a mix of services with shops, churches, medical practices, and leisure facilities. In the course of implementation, an upgrade of the neighbourhood should also be achieved.

Environmental concept and ambition

The ambition level of the development is to be energy positive. Furthermore, the development aims to achieve a certification in the Austrian klimaaktiv certification system. This includes the following ambitions: High quality public spaces that take into account green spaces and the oak forest close to the project area (goal: Greenpass® certification). High quality buildings that take into account sustainable building components in combination with a passive design and shading systems (goal: klimaaktiv declaration for each building). Upgrading of the neighbourhood by analyzing the existing building stock and make suggestions for optimizations.

Flexibility concept

Flexibility will be realised in several areas: Shared heating system: the new renewable heating systems should be able to replace the existing oil boilers in the buildings in the neighbourhood. Shared electricity: photovoltaics electricity can be used in each apartment and optional in the neighbourhood (new regulations in summer 2021); electricity from the grid will be provided depending on supply and demand (storage). Shared mobility: a mobility point will be implemented and ensure the flexible use of different mobility services. All three services will be planned together to ensure an integrated design.

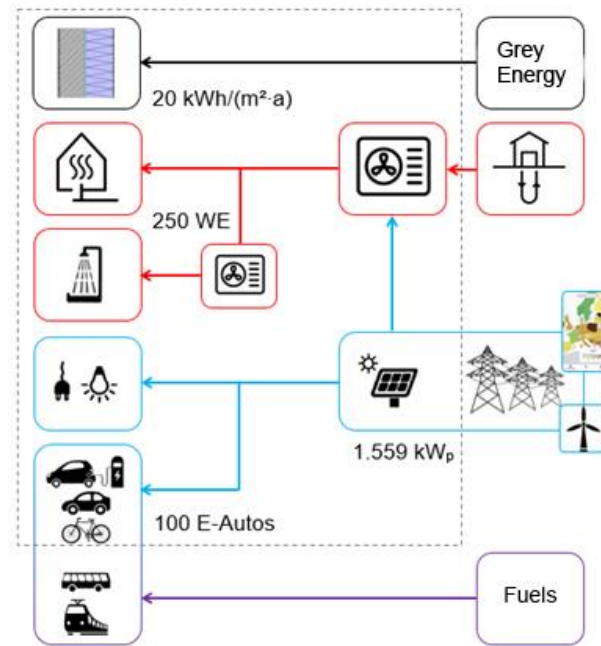


Figure 26. Map of the flexibility concept showing energy carriers and exchange vectors.

Architecture and sustainability

The project will be realised by three architects. The height of the buildings is in line with the existing neighbourhood (max. 4 floors). The integration of green areas and PV-panels into the design is under consideration. The window areas will be optimized to ensure a low energy demand and avoid summer overheating under consideration of a high daylight quality (goal: klimaaktiv certification for buildings). If financially feasible, the buildings are to be realised in hybrid construction (exterior wall: wood construction; ceiling: Solid construction with integrated underfloor heating.).



Figure 27. Planned section and facades of the buildings in GEWIN Gneis project.

Environmental and energy performance analyses

A two-staged approach has been applied in the optimization of the development. First, a neighbourhood scale approach with numerous scenarios will be run, and from those feasible scenarios that meet the goals of Syn.ikia, the klimaaktiv certification, and the Austrian regulations, will be chosen. These design options will be further evaluated with detailed modelling for performance and robustness under different future scenarios.

Regulatory framework and technical codes

For the energy and environmental performance analysis of the demonstration project in Salzburg, the base case envelope requirements were taken from the Austrian technical building guideline, the OIB Guideline 6 [18], which is also in line with the EPBD. The requirements used for the base case are presented in Table 30.

Table 30. Max. U-values and values of internal gains, occupancy, appliances, and setpoints, according to the OIB Directive 6.

Case descriptions			
Envelope	External wall U-value	0.35	W/(m ² K)
	Ground floor U-value	0.40	W/(m ² K)
	Roof U-value	0.2	W/(m ² K)
	External doors	1.7	W/(m ² K)
	Floor over garage	0.3	
Air tightness and ventilation	Air tightness n50	1.5	1/h
Internal gains	Occupancy/lighting/technical equipment	3.51/4.4/4.4	W/m ²
Heating and cooling	Heating setpoint (7-22)	20	°C
	Heating setback (22-7)	18	°C
	Cooling setpoint (7-22)	26	°C
	Cooling setback (22-7)	28	°C

Model and tools

The model is created with the CEA (City Energy Analyst) tool [19]. For this, a simplified geometry was built via QGIS and georeferenced. The data below was used as input for the base case scenario. The baseline and also the different scenarios are calculated with the CEA tool. This tool is capable to evaluate designs at city or neighbourhood level, even during early design phases with lower data availability by allowing to iterate through different possible scenarios.

Table 31. Characteristics of the base case design for the Austrian demo project.

CONTINENTAL DEMO	Salzburg base case			
Envelope	Wall	0.35	W/(m²K)	Source: OIB Guidelines [18]
	Slab on ground	0.4	W/(m²K)	
	Roof	0.2	W/(m²K)	
	Windows	1.4	W/(m²K)	
	Glass to wall ratio	35 %		
	Infiltration rate	1.5 ACH		
Ventilation	Air exchange rate	0,38 1/h residential 1,15 1/h kindergarten		
Internal gains	Peak sensible heat load of people	70 W/p		
	Peak load for lighting and technical equipment	10.7 W/m²		
	Operation time (hours/days/weeks)	16/7/52		
Heating set point		21°C		
Heating setback		18°C		
Cooling set point		26 °C		
Cooling setback		28 °C		
Heating system	District heating, Floor heating			
Heat recovery	-			
Specific fan power		0.45 KW/(m³ s)		
Electricity production	PV production on 30% of the available roof			
Control	Room temperature control			
Shading	Venetian blinds			

Building description and model settings used as base case

For the baseline building, the above described envelope values were used.:

The maximum allowed infiltration rate of 1.5 ach is used for the base case scenario. In line with the concept design documents, a window-to-wall ratio of 35% is specified for all buildings.

For heating and DHW in the base case, district heating is assumed, as it is the predominantly used heating type in the city. For cooling, individual AC units are used for every apartment, and a central AC is used for the Kindergarten.

Occupancy schedules are estimated via the integrated model of the CEA based on building use.

Automatic user control, based on room temperature is specified. For this, heating setpoints of 21°C and setback points of 18°C and cooling setpoint of 26°C and setback point of 28°C, were specified.

For the base case, no internal shading is assumed.

For renewable electricity generation, south facing PV panels are selected for the roof areas and façade areas that meet the threshold level of 700 kWh/(m²yr).

The energy performance of the base case is summarized in Table 32. Here only the final electricity balance of the building is presented. Since the heating demand in the base case is met via district heating, the picture is not complete without mentioning the contribution of district heating, summarized in Table 33. When looking at the primary energy balance, heating energy delivered by district heating contributes to the renewable and non-renewable primary energy balance, with the primary energy factors described in Table 35.

Table 32. Energy performance of the base case, electricity.

SYN.IKIA BASE CASE. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	28,25	2,11	1,89	2,07	1,97	2,16	3,23	3,79	2,31	2,02	2,04	2,58	2,09
non EPB uses	kWh/m ²	15,35	1,30	1,18	1,30	1,26	1,30	1,26	1,30	1,30	1,26	1,30	1,26	1,30
EPB used electricity	kWh/m ²	12,41	0,52	0,66	1,05	1,10	1,30	1,69	1,93	1,28	1,04	0,83	0,57	0,45
Energy produced on-site	kWh/m ²	30,35	0,77	1,21	2,41	3,31	4,35	4,35	4,61	3,76	2,55	1,61	0,79	0,62
Environmental energy	kWh/m ²	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Exported electricity	kWh/m ²	17,94	0,25	0,55	1,36	2,21	3,05	2,67	2,68	2,48	1,51	0,78	0,22	0,17
Exported for non EPB uses	kWh/m ²	7,43	0,17	0,42	0,58	1,05	0,88	1,15	0,83	1,07	0,77	0,28	0,13	0,09
Grid exported	kWh/m ²	10,51	0,08	0,13	0,78	1,15	2,18	1,51	1,85	1,41	0,74	0,51	0,09	0,08
Grid delivered, (EPB uses)	kWh/m ²	15,84	1,58	1,23	1,03	0,86	0,86	1,55	1,86	1,03	0,98	1,22	2,01	1,64
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-0,75	0,48	0,24	-0,12	-0,48	-0,78	-0,40	-0,29	-0,52	-0,19	0,16	0,64	0,52

Table 33. Energy performance of the base case, district heating.

SYN.IKIA BASE CASE. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
Heating energy delivered	kWh/m ²	66,33	15,49	11,23	7,76	2,86	0,00	0,00	0,00	0,00	0,70	3,54	10,10	14,65

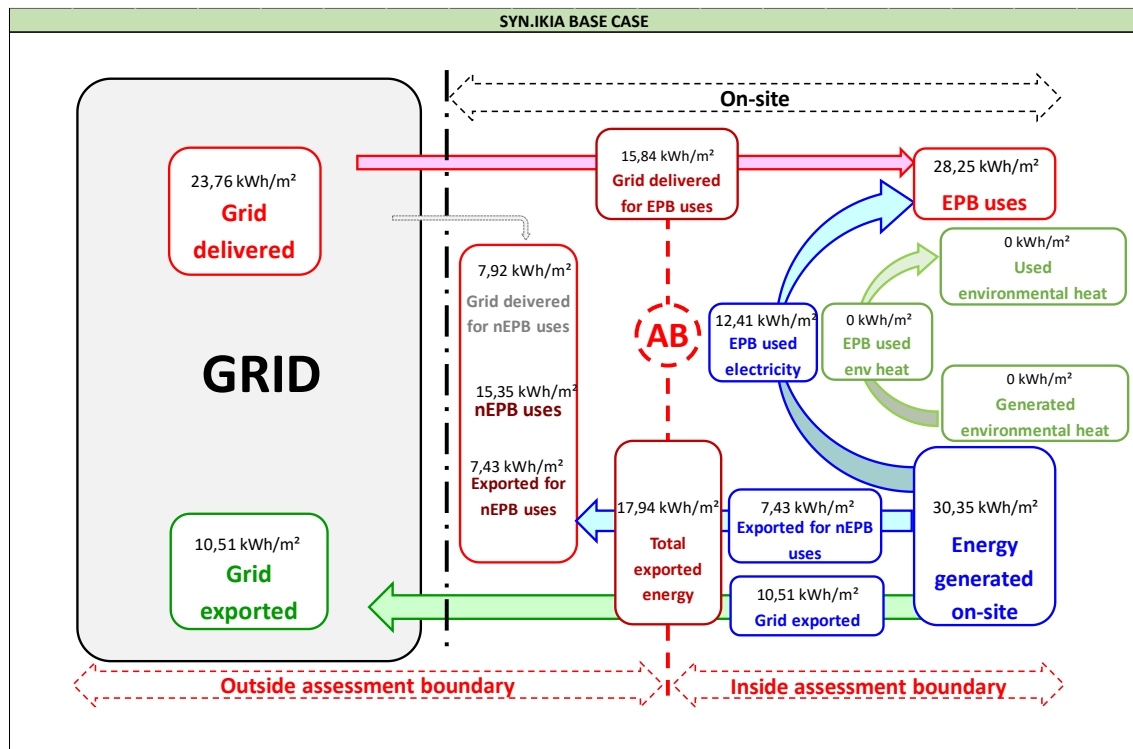


Figure 28. Energy balance of the base case.

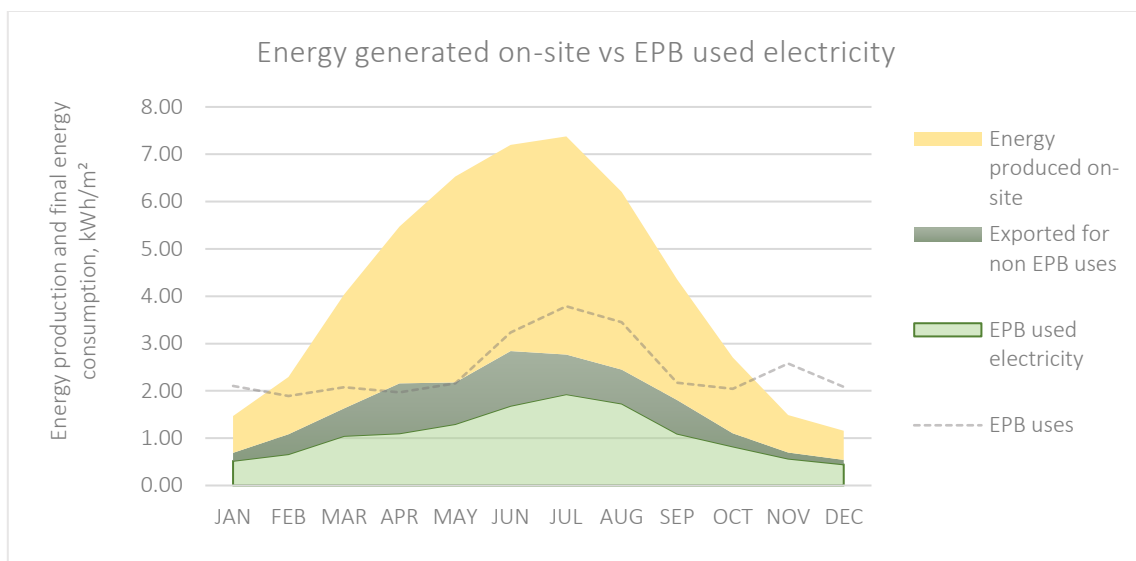


Figure 29. Energy generated on-site (PV), EPB used electricity, and exported electricity for nEPB uses per month, base case.

Design options

The Austrian demo consists of 17 individual buildings, and the design scenarios and optimization were done on a neighbourhood level rather than on a single building level. At each design scenario, the cumulative effects of all building were evaluated. To reach the optimal design, the following workflow was used:

To lower the energy demand, first two different passive design options were evaluated with different sets of U-values, infiltration rates, and shading options.

Subsequently, two different HVAC options have been assessed for both of the passive scenarios.

An alternative option is assessed for every scenario where PV is integrated not just on the roof areas, but also on the south facing façade areas of the buildings.

At the end the best design option that meets the design goals was chosen.

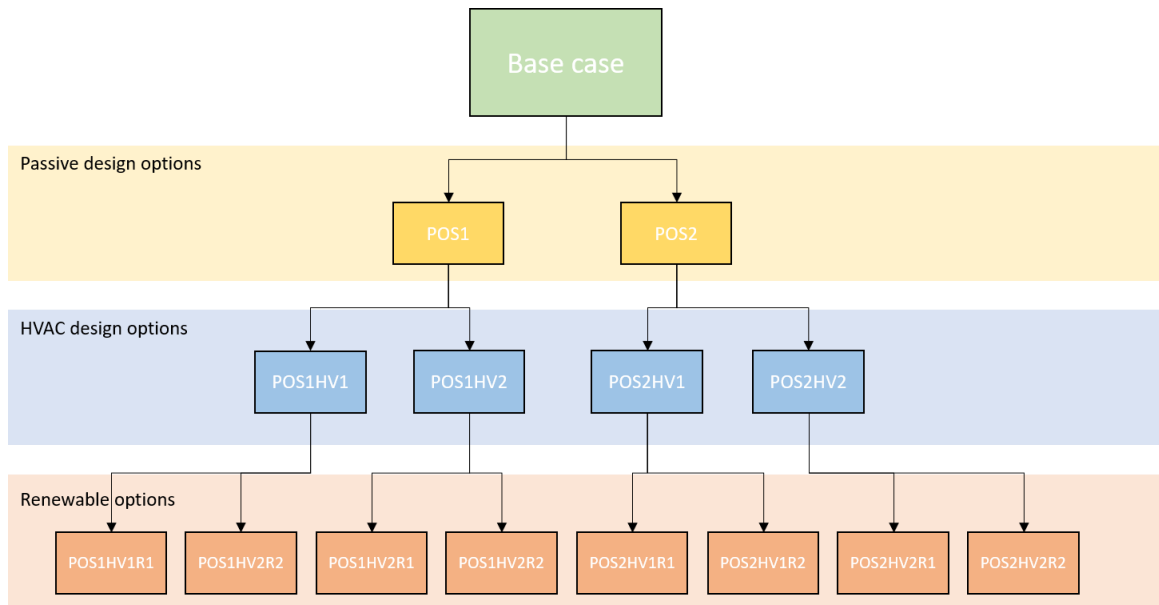


Figure 30. Scenario evaluation workflow.

Passive design options

Three different envelope options were assessed, with different U-values and infiltration rates. The OIB (Österreichisches Institut für Bautechnik) defined is handled as a base case (BC), described earlier. The second option (PO1) aims to comply with the stricter values prescribed for buildings to get housing subsidy. The third option (PO2) looks for the best practice values in the area, and aims to comply with the klimaaktiv standard. The values for PO1 and PO2 can be seen below.

PO1	PO2
Wall U values : 0.14 W/(m ² K)	Wall U values : 0.129 W/m ² K
Floor U values : 0.18 W/(m ² K)	Floor U values : 0.141 W/m ² K
Roof U values : 0.13 W/(m ² K)	Roof U values : 0.101 W/m ² K
Window U values : 0.69 W/m ² K	Window U values : 0.65 W/m ² K
Infiltration rates : 1 ach	Infiltration rates : 0.6 ach

Shading system

For the base case scenario, no shading is considered. As for the other two scenarios, manually controlled shading is considered for both of the options creating scenario 1 (POS1) and scenario 2 (POS2) as alternative options of the two mentioned previously.

Scenario name	POS1	POS2
Scenario description	PO1 scenario with manually controlled shading	PO2 scenario with manually controlled shading

The results of scenario 1 and scenario 2 are summarized in Figure 31.

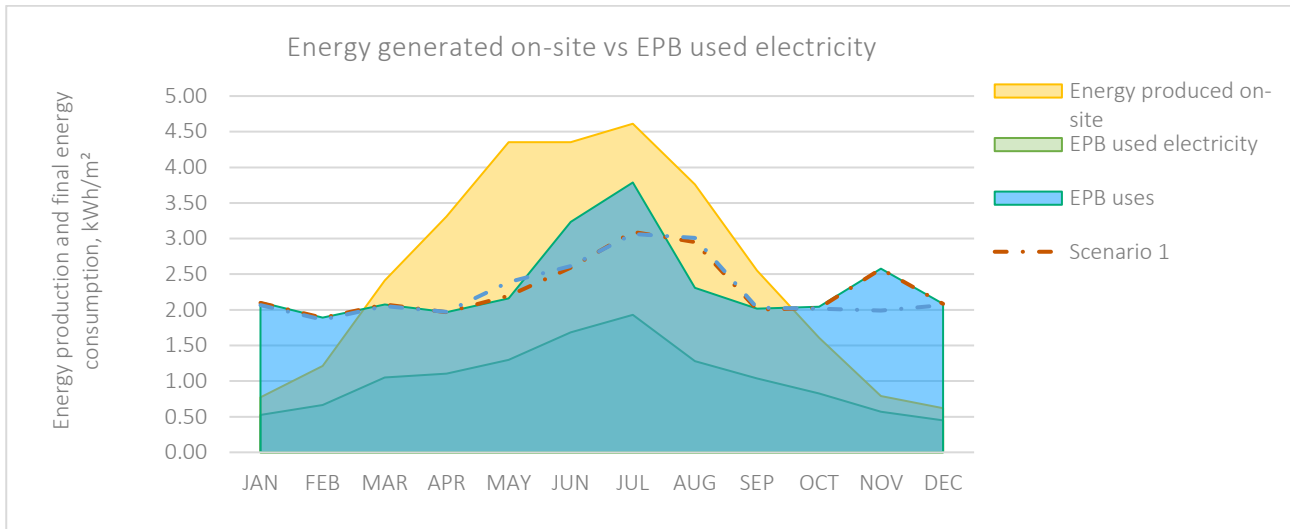


Figure 31. Results of scenario 1 and scenario2 compared to the base case scenario.

HVAC options

District heating and split AC units are considered in the base case for heating and cooling. For alternatives two types of heat pumps are considered. Using a geothermal heat pump is defined as a viable option, so it is investigated for this design option. As for the base case, radiators (70/55) are considered. To reach a better COP value of the heat pumps for these alternative design options, low temperature floor heating (40/35) and high temperature cooling(18/21) are considered.

Combined with POS1 and POS2 this gives scenario 3 (POS1HV1) and scenario 4 (POS2HV1).

Scenario name	HV1
Scenario description	Using heat pumps for heating and DHW production, with floor heating (40/35) and cooling (18/21)

Results for scenario 3 and scenario 4 are summarized in Figure 32.

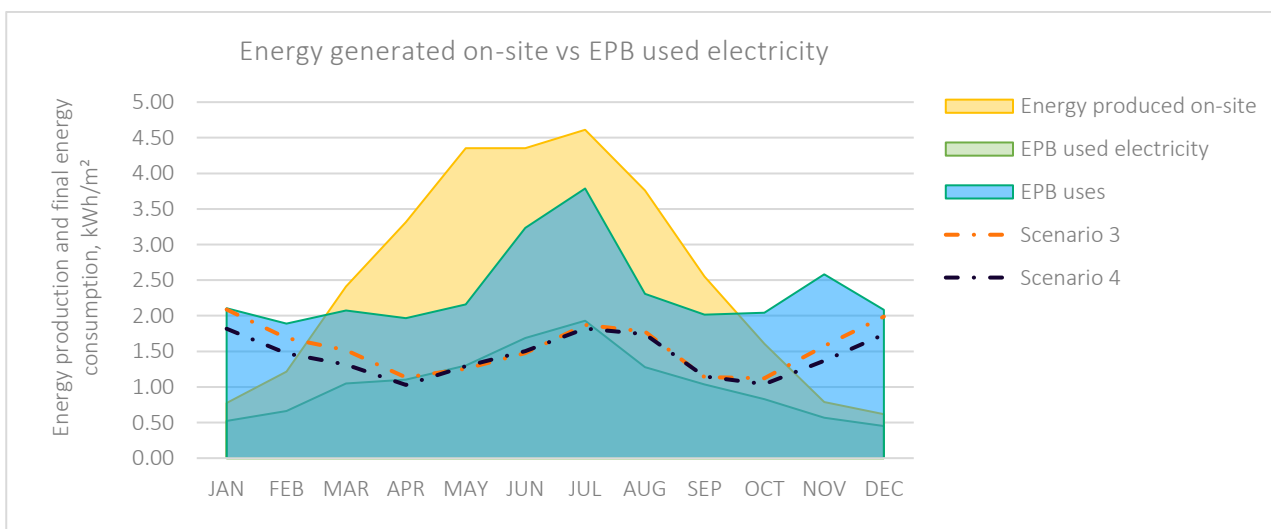


Figure 32. Results of scenario 3 and scenario 4 compared to the base case scenario.

Ventilation systems

The base case contains simple exhaust ventilation. Ventilation with heat recovery and economizer can be considered.

Alternative name	V1
Alternative description	Using heat recovery and economizer in ventilation

Automatic control

For the base case, room temperature control was considered. This was changed for a PI controller with optimum tuning when looking at the design options. This lowers the emission losses for both cooling and heating further.

Alternative name	AC1
Alternative description	Using PI controller with optimum tuning for temperature control.

To assess the effect of heat recovery ventilation with economizer and automatic controls, combined effect of the new ventilation and control option is added, creating the HV2 scenario which combined with the passive design options gives scenario 5 (POS1HV2) and scenario 6 (POS2HV2).

Scenario name	HV2
Scenario description	Using heat pumps for heating and DHW production. with floor heating (40/35) and cooling (18/21) combined with heat recovery ventilation and economizer and PI controller with optimal tuning.

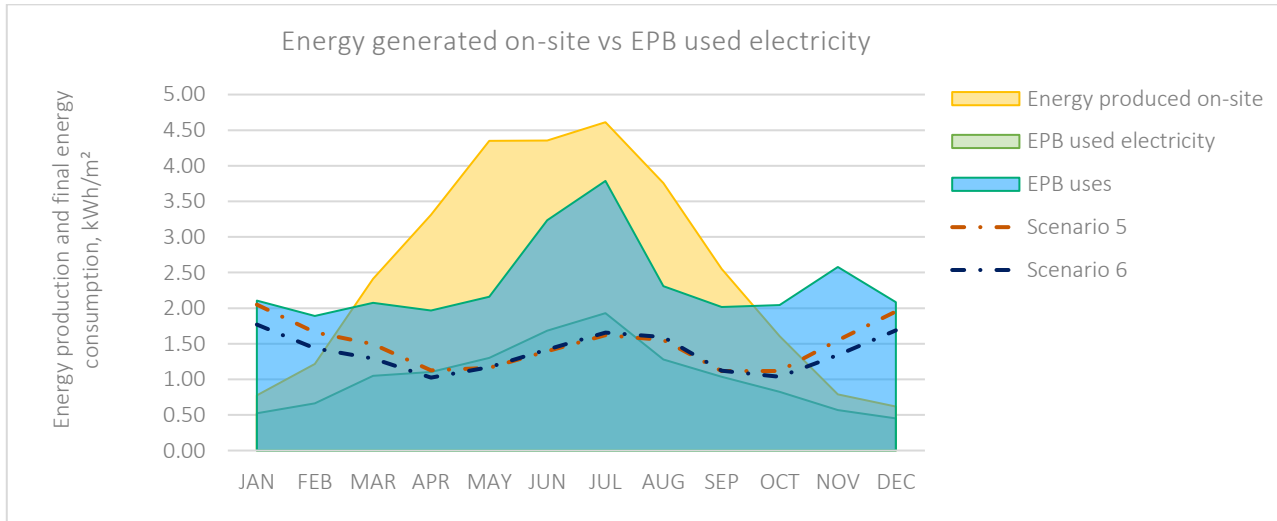


Figure 33. Results of scenario 5 and scenario 6 compared to the base case scenario.

Renewables

At the end, both PV and BIPV were considered. The original aim was to cover just the roof area with PV panels. In the alternative options, not just the roof area, but also some of the free wall area is covered with PV panels. Wall surfaces were only considered above the annual threshold of received yearly radiation of 700 kWh/(m²yr).

Scenario name	R1
Scenario description	PV is installed on both roof and wall areas which are above the radiation threshold.

This scenario is calculated for all the previous scenarios. The results for scenarios 7-12 are summarized in Figure 34.

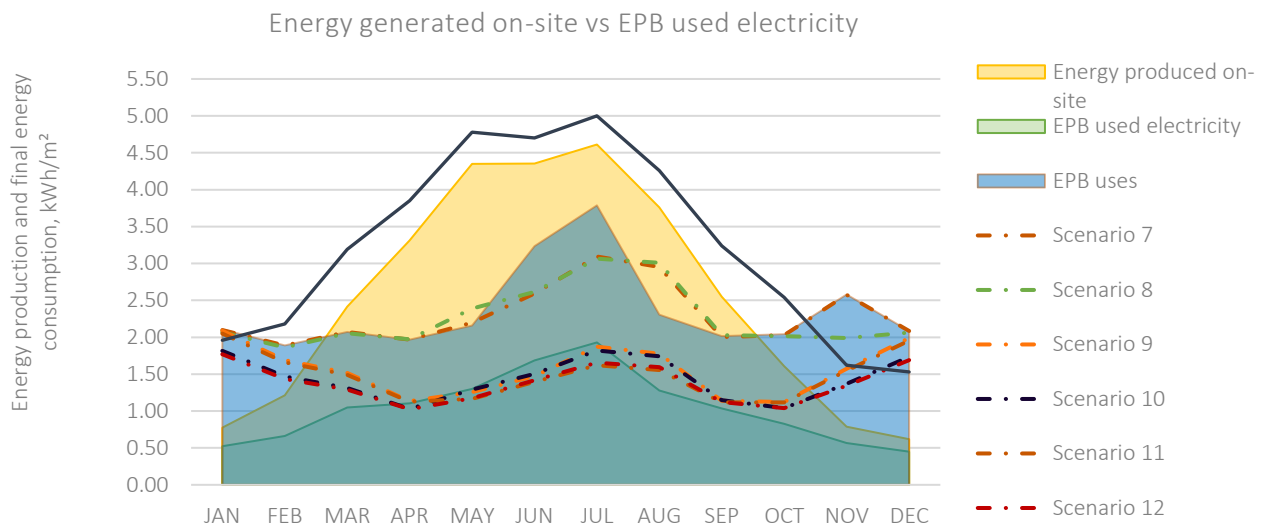


Figure 34. Results of scenario 7 - 12 compared to the base case scenario.

Simulation results

Results from each case are summarized in Table 34, below.

Table 34. Table energy performance of simulated model for alternative design options

Main KPIs	BC	POS1	POS2	POS1 HV1	POS2 HV1	POS1 HV2	POS2 HV2	POS1 R11	POS2 R1	POS1 HV1 R1	POS2 HV1 R1	POS1 HV2 R1	POS2 HV2 R1
Heating demand [kWh/m²]	66.3	16.2	10.5	15.3	10.2	14.7	9.55	16.2	10.5	15.3	10.2	14.7	9.55
Cooling demand [kWh/m²]	9.93	5.16	6.15	4.82	4.62	3.04	3.49	5.16	6.15	4.82	4.62	3.04	3.49
DHW demand [kWh/m²]	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4
Lighting [kWh/m²]	5.28	5.28	5.28	5.28	5.28	5.28	5.28	5.28	5.28	5.28	5.28	5.28	5.28
COP – Heating	-	-	-	4	4	4	4	-	-	4	4	4	4
COP – Cooling	2.6	2.6	2.6	4	4	4	4	2.6	2.6	4	4	4	4
COP – DHW	1	1	1	2.7	2.7	2.7	2.7	1	1	2.7	2.7	2.7	2.7
PV production [kWh/m²]	30.4	30.4	30.4	30.4	30.4	30.4	30.4	38.9	38.9	38.9	38.9	38.9	38.9
Total primary energy consumption [kWh/m²]	47.7	39.3	38.5	46.7	41.0	45.0	39.5	39.3	38.5	46.7	41.0	45.0	39.5
Non-renewable primary energy consumption [kWh/m²]	17.7	-2.86	-3.29	-12.0	-13.3	-12.8	-14.1	-11.5	12.0	-20.6	-22.0	-21.5	-22.7
Supply cover factor	0.27	0.24	0.27	0.25	0.29	0.26	0.30	0.24	0.27	0.25	0.28	0.26	0.29

Primary energy factors used to calculate the weighted renewable and non-renewable energy use can be found in Table 35 below. Values are obtained from the OIB 6 guideline.

Table 35. Primary energy factors used for the Salzburg energy model.

Primary energy conversion factors				
		Fp_ren	Fp_nren	Fp_tot
Electricity	Grid	0.61	1.02	1.63
Electricity	PV	1.0	0	1.0
Environment heat	ENV	1.0		1.0
District heating (Salzburg)	ENV	0.72	0.28	1.0

Discussion of simulation results

When comparing the design scenarios in Table 34, it is clear that changes in envelope construction and in infiltration rates have the biggest impact on energy demand. Switching from base case envelope values to the realistic envelope solutions (scenario1) reduces heating demand with more than 70% and cooling demand with around 48%. In a really optimistic scenario (scenario2), with best practice envelope solutions and a really air tight envelope (0.6 ach), heating demand can be further reduced by 35%, however, the cooling demand increases with around 20%. As heating demand is dominant, this can still be considered a positive impact.

Although the base case considered district heating, a more realistic option would be the use of heat pumps. When considering the use of heat pumps, radiators used in the base case are changed to low temperature floor heating (40/35) and high temperature cooling (18/21) to reach a better efficiency. These changes result in a slight drop in both heating and cooling demands.

In scenario 5 and 6, the use of heat recovery ventilation and optimum tuned PI controllers could reduce cooling demand by 24%, whilst heating demand only by 6%. This however does not make a great difference in non-renewable primary energy consumption.

When considering also the façade areas for PV production in scenarios 7-12, the supply cover factor does not increase significantly. However, the grid exported energy increases with around 30%. Grid exported energy and other outputs for every scenario can be seen in the Appendices.

Detailed results of final design

For the detailed final design, the POS2HV2 scenario in combination with the R1 scenario where PV is not only planned on the rooftops is considered to be the proposed design as this has almost the lowest energy demands and non-renewable primary energy consumption as well as high supply cover factors. The syn.ikia energy balance for this scenario is positive, with 16.29 kWh/(m²yr) exported to the grid. This excess energy can also be used in the future to provide electricity for EVs and other mobility solutions, in line with the future project goals. The energy balance for this proposed design can be seen in Figure 35.

Table 36. Figure 35. Energy balance for the proposed final design

SYN.IKIA FINAL CASE. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	20,74	1,82	1,47	1,31	1,03	1,71	2,17	2,99	2,78	1,31	1,04	1,37	1,73
non EPB uses	kWh/m ²	15,35	1,31	1,18	1,30	1,26	1,30	1,26	1,30	1,30	1,26	1,30	1,26	1,31
EPB used electricity	kWh/m ²	12,01	0,91	0,79	0,85	0,77	1,17	1,34	1,67	1,51	0,86	0,68	0,69	0,77
Energy produced on-site	kWh/m ²	38,85	1,96	2,18	3,19	3,85	4,78	4,70	5,00	4,26	3,24	2,54	1,62	1,53
Environmental energy	kWh/m ²	17,48	2,94	2,20	1,61	0,94	0,88	0,85	0,87	0,87	0,85	0,93	1,81	2,72
Exported electricity	kWh/m ²	26,84	1,05	1,39	2,34	3,08	3,61	3,36	3,33	2,75	2,38	1,86	0,93	0,76
Exported for non EPB uses	kWh/m ²	10,55	0,84	1,15	0,92	0,76	0,73	0,89	0,90	1,15	0,97	0,93	0,74	0,57
Grid exported	kWh/m ²	16,29	0,21	0,24	1,42	2,32	2,88	2,46	2,42	1,60	1,42	0,93	0,18	0,19
Grid delivered, (EPB uses)	kWh/m ²	8,72	0,91	0,68	0,46	0,26	0,54	0,82	1,32	1,27	0,46	0,37	0,67	0,96
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-6,47	-0,05	-0,25	-0,67	-1,01	-1,10	-0,90	-0,72	-0,53	-0,69	-0,54	-0,09	0,07

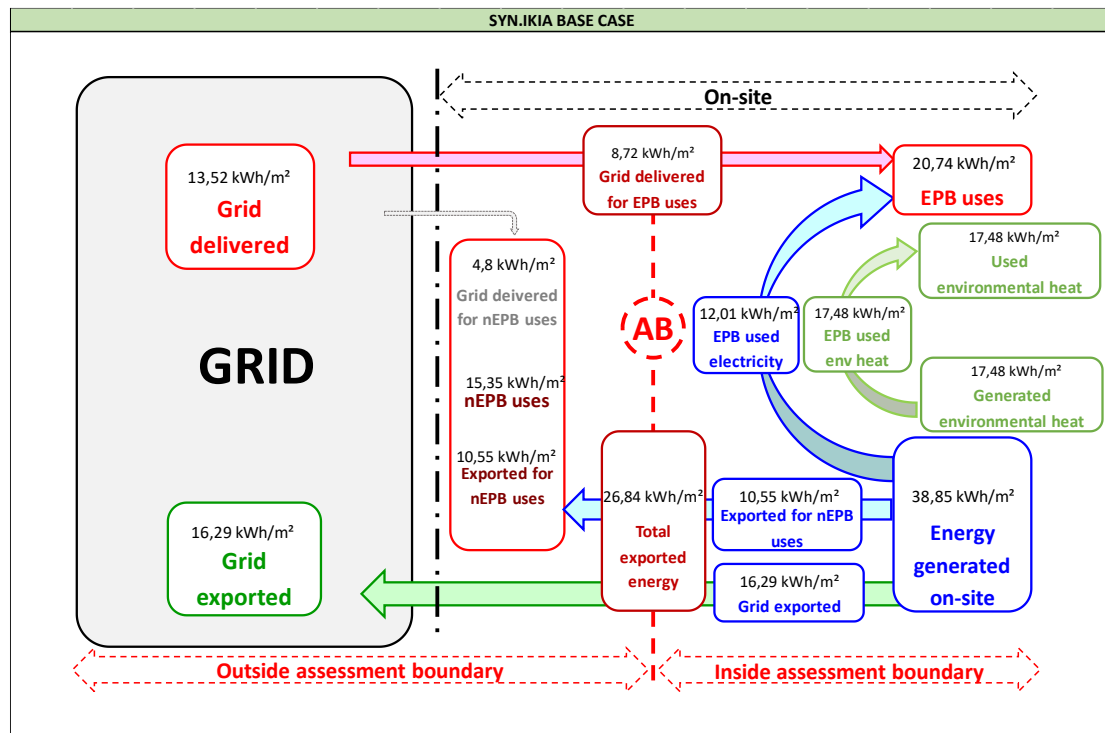
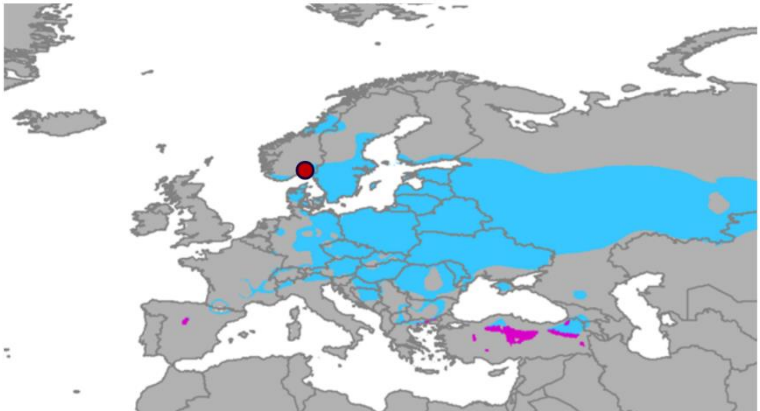
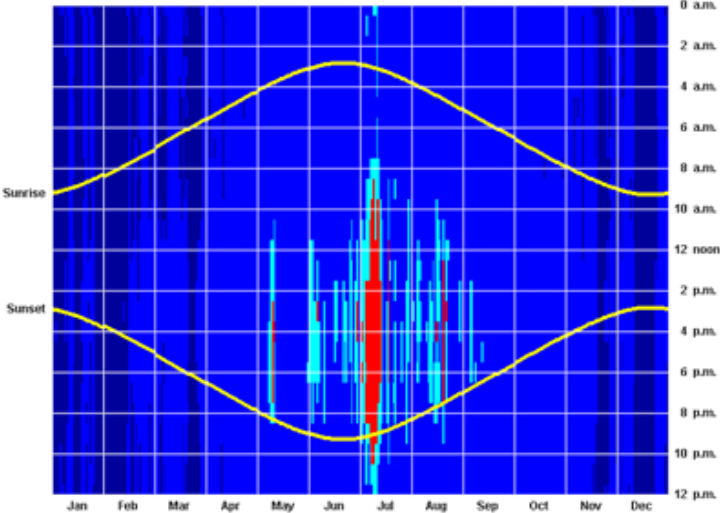


Figure 35. Energy balance for the proposed final design.

Sub-arctic climate demonstration project

DEMO	OEN		
Key data	Program: Residential		
	Heated floor area: 14 450 m ²		
	Number of housing units: 150		
	Ambition: SPEN		
	Energy carriers	1	Electricity
		2	District heat
Location	City: Oslo, Norway		
	Lat: 60.2 N		
	Long: 11.08 E		
Climate	Sub-arctic		
	HDD: 4112 hours		
	CDD: 2 hours		

Project scope and description

The Norwegian Demonstration case is a new residential development in the outskirt of Oslo, approximately 10 km away from the Oslo Central Station. It is located at a short distance from green recreation areas, and it is close to public transportation nodes. The development consists of a neighbourhood of flats collected in a circular shape and includes approximately 150 apartments distributed on 4-5 floors, with a total floor area of around 14450 m².

Program and social dimension

The circular shape of the building emphasizes the social dimension of a sustainable neighbourhood, stressing the overall concept of sharing spaces, functions, energy, and infrastructure. The form has therefore a high symbolic value highlighting the importance of community issues in neighbourhood developments. The central courtyard of over 3000 square meters constitutes a green social arena, a place where people want to meet and spend time together. Banqueting room in the courtyard will enable both activities and interaction among residents, while walkways will establish safe connection among properties, placing the community together.



Figure 36. View of the courtyard

Environmental concept and ambition

The OEN project aims to be an energy positive building, fulfilling ZEB-O targets, therefore compensating, thanks to integrated renewable energy systems, environmental impact – in terms of emissions - due to the building operation, including technical equipment but not appliances. Technologies applied include:

- Well insulated and airtight envelope
- Balanced ventilation with high heat recovery
- Connection to a district heating system based primarily on waste heat, ensuring a supply of 1 066 390 kWh/year
- Architecturally integrated PV system ensuring a 520 000 kWh/year with a surface of over 3500 square meters and a nominal efficiency of 21% (inverter loss 16%, soiling losses 10%).

The project will moreover focus on the use of materials characterized by low carbon footprint.

The building has been designed to ensure minimum energy consumption through passive means. A highly stringent envelope, characterized by low transmittance and high air tightness will minimize thermal losses during winter, while a glass to wall ratio of 50% will ensure optimal intake of solar gains.

Flexibility concept

A Smart house technology will be designed and implemented in a way to ensure exchange between flats' energy demands, smart charging of electric vehicles, and energy generation. The Technical IT platform will be also designed in a way to initiate activities to create a vibrant neighbourhood.

Architecture and sustainability



Figure 37. Visualization of the OEN project in context.

The project's main approach is a circle that provides a strong architectural dimension of differences between outside and inside, where "inside" is organized, clear and collective, while "outside" adapted to the surroundings and nature. The circle is an expression of the democratic community, and an expression of the sun's path across the sky.

The circle encloses an inner common park room adapted for collective community with the cultivation of plants and food, greenhouses, space for celebrations, play, weddings, meetings and safe recreation areas for children and adults. Here is located for parkour, maintenance of bicycles, lubrication of skis. All entrances are accessed from the courtyard, also helping to activate the park. The park is the heart of the neighbourhood. The park will give the residents a great experience value and seem engaging and "at home".

Outside is the circle and clear shape that fits into the flat plot between spheres of forest. The building is no more than four floors and lower than the trees in the forest that surround the square. From the hill behind can but look over the building and further out over the city.

The apartments will sell to the south or west. Most apartments have a side towards the park and a side towards «nature». Both sides have a balcony. In the two-sided apartments you can stay on the balcony towards the park, or towards nature and the city. The circle as a form should also provide an experience in the individual apartment.

The building will stand out as an example of new sustainable construction where social sustainability stands together with sustainable environmental measures. The roof is shaped to capture solar energy in an optimal way. Efficient building-integrated solar cells are used where there are sun rays to capture, the rest are green roofs for diversion and cooling. The building has very low heat loss, good sun protection and together with the technical measures to produce energy will be a plus house. Arrangements are being made for the use of public transport, car sharing, and bicycles.

Environmental and energy performance analyses

Environmental and energy performance analyses of the building were carried out to optimise the building construction and materiality towards energy efficiency while ensuring that energy produced by the integrated photovoltaic system would still be larger than the overall energy demand, excluding appliances. Design options were defined in a way to explore possibilities in alignment with the project concept and OBOS philosophy, evaluating the impact of alternative construction solutions and the use of equipment such as shading devices of alternative energy systems.

Regulatory framework and technical codes

The OEN project will follow the Norwegian passive house standard when it comes to quality in construction. Façades will be characterized by 50% glazed surfaces, admitting plenty of daylight, and 50% insulated wooden walls. Suspended floor slabs will be built over cast concrete walls and will span outside the perimeter of the building to create liveable balconies. Foundation will directly be built on solid ground made of rock. Insulated flat roof with solar panels will be attached to an open gabled roof structure (unconditioned). In order to ensure a low carbon footprint of the building recycled materials will be used. Natural stone, gravel and lawn will cover the courtyard, equipped with pergolas and bicycle parking. A retention pond will be placed in the centre of the courtyard to harvest rainwater for irrigation purposes.

National codes and regulatory framework, described in the following tables, were used as basis for defining characteristics of the base case, and used as starting point for the environmental and energy modelling of the building.

Table 37. National code and regulatory framework for residential buildings (apartment buildings)

Source	Criteria	Value
TEK17 14-4: Energy supply (selected criteria)	Total energy demand	$\leq 95 \text{ kWh}/(\text{m}^2 \cdot \text{y})$
	Energy supply solutions	No use of fossil fuels for covering the heating demand Buildings with a heated gross internal area of more than 1000 m ² shall have multi-source heating systems and be adapted for use of low-temperature heating solutions. Low temperature heating ($T_{\text{SUPPLY}} < 60^\circ\text{C}$) has to cover $\geq 60\%$ of the heating demand
	U-value outer roof	$\leq 0.18 \text{ W}/(\text{m}^2\text{K})$
	Outer wall	$\leq 0.22 \text{ W}/(\text{m}^2\text{K})$
	Slab on ground and towards exterior	$\leq 0.18 \text{ W}/(\text{m}^2\text{K})$
	Windows and doors	$\leq 1.2 \text{ W}/(\text{m}^2\text{K})$
	Air tightness (at 50 Pa pressure difference)	$\leq 1.5 \text{ ACH}$
NS 3700:2013 Criteria for passive houses / residential buildings	Specific space cooling demand	No mechanical cooling allowed
	Air tightness test (leakage at 50 Pa pressure)	$\leq 0.6 \text{ W}/(\text{m}^2\text{K})$
	Normalized thermal bridge value	$\leq 0.03 \text{ W}/(\text{m}^2\text{K})$
	Specific fan power (SFP) for ventilation fans	$\leq 1.5 \text{ W}/(\text{m}^3\text{s})$
	Ventilation heat recovery efficiency	$\geq 80\%$
	Specific space heating demand	$\leq 15 \text{ kWh}/(\text{m}^2\text{y})$ considering an annual average temperature at site over 6.3°C
	U-values:	
	Roof	$0.08\text{-}0.09 \text{ W}/(\text{m}^2\text{K})$
	Outer wall	$0.10\text{-}0.12 \text{ W}/(\text{m}^2\text{K})$
	Foundation	$0.08 \text{ W}/(\text{m}^2\text{K})$
	Windows and doors	$\leq 0.8 \text{ W}/(\text{m}^2\text{K})$
	Heat loss factor for transmission and infiltration (building area > 250 m ²)	$\leq 0.43 \text{ W}/(\text{m}^2\text{K})$

Model and tools

To model the environmental and energy performance of the neighbourhood, a cluster of the OEN building was extracted from the circular form and modelled in the dynamic simulation program IDA-ICE [20]. Curved exposed surfaces towards north and south were straightened in the model, because of the impossibility to adapt some calculation routines to curved surfaces, while East and West facades were assumed as adiabatic, considering they are adjacent to the rest of the neighbourhood. In the extracted cluster, four different residential units per floor are included; living areas are facing South, sleeping areas are facing North. A sensitivity analysis of the model showed that incidence of the orientation in the overall energy performance of the building cluster was limited to 5%.

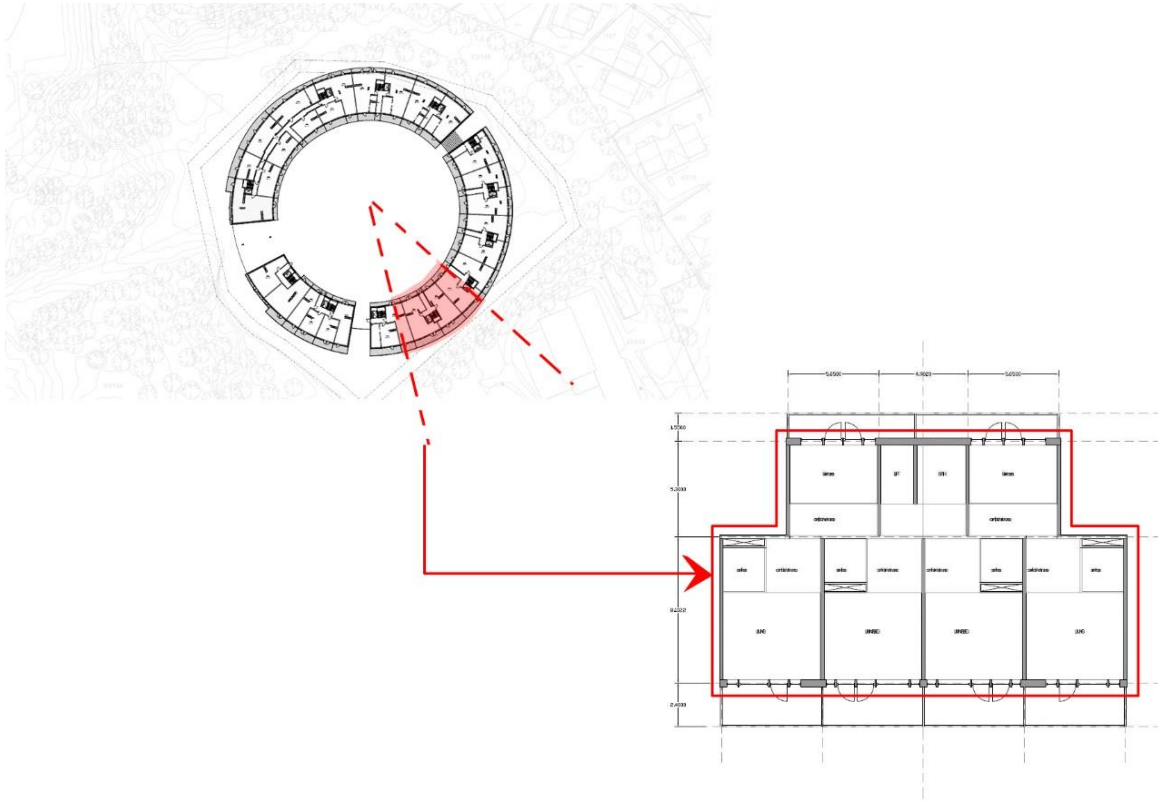


Figure 38. For the simulation model for the OEN project, a cluster from the circular building was extracted and straightened

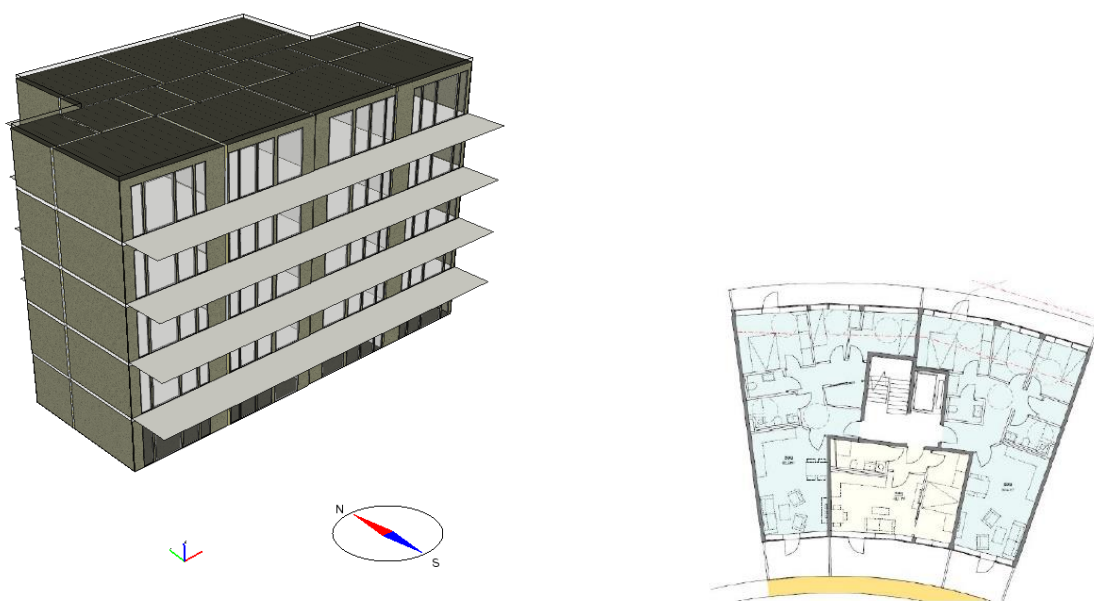


Figure 39. Digital model developed in IDA ICE for environmental and energy performance analyses.

Table 38. Base case model characteristics for the Norwegian demo project.

DEMO	OEN cluster		
Gross area	1360 m ²		
Heated floor area	1258 m ²		
Envelope	Wall U-value	0.1	W/(m ² K)
	Slab on ground U-value	0.08	W/(m ² K)
	Roof U-value	0.11	W/(m ² K)
	Windows U-value	0.8	W/(m ² K)
	Normalized thermal bridges	0.03	W/(m ² K)
	Glass to wall ratio	50	%
	Infiltration rate	0.6	ACH
Normalized thermal capacity	Concrete construction	120	Wh/(m ² K)
Ventilation	Exchange rate	0.62	l/s per m ²
	Heat recovery efficiency	80	%
	Specific fan power	1.3	W/(m ³ s)
Internal gains	occupancy/lighting/appliances	1.5/1.95/3.0	W/m ²
Operation time	hours/days/weeks	16/7/52	
Heating set point	constant	21	°C
Cooling set point	n/a		
Heating system	District heating system, radiators	60/40	°C
Cooling system	n/a		

Simulation tools

Simulations were carried out using the code IDA-ICE v.4.8. The model used is the Energy Zone Model embedded in the software. The calculations make use of a dynamic time step of maximum 1 hour. The climate file used was provided in the software, and it is the OSLO_GARDERMOEN_013840(IW2) with a default urban wind profile. The simulation time is 1 year (365 days). A digital model of the building in Grasshopper, a plugin for Rhino using Energy Plus engine, was used to quantify energy generation by the integrated photovoltaic system.

Base case and design options

Building description and model settings used as base case

The base case geometry is based on the drawings provided by OBOS. The building is designed to be circular; therefore, it presents a curved external surface. To accommodate the thermal zones which in this version of the software require to have straight surfaces, the computational domain was adapted (ref. Fig.3).

Since the building is located in an area served by district heating, all the space heating energy is considered coming from this system. Fresh air is provided by an AHU that preheats the external air to 19°C, recovering heat from collected exhausted air. The rest of the heating is provided by radiators connected to the district heating system and running at a temperature of 55 degrees. The radiators are modelled as ideal heating unit to fulfil the setpoint requirements, and the amount of thermal energy is calculated as the load on the district heating independently by the temperature at which the heat is provided. The domestic hot water (DHW) needs are fulfilled by means of an ideal electric boiler common for the whole domain. The consumption associated to DHW is 25 kWh/m² floor area per year.

Modelling of the base case shows that EPB uses are mostly used to heating demand, with peaks in the winter. A large part of the energy produced on site is exported to the grid, while up to 4 kWh/m² are monthly used for EPB purposes or exported for non EPB uses.

Table 39. Energy performance of base case

		YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EPB uses	kWh/m ²	53.50	7.17	5.51	5.05	3.79	3.47	3.36	3.42	3.52	3.60	4.07	4.65	5.90
non EPB uses with lighting	kWh/m ²	18.49	1.55	1.42	1.60	1.50	1.55	1.56	1.55	1.57	1.53	1.54	1.53	1.58
EPB used electricity	kWh/m ²	21.57	0.46	1.15	2.86	2.65	2.43	2.35	2.39	2.46	2.52	1.45	0.53	0.31
Energy produced on-site	kWh/m ²	55.85	0.66	1.64	4.08	6.28	9.27	9.82	9.37	6.88	4.58	2.07	0.76	0.44
Environmental energy	kWh/m ²	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Exported electricity	kWh/m ²	34.28	0.20	0.49	1.22	3.62	6.84	7.47	6.97	4.42	2.06	0.62	0.23	0.13
Exported for non EPB uses	kWh/m ²	12.16	0.20	0.49	1.22	1.50	1.55	1.56	1.55	1.57	1.53	0.62	0.23	0.13
Grid exported	kWh/m ²	-22.12	0.00	0.00	0.00	-2.12	-5.29	-5.91	-5.42	-2.85	-0.53	0.00	0.00	0.00
Grid delivered. (EPB uses)	kWh/m ²	31.93	6.70	4.36	2.20	1.14	1.04	1.01	1.03	1.06	1.08	2.62	4.12	5.59

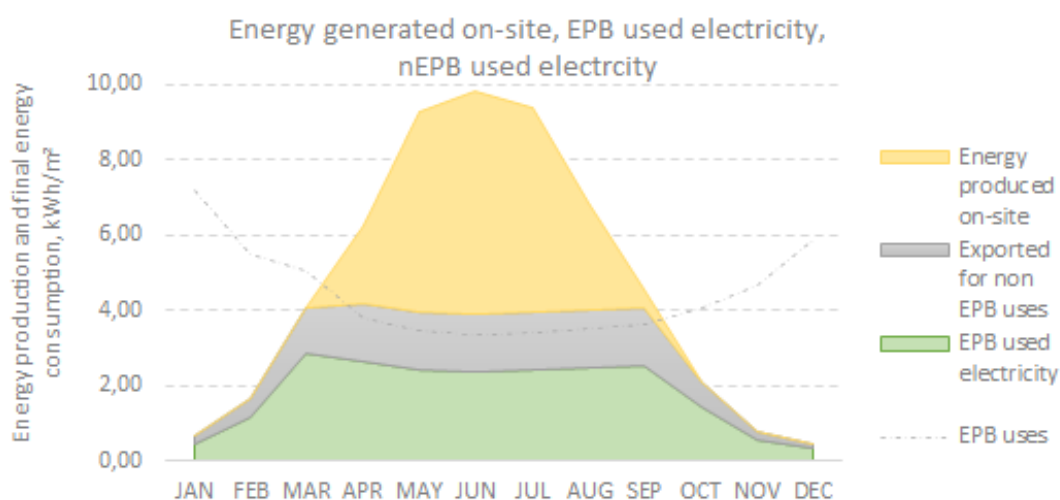


Figure 40. Energy balance of the Base case

Design options

The following design options were modelled for environmental and energy performance:

Thermal mass

In the base case scenario, each floor slab is constituted of 0.15 m thick concrete. This thermal mass is further increased in the two following analyses of 0.05 m extra. In the option Tm1 this mass is covered by a layer of light insulation (0.05 m) and gypsum panels (0.025 m) while in the option Tm2 the same concrete mass is exposed.

Shading system

A shading system constituted by an external integrated textile blind is included in the building model for all the windows on the Southern façade. In the first option (Ss1) the solar screen is not active, the natural ventilation is deactivated while each room has an ideal cooler to understand what the impact would be on a hypothetical cooling system or in other words what is the amount of overheating we have to deal with in a building like that in this climate zone. The second scenario (Ss2) presents a system with no natural ventilation, with a hypothetical cooling load and a shading device with an automatic control based on the operative temperature inside the room. The third scenario (Ss3) introduces the natural ventilation alongside the hypothetical cooling load while the automatic control of the shading system is deactivated.

Design and control of heating and ventilation systems

The scenario Hv1 makes use of the floor heating in all the zones of the building sustained by the district heating, thus replacing the room units. The ventilative heating is excluded. The second scenario, Hv2, instead keeps the heating units in each room and excludes the ventilative heating. Both the scenarios excluded the natural ventilation under 26°C.

Ground source heat pump

In the scenario with the GSHP, the ventilative heating and the units in the rooms are kept as they are in the base case, the heat is provided by a heat pump with ground accumulation.

Simulation results

Figure 41 shows the EPB uses in the two thermal mass scenarios - TM1 and TM2 - when compared with the EPB use of the base case scenario. The renewable energy generated on site is the same since this scenario, as all the other proposed, do not involve any change in the energy harvesting system, namely the BIPV panels. As results show, placing a layer of insulation between the gypsum ceiling and the slab would result in a significant increase in the energy demand of the building. This is certainly related to the fact of not taking advantage of thermal inertia of the building. An increase of thickness of the slabs as defined in TM2 would on the other hand be beneficial.

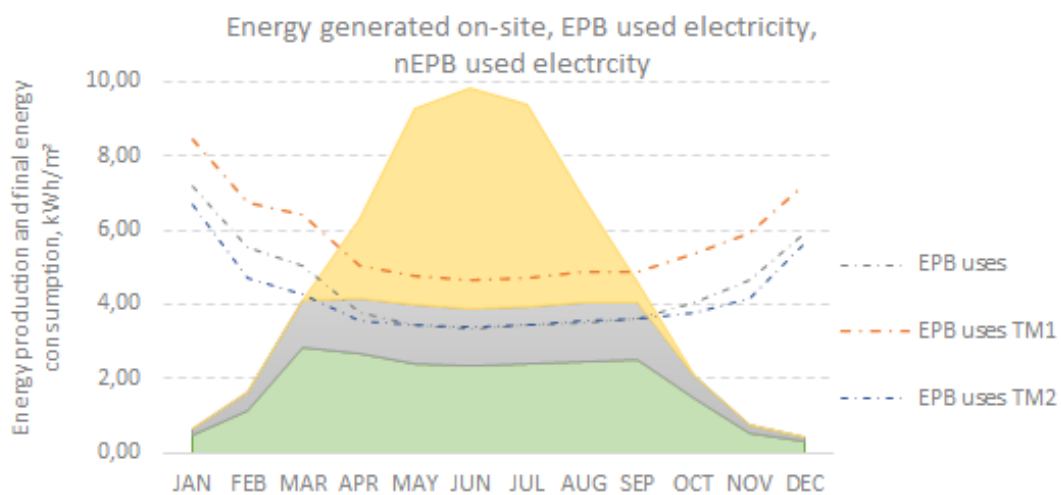


Figure 41. Energy balance of the design options related to thermal mass.

Figure 42 illustrates the simulation results for the scenarios related to the use of shading system. Scenario SS1 does not involve any use of shading system nor natural ventilation. This reflects into a higher thermal load that in this case was removed by calculating how much energy would a hypothetical cooling system require. The hypothetical cooling load was counted in the energy consumption, imagining some action taken by the occupants. The result thus presents a lower heating demand, but counting the cooling load in the total, this explains the increase in the EPB uses in the summer months, namely mid-June to August. Both design options evaluated in SS2 and SS3 solve the cooling demand prospected in the SS1, but results in an increase in the EPB uses because of lost solar gains.

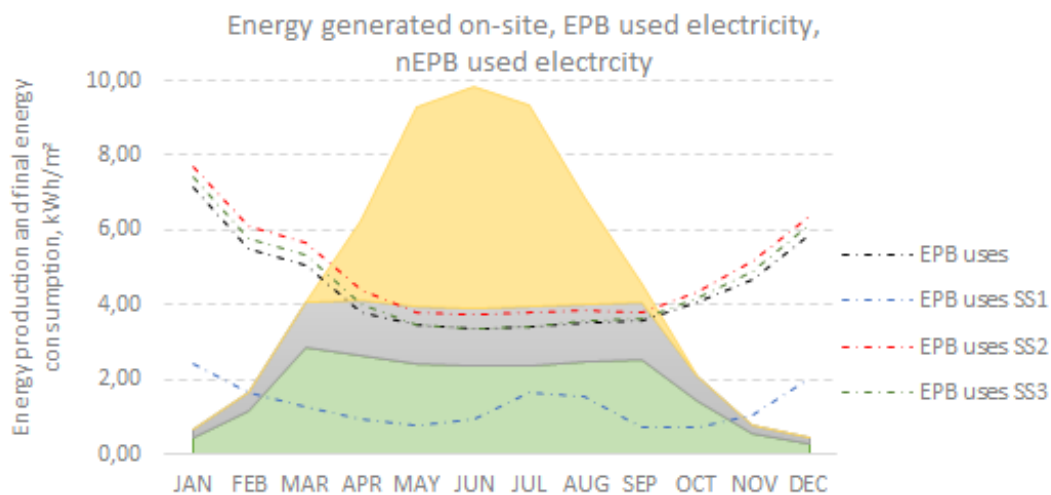


Figure 42. Energy balance of the design options related to the use of solar shading systems.

Figure 43 shows the energy balance of the design options involving changing the heating and ventilation systems. The different energy use in the two scenario HV1 and HV2 does not present any apparent difference in the consumption. Both the scenarios use the heat from the district heating and the distribution is alternatively performed by floor heating and radiators.

Finally, the results in Figure 44 presents a case in which the whole heating is realised by a heat pump. The EPD consumption in terms of electrical work is minor. this is due to the seasonal COP = 3.5 considered for the heat pump. The scenario is hypothetical. and its environmental impact strictly depends on the primary energy mix of the grid that feeds the heat pump.

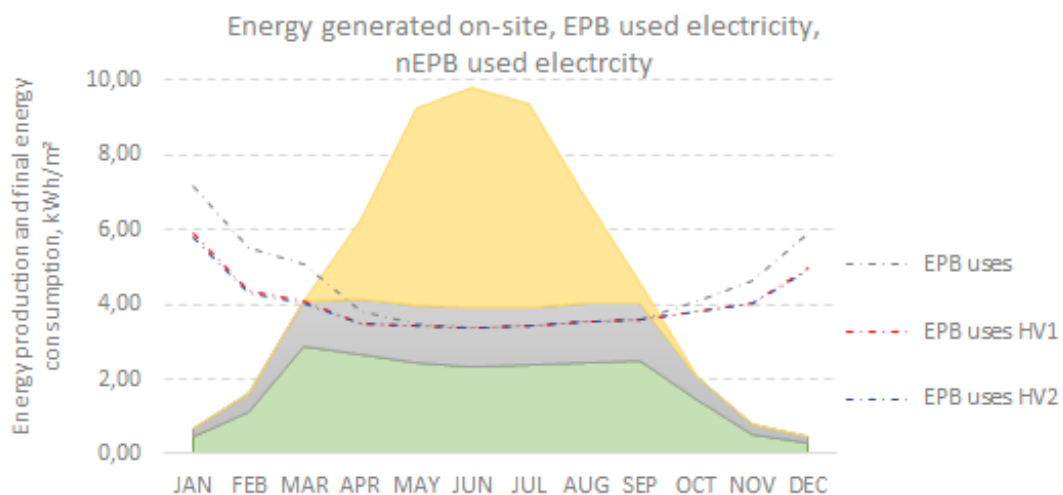


Figure 43. Energy balance of the design options related to alternative heating systems.

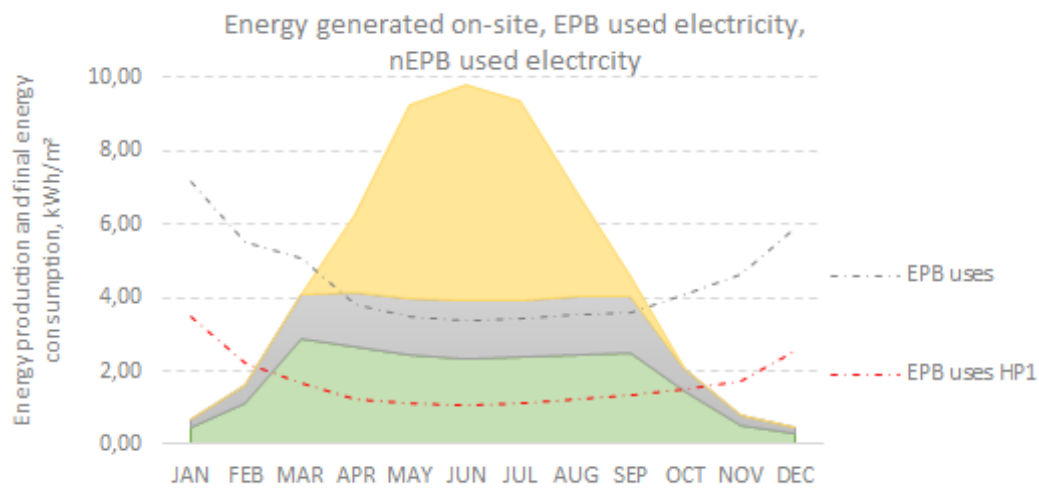


Figure 44. Energy balance of the design options related to the use of a geothermal heat pump.

The following primary energy factors have been assumed when calculating supply cover factor:

Table 40. Primary energy factors used for the demo project in Oslo.

Primary energy conversion factors				
		Fp_ren	Fp_nren	Fp_tot
Electricity	Grid	0.94	0.6	1.54
Electricity	PV	1	0	1
District heating	ENV	1	0.07	1.07

Table 41. Summary of results.

Main KPI	BC	TM1	TM2	SS1	SS2	SS3	HV1	HV2	HP1
Heating Demand [kWh/m²]	9.14	9.35	5.97	10.6	12.0	10.6	3.99	3.74	9.40
Cooling Demand [kWh/m²]	0	0	0	42.7	12.7	14.7	0	0	0
DHW Demand [kWh/m²]	25	25	25	25	25	25	25	25	25
Lighting	13	13	13.1	13	15	13	13	13	13
COP-Heating	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	3.5
COP-Cooling	1	1	1	1	1	1	1	1	1
COP-DHW	1	1	1	1	1	1	1	1	1
PV production	55.4	55.4	55.4	55.4	55.4	55.4	55.4	55.4	55.4
Total primary energy consumption	66.2	66.21	62.55	66.19	68.83	67.84	59.97	60.25	58.8
Non-renewable primary energy consumption	-6.76	-6.68	-6.91	-8.42	-5.28	-6.55	-7.08	-3.27	-7.10
Supply cover factor	0.50	0.5	0.49	0.57	0.53	0.5	0.49	0.49	0.54
PMV>0.5 [%]	0.4	0.37	0.4	0.31	0.31	0.09	0.4	0.4	0.4
Cost [MNOK]	5.06	5.13	5.12	-	5.11	5.09	5.16	-	5.09

Detailed results of final design

Characteristics of the final model are similar as for the base case except that it includes the use of floor heating systems instead of radiators (HV1), resulting in lower energy demand and increased comfort. Energy quantities are represented in the following diagram:

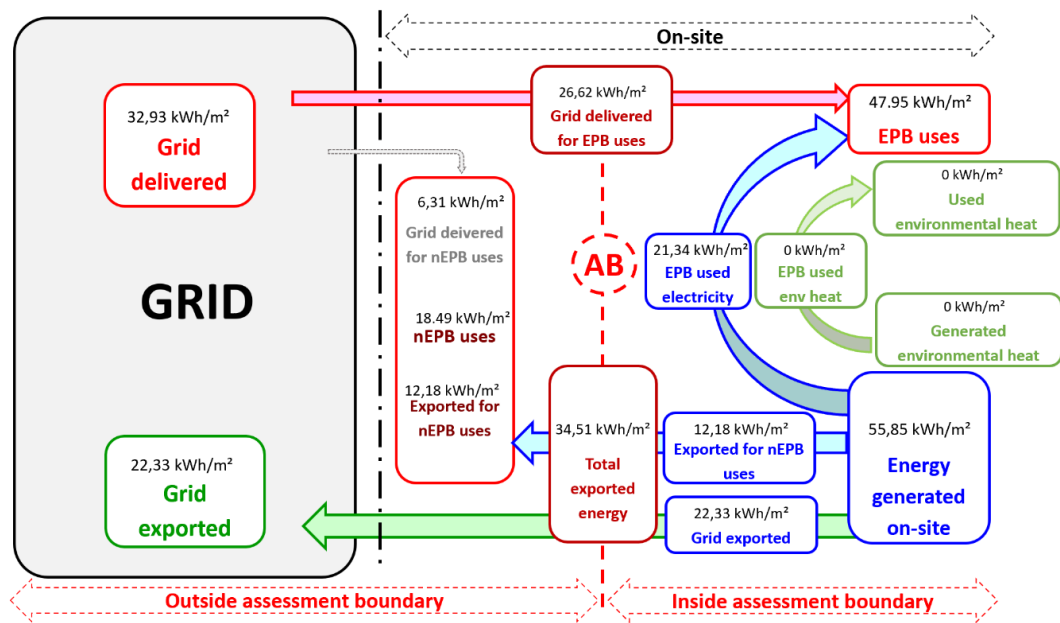


Figure 45. Energy balance for the proposed final design.

9. Scenario planning

This chapter presents the results of performance simulations of the four demo projects, taking into account future scenarios of climate change, user behaviour, and energy flexibility and costs, as described in Chapter 7.

Mediterranean climate demonstration project

Description of scenarios

Climate change

It is known that the climatic emergency is producing an important change in the regional climates. In Catalonia. METEOCAT (Servei Meteorològic de Catalunya, Catalan weather service) performed different future scenarios of weather forecasts with a very high geographical resolution of the Metropolitan Area of Barcelona [21]. The main findings of the forecasts can be divided in three: 1) an increase of the temperature, representing higher temperature indexes during the day and the nighttime; 2) less precipitation days, however, more intense rainfalls; and 3) less differentiation between seasons.

In that sense, two future scenarios of climate change were simulated in order to evaluate the performance of the building design. The climate change scenarios are based on IPCC and are obtained through Meteonorm [22] for the location of Barcelona.

- IPCC A2 – 2050
- IPCC B1 – 2050

Table 42. Climate change scenarios for the Mediterranean Demo.

Scenario	Description
Cl0	Current climate
Cl1	Future climate scenario based on IPCC A2 for 2050
Cl2	Future climate scenario based on IPCC B1 for 2050

The main characteristics of the climate scenarios are presented in Figure 46, compared to current weather data. A general increase in temperatures is observed in both climate change scenarios. The monthly average temperatures increase around 3°C. the minimum temperature of the year goes from -1°C to 3°C. and the maximum temperature from 33°C to 35°C. The A2 scenario shows slightly higher temperatures than the B1 scenario.

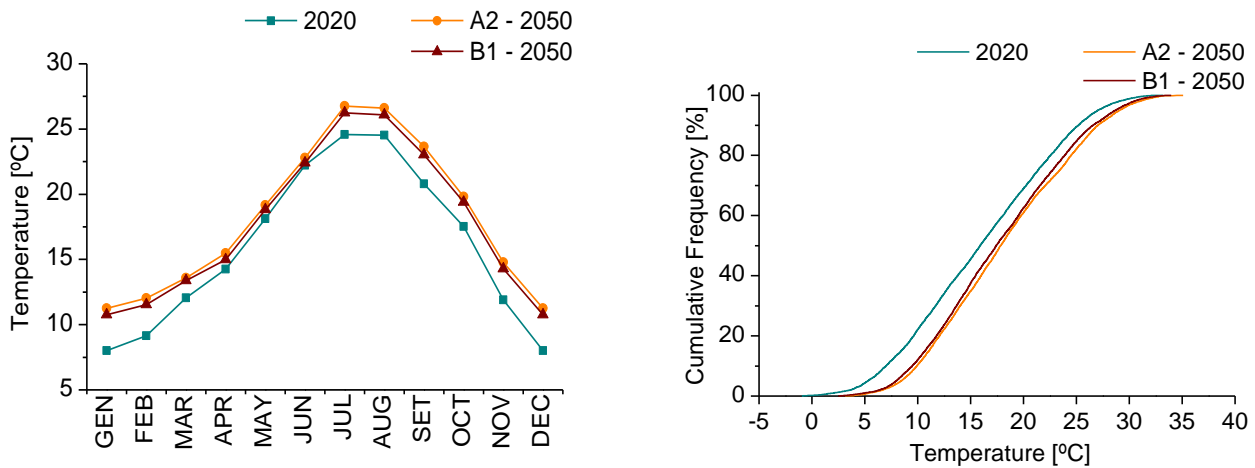


Figure 46. Weather conditions for the three scenarios: current climate (2020). IPCC A2 – 2050 and IPCC B1 – 2050. Left: monthly average temperature. Right: cumulative frequency of temperature.

User behavior

The actual occupancy and its interactions with buildings are the key factors determining the final energy consumption of the building [23]. For that reason, four different scenarios are proposed including two main characteristics: the number of occupants and the energy awareness of the users.

For the number of occupants, two levels are proposed: 1) average occupancy based on statistical data from Catalonia; and 2) an increased occupancy level. The increased occupancy level aims to emulate an extreme scenario of occupancy, which could be quite common in the Fondo neighborhood of Santa Coloma de Gramenet as the statistics of the neighborhood shows. The different levels of occupancy have been assigned to each household, and the distribution are detailed in Table 43. The average occupancy per household for both occupancy levels are: 2.46 and 2.93. for average and increased occupancy, respectively.

The main impacts of the occupancy level are:

- Activation of the different elements that depends on the occupancy: natural ventilation, solar shadings, lighting, and heating system.
- Domestic Hot Water (DHW) demand
- Appliances energy consumption
- Energy consumption, in general
- Thermal comfort, the passive and active strategies are implemented depending on the occupancy of the household and not following an ideal operation (e.g. the natural ventilation is applied only when there is occupancy, although it could be more convenient at other times of the day)

Table 43. Occupancy distribution per household. Statistical data (Catalonia and Fondo neighborhood Santa Coloma de Gramenet) and occupancy levels for the different scenarios (average occupancy and increased occupancy): % and absolute numbers represent the number of dwellings based on the nº of occupancy from a total number of 38 dwellings

Nº Occupants / household	Statistical data		Scenarios	
	Catalonia	Fonda neighborhood. Sta Coloma de Gramenet	Average occupancy	Increased occupancy
1	23%	18%	23% - 9	13% - 5
2	32%	29%	32% - 12	18% - 7
3	21%	24%	21% - 8	32% - 12
4	24%	29%	24% - 9	37% - 14
Average	2.46	2.64	2.46	2.93

The definition of the energy awareness of the users aims to see the impact of what happens if the building is used as was designed or not, in terms of user interaction. Two levels are defined: energy aware and energy unaware user. The main characteristics of the use scenarios are related to user's interaction with the building elements (natural ventilation, solar protection and heating use) and are detailed in Table 44.

Table 44. Energy aware and unaware user definition

Building	Energy aware user	Energy unaware user
Natural ventilation	Natural ventilation is used depending on: <ul style="list-style-type: none"> - Temperature - Occupancy > 0 	No use of natural ventilation
Solar protection	Optimal use: preventive use of the solar shadings. The solar shading activation depending on: <ul style="list-style-type: none"> - Temperature - Radiation - Shading factor: 70% 	Standard use: the solar shadings are use depending on: <ul style="list-style-type: none"> - Temperature - Radiation - Occupancy > 0 - Shading factor: 50%
Heating use	The heating system is used only when: <ul style="list-style-type: none"> - Occupancy > 0 	The operation of the heating system follows: <ul style="list-style-type: none"> - a constant schedule. independent of the household's occupancy.

The four user behaviour scenarios are defined combining the two use scenarios, and are shown in Table 45: number of occupants and energy aware of the users.

Table 45. User behaviour scenarios for the Mediterranean Demo

Scenario	Occupancy	Energy aware user
Ub0	Average occupancy	Energy aware user
Ub1	Average occupancy	Energy unaware user
Ub2	Increased occupancy	Energy aware user
Ub3	Increased occupancy	Energy unaware user

Energy flexibility and costs

A preliminary evaluation of the energy flexibility potential of the building has been done, and has been evaluated from an energy and cost point of view. Two energy operation strategies have been proposed in terms of how the energy generated on-site is managed. together with different price schemes.

Table 46 describes the objective and the main features of the two energy operation strategies. The standard strategy operates the building as usual, exporting the excess of PV to the grid. The flexibility strategy has the objective to increase the on-site consumption of the PV generated energy by increasing the demand when there is an excess of PV production (generated PV is greater than the demand).

Table 46. Description of the energy operation strategies: standard and flexibility

Energy operation strategy	Standard	Flexibility
Objective	Standard use of the building	Increase the use of the PV produced on-site
If there is excess of PV generation	The energy will be exported to the grid	Increase the demand by: <ul style="list-style-type: none"> - Increasing the household setpoint (+1°C) - Increasing the DHW tank setpoint (+5°C)

Those two energy operation strategies are combined with different price schemes. The price scheme is defined by two main features: energy price and compensation of exported energy.

Figure 47 and Table 47 describe the two energy price scenarios: current and future. The current energy price scenario is based on the Spanish tariffs that will be operative by June 2021 in all the buildings with a power <15 kW. The current energy price scenario includes three different price periods: 'valley', 'flat', and 'peak', see Figure 47. The future energy price scenario introduces an additional price period, 'super valley', in order to reproduce the 'duck chart'. The 'duck chart' represents the effect of a significant increase of the renewable energy production during the mid-day, causing an imbalance between the peak demand and the renewable energy generation and was introduced by the California Independent System Operator in 2013 [24]. The future scenario represents what could happen if the photovoltaic production increases significantly in the energy market, causing a super valley period tariff during the mid-day hours, as Figure 47 shows.

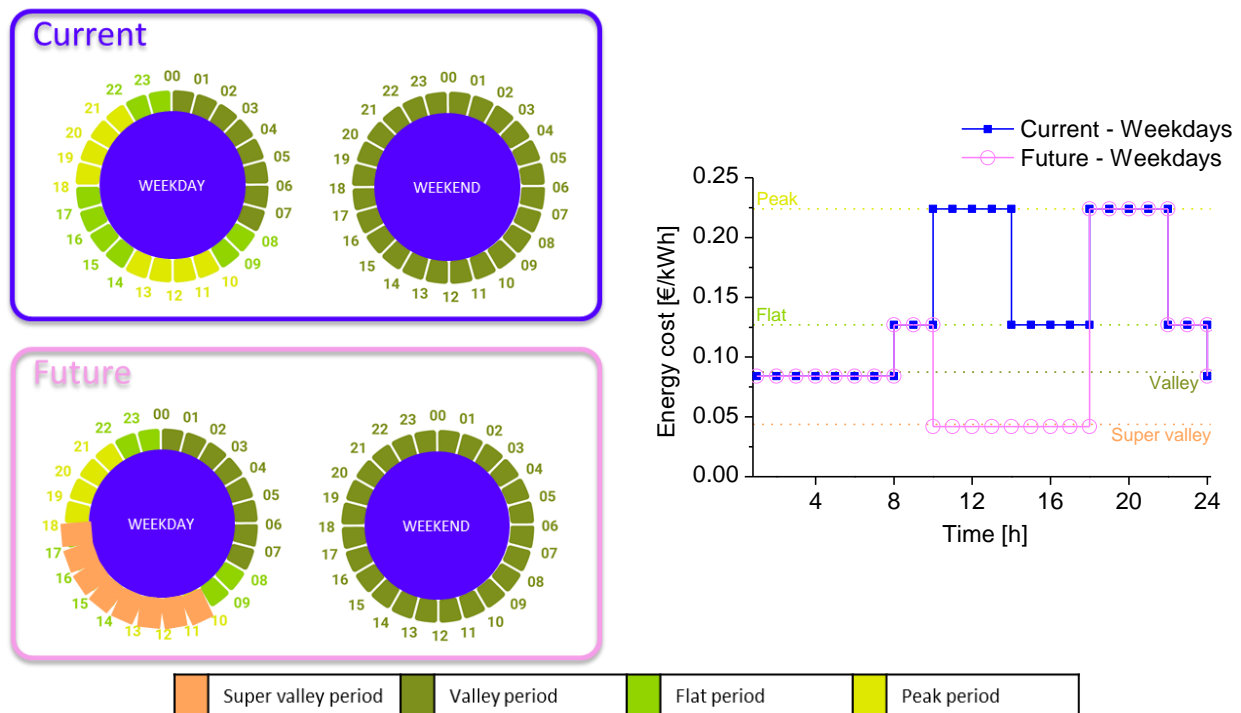


Figure 47. Current and future price schemes: super valley, valley, flat and peak periods

Table 47.2 Energy price scheme characteristics: price period and energy price.

Price period	Energy price	Current scheme		Future scheme	
		Weekday	Weekend	Weekday	Weekend
Super valley	0.042 €/kWh	-	-	10-17h	-
Valley	0.084 €/kWh	24-07h	01-24h	24-07h	01-24h
Flat	0.127 €/kWh	08-09h 14-17h 22-23h	-	08-09h - 22-23h	-
Peak	0.224 €/kWh	10-13h 18-21h	-	- 18-21h	-

The second feature used to define the price scheme is how the exported energy is compensated. Three possibilities are established:

- No compensation: the energy is exported to the grid without compensation.

- Partial compensation: a fraction of the purchase price is paid for the exported energy. being the current situation in Spain with around 30% of compensation.
- Net metering: the exported energy is fully compensated with the purchase price.

The energy flexibility and cost scenarios has been defined by combining the energy operation strategies and the energy price schemes, as Table 47 shows. The combination of the flexibility energy operation strategy with net metering compensation has not been considered, because of the fact that if the price scheme is allowed to compensate the exported energy by 100% of the purchase price, then there is no motivation for increasing the self-consumption. The cost and flexibility analysis apply to all energy uses of the building (both EPB and non-EPB uses), and include only the energy price (Table 48), excluding the taxes and operational costs.

Table 48. Energy flexibility and costs scenarios for the Mediterranean demo.

Scenario	Energy operation strategy	Energy price scheme
FI0-0	Standard	Current energy price. Partial compensation – 30%
FI0-1	Standard	Future energy price. Partial compensation – 30%
FI0-2	Standard	Current energy price. No compensation
FI0-3	Standard	Future energy price. No compensation
FI0-4	Standard	Current energy price. Net metering
FI0-5	Standard	Future energy price. Net metering
FI1-6	Flexibility	Current energy price. Partial compensation – 30%
FI1-7	Flexibility	Future energy price. Partial compensation – 30%
FI1-8	Flexibility	Current energy price. No compensation
FI1-9	Flexibility	Future energy price. No compensation

Results

Results of the base case

The base case (CI0 / Ub0 / FI0) of the scenarios included average occupancy profile (2.46 occupants per household); energy aware user behavior that included temperature based natural ventilation control, temperature and radiation based shading control with the shading factor 70%, and occupancy-based heating set-point control. It is based on current climate and current energy prices, with the 30% compensation from exported electricity. The main annual results of the base case are: Total primary energy consumption is 43.0 kWh/m² and the non-renewable primary energy is -10.2 kWh/m², indicating energy export, and average supply cover factor of 0.24. Figure 48 shows the final energy balance of the base case scenario, representing the energy produced on-site, the energy uses of the building considered as EPB, and the balance results in terms of EPB used electricity and non-EPB used electricity generated on-site (or in other words. exported for non-EPB uses).

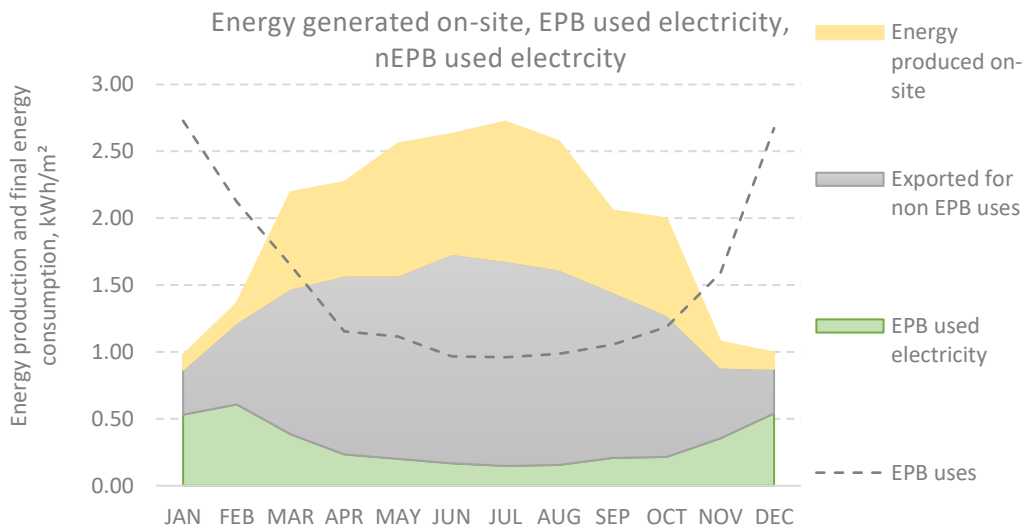


Figure 48. Final energy balance for base case scenario.

To complement the evaluation of the building design, a comfort analysis of summer conditions is included, due to the building has not mechanical cooling system, and only passive strategies are considered (solar shadings and natural ventilation). The selected comfort index is the percentage of overheating hours over the year, and is calculated following the adaptive comfort model [8]. The overheating is considered when the operative temperature is above the upper limit of adaptive comfort range, assuming a “medium” level of expectation (IEQ_{II}), as Table 49 shows. The results of the base case design reveal a very low level of overheating, in average 1.06%, and 5.48% for the worst performing zone.

Table 49. Comfort range for operative temperature, based on adaptive comfort model [8].

Comfort range	Level of expectation	Operative temperature (T_{op})
IEQI	High. Occupants with special needs (children, elderly, persons with disabilities, etc.).	$T_{op} = 0.33 \cdot T_{o,rm} + 18.8 + 2^{(*)}$ $T_{op} = 0.33 \cdot T_{o,rm} + 18.8 - 3$
IEQII	Medium. Standard level.	$T_{op} = 0.33 \cdot T_{o,rm} + 18.8 + 3$ $T_{op} = 0.33 \cdot T_{o,rm} + 18.8 - 4$
IEQIII	Moderate. It will not provide any health risk but may decrease comfort.	$T_{op} = 0.33 \cdot T_{o,rm} + 18.8 + 4$ $T_{op} = 0.33 \cdot T_{o,rm} + 18.8 - 5$

(*) $T_{o,rm}$ is the running mean outdoor temperature of the daily mean outdoor air temperature

Results of climate change scenarios

The changes from current climate to the one of the year 2050 causes a decrease in EPB used electricity as Figure 49 presents, due to higher ambient temperatures and therefore lower heating needs. Compared to the current climate case, the heating needs dropped from 10.5 kWh/m² to 5.8 kWh/m² and the total primary energy consumption from 43.0 kWh/m² to 34.0 kWh/m² (Cl1) and 35.3 kWh/m² (Cl2). The base case building has 1.06% of overheating over the year, while the future climate change scenarios with the increase in ambient temperatures face the increase of overheating to 2.03% (Cl1) and 1.60% (Cl2). The coloured areas of Figure 49 correspond to the current base case. It can be observed from Figure 49 that in case of climate change, the EPB used electricity consumption has dropped during winter (due to the lower heating demand). This leads to higher export for non-EPB uses (appliances), as the PV production stays the same and there is more locally produced electricity available for non-EPB uses.

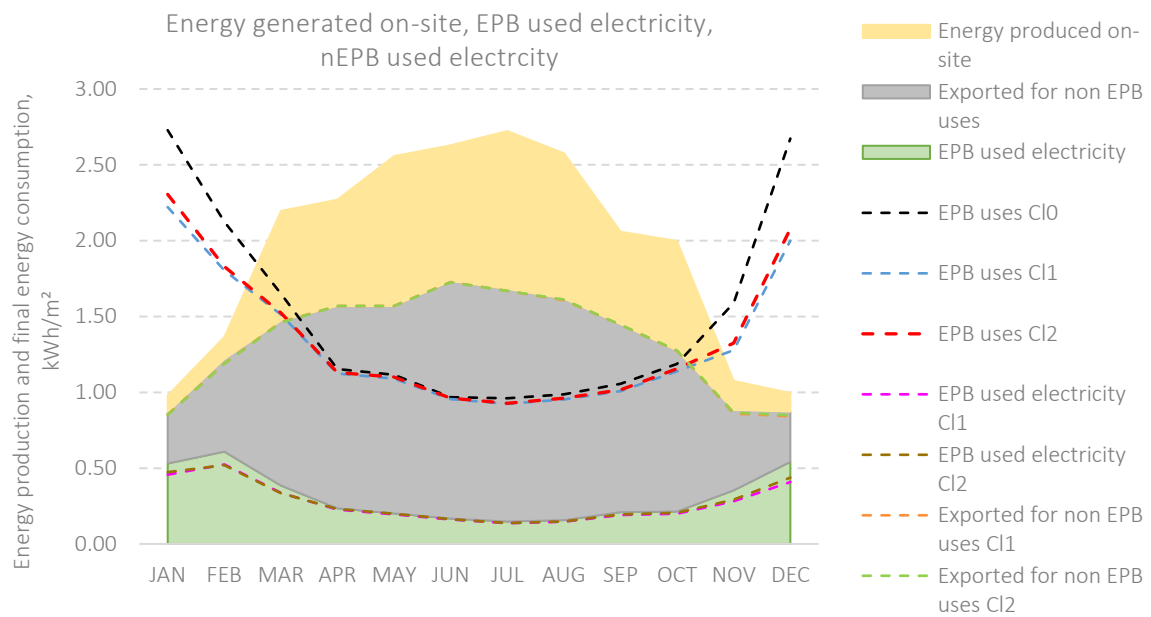


Figure 49. Final energy balance in Climate Change scenarios.

Results of user behaviour scenarios

Energy aware vs energy unaware user behaviour

The results in Figure 50 represent the final energy consumption of the base case (Ub0) and the case Ub1 which is the average occupancy case with energy unaware user. The change between those two scenarios is only in the user behaviour profile: the base case has a temperature based natural ventilation, while the Ub1 scenario does not have natural ventilation implemented. The base case has temperature and radiation based shading control (shading factor 70%), while the Ub1 case has standard shading control (shading factor 50%). There is also difference in heating set-point management – the base case has occupancy-based set-point control, while the Ub1 scenario follows a fixed schedule.

This all results in an increase in final energy consumption of 7% during winter months, as well as in EPB used electricity due to higher EPB consumption and therefore also a higher supply cover factor. As EPB consumption is increased during winter months, there is less locally produced electricity available for non-EPB uses, so that is why the export to non-EPB uses has decreased during winter. The average supply cover factor of the base case (Ub0) is 0.24 and the one of energy unaware user behaviour scenario (Ub1) is 0.25, due to increase of EPB consumed electricity. Yet the major difference comes with overheating, that increased from 1.06% to 42.62%, due to the poor use of the passive strategies in the case of Ub1. The coloured areas in Figure 50 correspond to the current base case (Ub0).

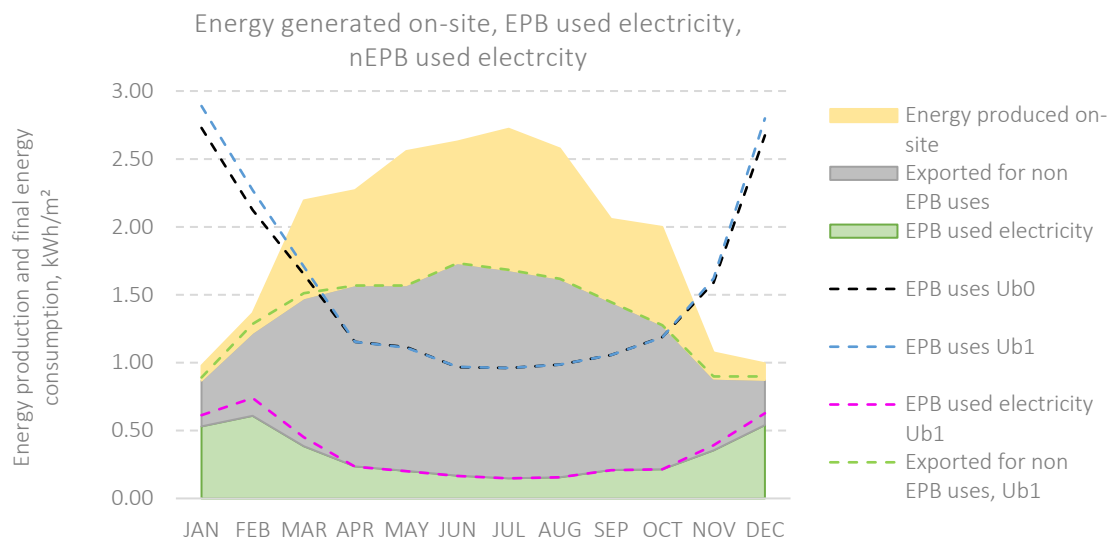


Figure 50. Final energy consumption for the user behaviour scenarios Ub0 and Ub1. Average supply cover factors is 0.24 for Ub0 and 0.25 for Ub1.

Average occupancy vs increased occupancy profile

The graphs in Figure 51 represent the final energy consumption of the base case (Ub0) with average, current occupancy, and energy aware user behaviour, while the case Ub2 is the case of increased occupancy profile with energy aware user profile. The average increase in occupancy from 2.46 to 2.93 occupants per household is causing the raise in both the EPB uses (of 6% as an average) and the non-EPB uses. This is also causing an increase in the exported energy for non EPB uses (3% as an average). The average supply cover factor is 0.24. that is the same as for the base case, and consequently the overheating percentage stays unchanged. Yet the major impact from the increase of occupancy can be noted in total primary energy consumption that increases from 43.0 to 47.5 kWh/m².

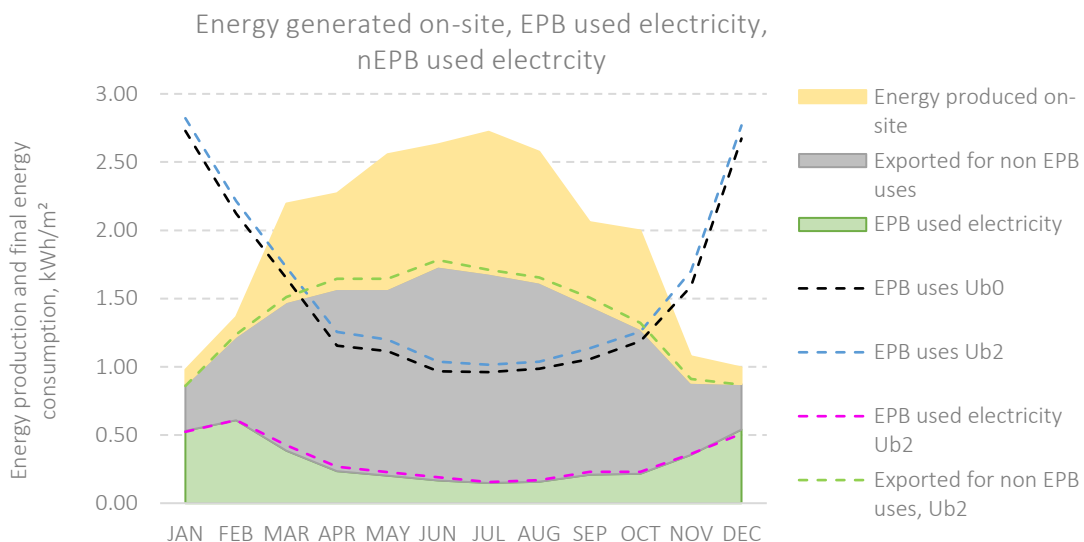


Figure 51. Final energy consumption from the user behaviour scenarios of Ub0 and Ub2. Average supply cover factor of Ub2 is 0.24.

Average occupancy and energy aware user vs increased occupancy and energy unaware user

This comparison includes the best- and worst-case scenarios of user behaviour in terms of energy and overheating. The increase on occupancy and change in user behaviour from energy aware to energy unaware. results in 11% increase in the maximum EPB uses and 27% maximum increase in the EPB used electricity from

on-site production. The average increase in EPB used electricity from on-site production is 16%. As the exported electricity to non-EPB uses is affected both by the EPB consumed electricity and the occupancy profile, a reduction in exported electricity for non EPB uses can be observed in the winter months (due to drastically increased of EPB used electricity from on-site production). An increase of exported electricity for non-EPB uses can be noted in summer months, due to the higher occupancy and consequently higher appliances consumption (as there is no cooling implemented). The average supply cover factor of the increased occupancy and energy unaware user scenario (Ub3) is increased from 0.24 to 0.26, compared to the base case (Ub0), due to increase in EPB used electricity. As the occupancy is increased and the user behaviour profile is changed from energy aware to energy unaware, significant changes could be observed both in overheating and in primary energy balance. The overheating increased from 1.06% to 42.85% and the total primary energy consumption increased from 43.0 to 49.9 kWh/m².

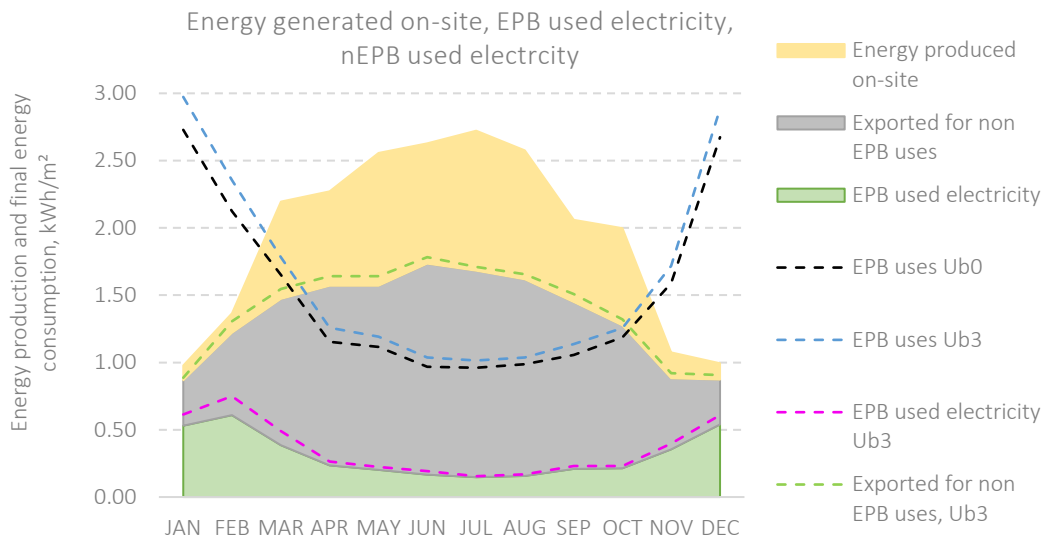


Figure 52. Final energy consumption of user behaviour scenarios Ub0 and Ub3. Average supply cover factor of Ub3 is 0.26.

Results of energy flexibility and cost scenario

Figure 53 shows the base case scenario (EfC0- EfC5) in comparison to the energy flexibility scenario (EfC6- EfC9). The energy flexibility scenario has increased EPB uses, as the flexibility strategy defines an increase in the set-point of the heating thermostat of households and also in the DHW storage tank heating in case of excess of energy. In the summer months there is naturally more often excess PV production, which is why the difference between the base case and the flexibility scenarios in the EPB uses is greater in the summer season. As EPB uses increase in winter months, less PV electricity is available to be exported to non-EPB uses. The increase in heating demand is from 10.5 to 11.0 kWh/m² and in DHW demand 20.5 to 21.4 kWh/m². This strategy, with the higher EPB consumption, results therefore in an increase of the yearly average supply cover factor from 0.24 (base case) to 0.29 and the EPB used electricity from on-site production increases 6% as an average.

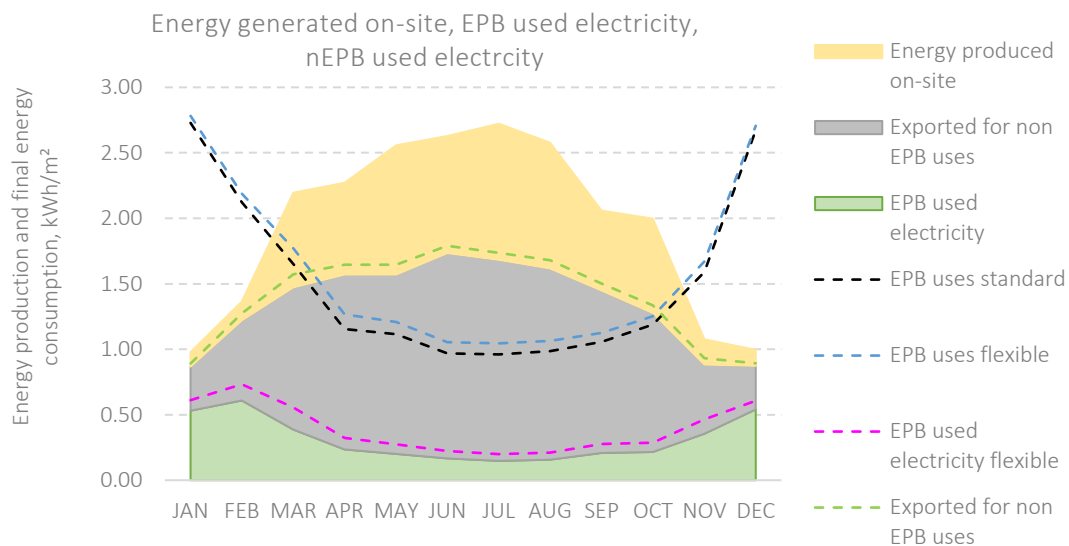


Figure 53. Final energy consumption of the energy flexibility and cost scenarios. Average supply cover factor of the flexibility case is 0.29.

Additional analysis of costs and flexibility are carried out, comparing the base case strategy (FI0-0 / FI0-5) to the flexibility strategy (FI1-6 / FI1-9) and the different energy price schemes. The cost analysis is carried out for all the uses in the building (both EPB and non EPB uses) and only the energy costs are considered (excluding the taxes). Table 50 summarizes the energy cost balance of the different strategies. including the delivered energy cost (+), the exported energy cost (-), and the cost balance (positive costs mean that the building is earning money, and negative values mean that the building is paying). Analysing the standard energy operation without the flexibility strategy, it can be noted that the exported cost is lower than the current energy price, which is caused by the lower energy price during peak hours. However, analysing the cost balance, the future energy cost is more favourable since the delivered energy is higher than the exported. The flexible energy operation scenarios present slightly higher energy costs due to the increase in consumption.

The most optimistic scenario is the EfC5 scenario with the standard energy operation (no flexibility strategy) and future energy prices (lower energy prices during day) with net metering (100% compensation), resulting in 10 535€/building and 22€/month per household as a yearly average. The worst scenario would be the flexible case (increased thermal demands), current energy prices (higher price during day) and no compensation, resulting in annual cost of 13 455€/building. which is 30€/month per household as a yearly average.

Table 50. Flexibility and cost scenarios comparison: energy costs. Positive cost: earn money; Negative cost: pay money

Scenario	Energy operation	Energy price	Compensation	Delivered	Exported	Balance
FI0-0	Standard	Current	30%	-13 405€	+861 €	-12 544€
FI0-1	Standard	Future	30%	-11 071€	+279 €	-10 792€
FI0-2	Standard	Current	No	-13 405€	0	-13 405€
FI0-3	Standard	Future	No	-11 071€	0	-11 071€
FI0-4	Standard	Current	100%	-13 405€	+2 870 €	-10 535€
FI0-5	Standard	Future	100%	-11 071€	+930 €	-10 141€
FI1-6	Flexible	Current	30%	-13 455€	+791 €	-12 664€
FI1-7	Flexible	Future	30%	-11 065€	+242 €	-10 823€
FI1-8	Flexible	Current	No	-13 455€	0	-13 455€
FI1-9	Flexible	Future	No	-11 065€	0	-11 065€

Overall results of all the scenarios

There are 7 scenarios in terms of thermal behaviour of the building, and the results are presented in Table 51, where BC represent the base case scenario (CI0 / Ub0 / FI0). The cost analysis has been excluded in this section. as it has already been discussed in the “Energy flexibility and cost” section.

The lowest heating demands correspond to the future climate scenarios. where due to the higher ambient temperatures. less space heating is needed. The DHW demand is directly correlated to the occupancy profile. increasing from 20.5 to 23.4 kWh/m² in case of increased occupancy, in comparison to the base case (BC). Also. the flexibility strategy causes an increase in DWH consumption, as in this scenario (FI1) the storage tanks are heated to a higher set-point in case of excess PV produced electricity. The lighting and appliances’ consumption is also directly related to the increase in occupancy (scenarios Ub2 and Ub3). The auxiliary consumption is the electricity consumption of the pumps of the technical systems. and this consumption is directly related to the heat pump (HP) demand – therefore having higher values when both heating and DHW demand is increased. The highest COP values of the HPs are observed in the climate change scenarios (CI1 and CI2). and this can be linked to the higher ambient temperatures that provide more suitable working conditions for the HP.

Figure 54 (left) compares all the scenarios in terms of annual primary energy consumption. Total primary energy consumption is the lowest for the climate change scenarios (CI1 and CI2). dropping from 43.0 to 34.0-35.3 kWh/m² in comparison to the base case (current climate). The highest total primary energy consumption corresponds to Ub3, where there are the highest (increased) occupancy profile and the worst user behaviour profile (energy unaware user). This increases the total primary energy consumption from 43.0 to 49.9 kWh/m² in comparison to the base case. The negative numbers for the non-renewable primary energy consumption indicate that there is export of energy in all the future scenarios. The highest exported energy (14.5 kWh/m²) is in the CI1 climate change scenario (CI1 correspond to the higher climate change case, year 2050). The highest supply cover factor is in the flexible scenario (FI1), as its strategy promotes self-consumption.

Finally, the overheating is analysed to verify that the building is providing comfortable conditions for the users. as there is no cooling system in the final design. Figure 54 (right) compares the overheating values of all the scenarios, represented by the annual average values and the worst values of overheating. The best performing scenario in terms of overheating is the base case (current climate – CI0, energy aware user behaviour and average occupancy Ub0, and standard energy operation FI0) having average yearly overheating of 1.06% of the year and 5.48% in the worst performing zone. The overheating increases drastically in the scenarios with unaware user behaviour (no natural ventilation, standard shading control with shading factor 50% and fixed heating set-point by a schedule), which is present in scenarios Ub1 and Ub3, resulting in worst performing zone overheating of 61.96 and 62.15% of the year and in average 42.62% and 42.85%, respectively. The discomfort limit allowed by the Spanish Technical Code of Buildings is 4%.

Table 51. Results of all the scenarios. main KPIs.

Main KPIs	BC	CI1	CI2	Ub1	Ub2	Ub3	FI1
Heating demand [kWh/m ²]	10.5	5.8	6.4	12.4	10.4	12.2	11.0
DHW demand [kWh/m ²]	20.5	20.5	20.5	20.5	23.4	23.4	21.4
HPs electricity consumption [kWh/m ²]	10.8	9.1	9.3	11.0	11.6	11.8	11.6
Lighting consumption [kWh/m ²]	2.9	2.8	2.9	2.9	3.0	3.0	2.9
Appliances consumption [kWh/m ²]	39.9	39.9	39.9	39.9	42.1	42.1	39.9
Ventilation consumption [kWh/m ²]	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Auxiliary consumption [kWh/m ²]	4.7	4.1	4.2	5.0	4.7	5.0	4.8

COP of HPs (heating/DHW)	4.2	4.3	4.3	4.2	4.1	4.2	4.1
PV production [kWh/m ²]	23.4	23.4	23.4	23.4	23.4	23.4	23.4
Total primary energy consumption [kWh/m ²]	43.0	34.0	35.3	45.8	47.5	49.9	46.5
Non-renewable primary energy consumption [kWh/m ²]	-10.2	-14.5	-13.9	-9.2	-8.2	-7.4	-8.4
Supply cover factor. [-]	0.24	0.22	0.22	0.25	0.24	0.26	0.29
Overheating. yearly average [%]	1.06	2.03	1.60	42.62	1.01	42.85	1.06
Overheating. worst zone [%]	5.48	7.02	7.10	61.96	5.75	62.15	5.51

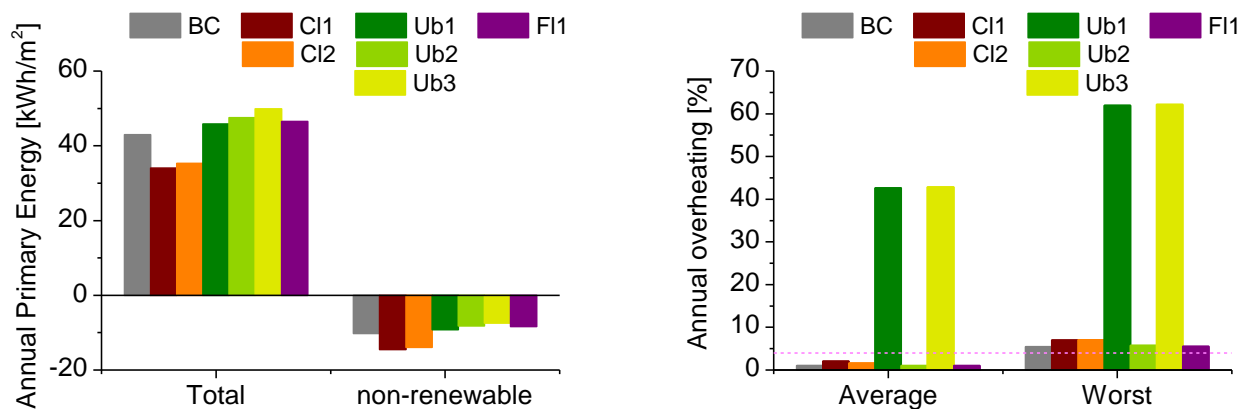


Figure 54. Comparison of all the scenarios. Left: Annual primary energy balance. total primary energy consumption and non-renewable primary energy. Right: Percentage of overheating. building average and worst zone of the building.

Conclusions

Based on the different scenarios described above, the most optimistic and pessimistic scenarios have been determined in terms of:

- User comfort
- Primary energy balance

In case of similar results, user comfort is prioritized over the primary energy balance, as the building should guarantee comfortable condition to the users. The optimistic and pessimistic scenarios have been chosen based on the above-mentioned criteria, and the details are shown in Table 52.

Table 52. Optimistic and pessimistic scenario definition

Scenario	Climate change	User behaviour	Energy flexibility
Optimistic (OPT)	Current climate: CI0	Average occupancy and energy aware user: Ub0	Standard operation: FI0
Pessimistic (PES)	Future climate scenario based on IPCC A2 for 2050: CI1	Increased occupancy and energy unaware user: Ub3	Flexible operation: FI1

Table 53 details the main key performance indicators of the optimistic (OPT) and pessimistic (PES) scenarios. The main trends of the results follow the discussion presented before, where all the scenarios are compared. The heating demand of the OPT scenario is higher than the PES one. Even though the PES scenario includes the flexibility management of the building and an increased occupancy which should lead to an increase in

heating and DHW demand, the climate change scenario causes a reduction of the heating demand. Regarding the DHW demand, the OPT scenarios has lower demand than the PES scenario. In that case, the increased occupancy and the flexibility strategy of the PES scenario are the main cause of this increase. However, the difference between them is small. Energy use for lighting and appliances has some small variations due to the difference in the occupancy level, with the PES scenarios having the higher consumption (2.46 and 2.93 average occupancy per household, respectively).

Table 53. Results of optimistic and pessimistic scenarios, main KPIs.

Main KPIs	Optimistic - OPT	Pessimistic - PES
Heating demand [kWh/m ²]	10.5	8.2
DHW demand [kWh/m ²]	20.5	24.4
HPs electricity consumption [kWh/m ²]	10.8	10.9
Lighting consumption [kWh/m ²]	2.9	3.0
Appliances consumption [kWh/m ²]	39.9	42.1
Ventilation consumption [kWh/m ²]	0.5	0.5
Auxiliary consumption [kWh/m ²]	4.7	4.7
COP of Heat pumps (heating/DHW)	4.2	4.2
PV production [kWh/m ²]	23.4	23.4
Total primary energy consumption [kWh/m ²]	43.0	44.8
Non-renewable primary energy consumption [kWh/m ²]	-10.2	-9.7
Supply cover factor [-]	0.24	0.29
Overheating, yearly average [%]	1.06	46.40
Overheating, worst zone [%]	5.48	63.75

Figure 55 compares the OPT and PES scenarios in terms of annual primary energy balance (left) and annual overheating (right). The OPT scenario results in a total primary energy consumption of 43.0 kWh/m² and a non-renewable primary energy of -10.2 kWh/m². In terms of thermal comfort, the OPT scenario reveals overheating in 1.06% of the time as a yearly average and 5.48% in the worst performing zone. The PES scenario results in having worst results of both. primary energy balance and overheating. The total primary energy consumption is 44.8 kWh/m² and the non-renewable primary energy -9.7 kWh/m², implying a variation lower than 5% in comparison with the OPT scenario. However, the higher impact is observed analyzing thermal comfort. having an average overheating of 46.40%. and 63.75% in the worst performing zone. To achieve thermal comfort in summer, a cooling system should be installed and consequently, the primary energy balance would change considerably.

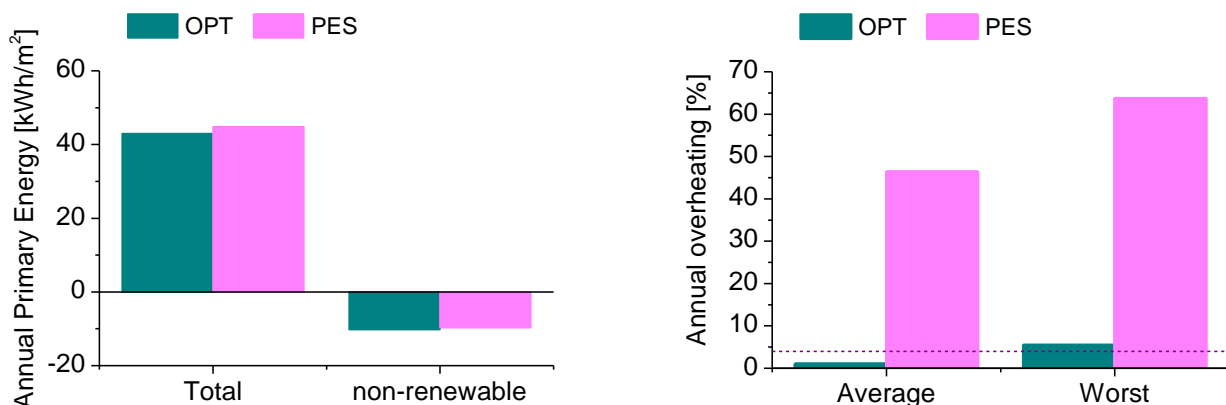


Figure 55. Comparison of optimistic (OPT) and pessimistic (PES) scenarios. Left: Annual primary energy balance. total primary energy consumption and non-renewable primary energy. Right: Percentage of overheating. building average and worst zone of the building.

Figure 56 compares the monthly final energy balance of both scenarios, and the annual results are presented in Figure 57 and Figure 58 for the OPT and PES scenario, respectively.

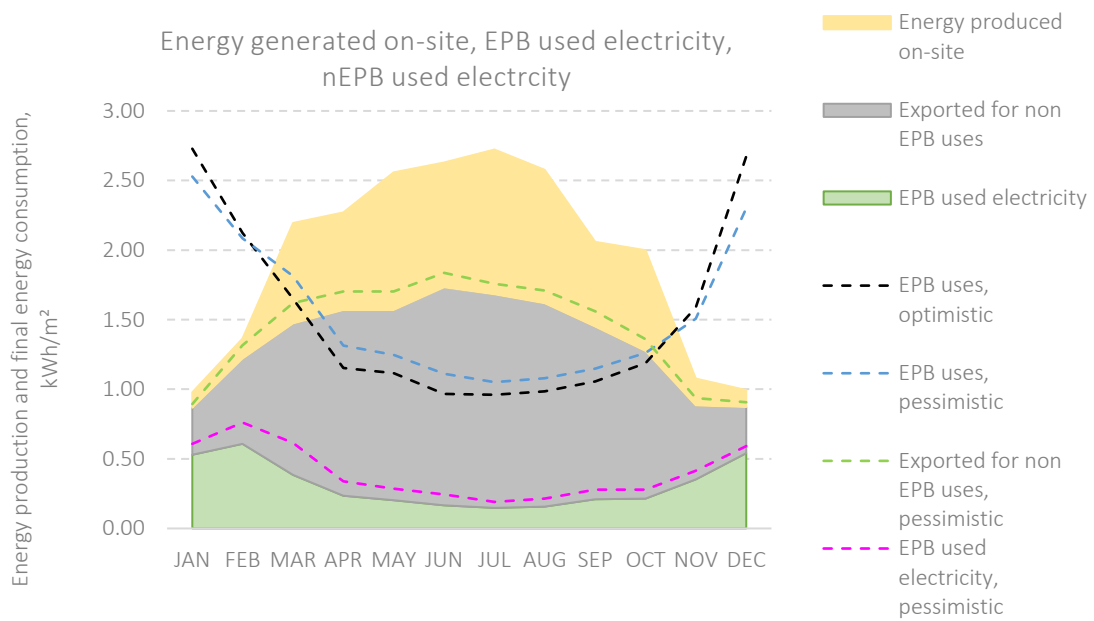


Figure 56. Optimistic and pessimistic scenario: final energy balance comparison

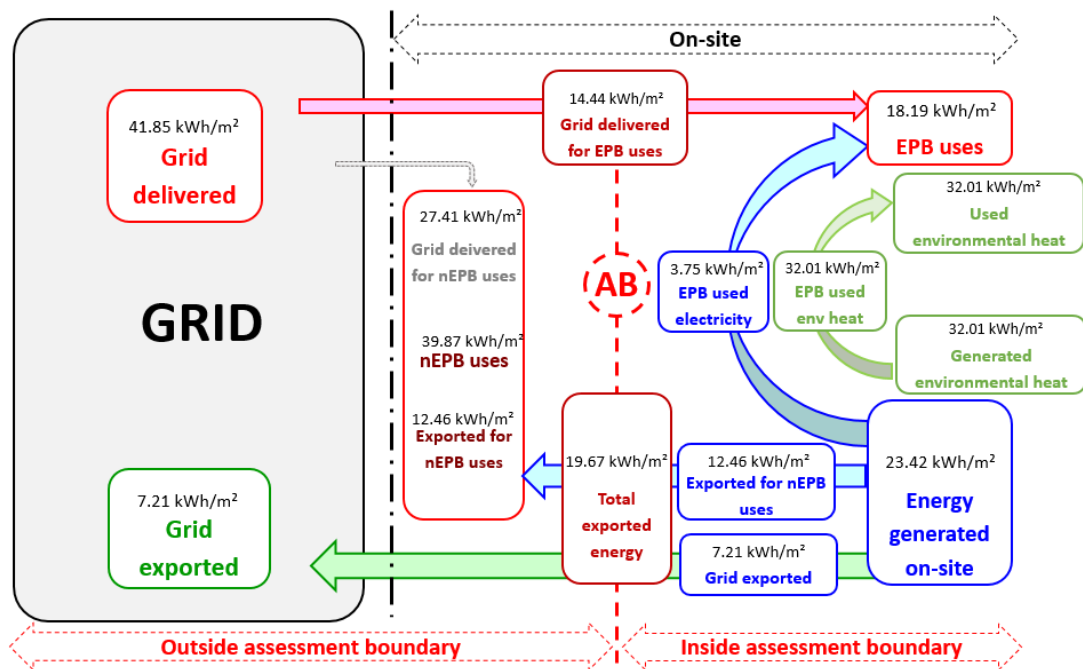


Figure 57. Optimistic scenario: final energy diagram.

The comparison between the optimistic and pessimistic scenario, together with the analysis of all scenarios, reveals some important findings:

- The highest impact on the building consumption comes from the number of occupants and their energy awareness affect drastically to the thermal comfort of the building (higher occupancy, higher consumption; less energy awareness, higher overheating).
- The climate change reduces the heating demand, but at the same time increases slightly the overheating in summer.
- The flexibility strategy proposed needs to be optimized in order have a better impact in the energy balance and the energy costs. Further research is needed in order to improve the algorithm to activate flexibility.

Sustainable plus energy neighbourhoods

Marine climate demonstration project

Description of scenarios

Climate change

Two scenarios for climate change have been simulated. as described in the table below.

Table 54. Scenarios for climate change

Scenario	IPCC	Year	Description
Cl1	A2	2050	This can be seen as a worst-case climate change scenario. Emissions continue to rise throughout the 21 st century. This scenario is useful for predicting mid-century (and earlier) conditions based on current and stated policies. ⁵
Cl2	B1	2050	This can be seen as an optimistic climate change scenario. The expected global temperature rise in 2100 is limited to 2°C, which is however above the goal of the Paris Agreement. The CO ₂ emissions from 2010 to 2100 need to be reduced to 70%. ⁶

Both scenarios concern the year 2050 and are based upon two representative concentration pathways. namely RCP2.6 (scenario Cl2) and RCP8.5 (scenario Cl1), as defined by the IPCC.

The effect of the climate change is simulated for the final design in which the domestic hot water boiler is filled during the day.

The differences between the climate scenario nowadays used in the Netherlands (according to NEN 5060) and the two climate scenarios for 2050 are illustrated in Figure 59. The numbers in Figure 59 represent the average outside air temperatures per month as well as the percentage of time in which the outside air temperature is below the indicated value. According to the collected data. more periods with a higher outside air temperature will occur in 2050. However, minor differences occur when it comes to lower outside air temperatures.

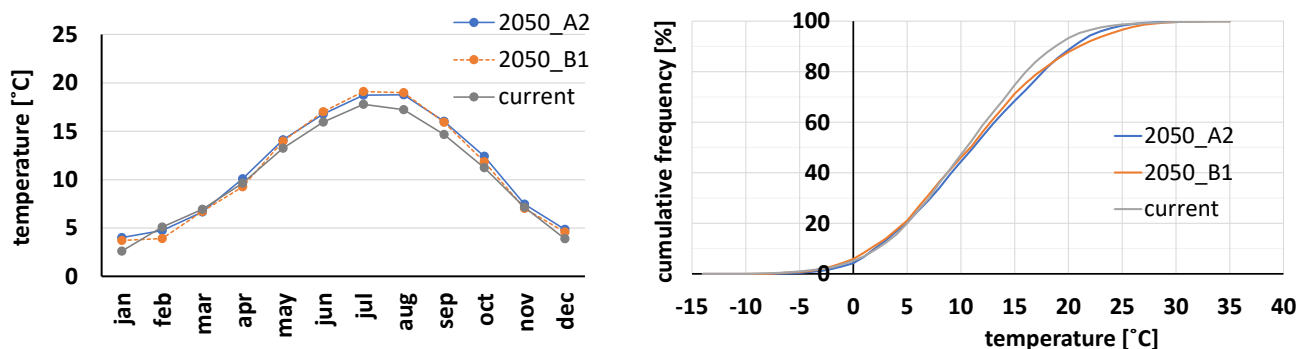


Figure 59. Weather conditions for the three different climates (current climate NEN5060. predicted climate 2050_A2 and 2050_B1 according IPCC)

⁵ Riahi, K., Rao, S., Krey, V. et al. RCP 8.5—A scenario of comparatively high greenhouse gas emissions. Climatic Change 109, 33 (2011). <https://doi.org/10.1007/s10584-011-0149-y>

⁶ van Vuuren, D.P., Stehfest, E., den Elzen, M.G.J. et al. RCP2.6: exploring the possibility to keep global mean temperature increase below 2°C. Climatic Change 109, 95 (2011). <https://doi.org/10.1007/s10584-011-0152-3>

User behavior

The scenarios concerning user behaviour are described in the table below.

Table 55: Scenarios concerning user behaviour.

Scenario	Aspect	Description
Ub1	Active window use	A two times higher ventilation rate due to the opening of windows is assumed. For the 2-room and 3-room apartments the ventilation is increased from respectively 22.5 and 27.5 dm ³ /s to 45 and 55 dm ³ /s. For illustration: a window opened 2 cm ajar leads at 1 Pa pressure difference to an air flow of 24 dm ³ /s.
Ub2	Always present at home	All occupants are assumed to be present at home every day. For the 2-room and 3-room apartments this means that respectively 2 and 3 persons are every day of the week at home during the whole day. In the final design scenario, it was assumed that only one person was at home every day of the week, while the other person(s) went to work or school during the weekdays from 8-18 hours.
Ub3	Use of energy efficient lighting	In this scenario the energy consumption by lighting is reduced to zero. In the final design scenario 250 kWh per year energy use for lighting was assumed.

Note that these scenarios were simulated for the final design in which the domestic hot water boiler is filled during the day.

Energy flexibility

The scenarios for energy flexibility are described in the table below.

Table 56: Scenarios concerning energy flexibility

Scenario	Aspect	Description
EpC1 (final design)	Hot water boiler filled during the day	In this scenario (which concerns our final design) the hot water boiler is filled during the day (from 12-14h) instead of during the night (from 3-5h). Filling the hot water boiler during the day increases the possibility to use the on-site PV production. The scenario in which the boiler is filled during the night is our base case scenario, because this is common practice in the Netherlands.
EpC2	Heating setpoint during the day increased with 1K	In scenario EpC2 the space heating setpoint during the day is increased with 1K. Thus, the heating setpoint for the night (23-8h), day (8-18h) and evening (18-23h) is respectively 19, 21 and 21°C instead of 19, 20 and 21°C in the final design scenario. In this way during the day more energy is stored in the floor mass, which can reduce the energy use for heating during the evening. Furthermore, heating during the day can increase the possibility to use the on-site PV production.
EpC3	Use of household appliances shifted to the daytime period	In scenario EpC3 25% of the electricity use for household appliances is shifted from the evening to the daytime periods from 10-12h and 14-16h. Thus, an additional electricity use takes place in periods in which high loads by PV-panels might occur. Furthermore, the period with this additional electricity use differs from the period during the day in which the hot water boiler is filled (see scenario EpC1) to increase the use of the on-site PV production as much as possible.

Note that these scenarios were simulated for the final design in which the domestic hot water boiler is filled during the day. Furthermore, it is noted that the simulation of domestic hot water preparation was not part of our TRNSYS simulation, but was added separately to the TRNSYS simulation (post processed). Based upon the energy performance calculation, the energy use for domestic hot water preparation was calculated per day and considered to be delivered to the hot water boiler within a time frame of 2 hours each day.

Results

The results for the different scenarios are given in table 57 (EPB uses only) and table 58 (including non-EPB uses).

Discussion of climate change scenarios

The results (see Table 57) show that the main effect of the climate change scenario is the higher cooling load. This is caused by the fact that higher outside air temperatures occur more often (see also Figure 59). An incidental advantage is that this leads to a better balancing of the heat withdrawn (environmental use) and added (environmental return) to the ground source of the heat pump. Furthermore, this leads to an increase of the percentage of time in which the PMV is >0.5 (overheating).

The exported electricity in 2050 (exported EPB uses, see table 57) is reduced somewhat compared to the climate scenario according to NEN 5060 (final design). This is a result of the somewhat lower solar loads in 2050, causing less electricity production by the PV-panels (23.4 to 23.7 kWh/m² instead of 24.5 kWh/m² over a year). The same is shown from table 58 for the exported energy when including the non EPB uses.

Discussion of user behavior scenarios

Active window use (scenario Ub1)

Due to the higher ventilation rate, the heating demand is strongly increased, while the cooling demand decreases (compared to the final design, see table 57). Both is as might be expected. The apartments are very well insulated; thus the ventilation heat losses have a big influence on the heat balance.

The imported EPB energy use increases significantly with 4.6 kWh/m² compared to the final design, see Table 57. The increase in electricity use for heating is, with a COP of 5.7, roughly $(60.8-32.3)/5.7 = 5$ kWh/m². The decrease in electricity use for cooling is, with a COP of 50, roughly $(40.8-28.6)/50 = 0.24$ kWh/m². Together, the increased electricity use for heating and the reduced electricity use for cooling almost add up to the increased imported EPB energy use. This increased imported EPB energy use also explains the decrease of the supply cover factor from 0.33 to 0.28.

The exported EPB energy use hardly changes, it reduces only slightly. At moments when electricity can be exported (when there is electricity production by the PV-panels), the heating demand is hardly changed. This can be explained because the higher heating demands occur at 8 AM and 6 PM when the setpoint for heating is increased, while between these moments the higher PV production is likely to occur.

Although the explanation above focuses on the EPB energy uses, the same findings also apply to the energy uses including non-EPB energy use (see Table 58).

Furthermore, due to the higher ventilation rate (compared to the final design):

- The percentage PMV >0.5 (overheating) is reduced significantly.
- The total primary energy consumption increases rapidly. This is also caused by the fact that the renewable environmental energy use is taken into account in the total primary energy consumption. The increase of the non-renewable primary energy consumption is therefore less.
- The energy costs increase significantly, this is the scenario with the highest energy costs, see Tables 57 and 58.

Always present at home (scenario Ub2)

The effects on the energy balance of this scenario are limited (compared to the final design, see Tables 4 and 5). The internal heat production increases and therefore the heating demand decreases to some extent, while the cooling demand increases.

Use of energy efficient lighting (scenario Ub3)

Due to the lower electricity use for lighting, the imported EPB energy use decreases and the exported EPB energy use increases (compared to the final design, see Table 57). The supply cover factor of PV for EPB uses increases from 0.33 to 0.38. This scenario has two benefits. On one hand the overall electricity consumption

is reduced. while on the other hand the exported electricity is increased to some extent. This leads (for the investigated scenarios) to the lowest non-renewable energy consumption and the lowest energy costs.

It is noted that the explanation above also applies to the energy uses including non-EPB energy use (see Table 58). The numbers differ however, because when including non-EPB energy uses, more on-site PV production is used in the final design scenario.

Table 57. Simulation results for the different scenarios (exported and imported energy use, supply cover factor and energy costs based upon EPB uses only)

Main KPI	Base case	Final design	Climate change		User behaviour			Energy flexibility	
			CI1	CI2	Ub1	Ub2	Ub3	EpC2	EpC3
Heating demand [kWh/m ²]	32.3	32.3	31.3	33.3	60.8	29.6	35.6	35.7	33.3
Cooling demand [kWh/m ²]	40.8	40.8	48.1	47.0	28.6	43.5	39.5	41.0	40.8
DHW demand [kWh/m ²]	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6
Lighting [kWh/m ²]	5.2	5.2	5.2	5.2	5.2	5.2	0	5.2	5.2
COP – Heating	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7
COP – Cooling	50	50	50	50	50	50	50	50	50
COP – DHW	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
PV production [kWh/m ²]	24.5	24.5	23.4	23.7	24.5	24.5	24.5	24.5	24.5
Total primary energy consumption [kWh/m ²]	82.4	82.4	81.4	83.6	112.7	79.5	78.3	86.0	83.5
Non-renewable primary energy consumption [kWh/m ²]	33.6	33.6	33.6	34.0	40.5	33.0	26.9	34.5	33.9
Renewable primary energy delivered by PV [kWh/m ²]	35.5	35.5	33.9	34.3	35.5	35.5	35.5	35.5	35.5
Non-renewable primary energy consumption [kWh/m ²]	-1.84	-1.84	-0.32	-0.27	5.05	-2.46	-8.55	-0.98	-1.58
Imported EPB uses [kWh/m ²]	20.1	15.6	15.3	15.7	20.2	15.2	11.5	15.6	15.8
Exported EPB uses [kWh/m ²]	21.3	16.8	15.5	15.9	16.7	16.9	17.4	16.2	16.9
Environmental use [kWh/m ²]	48.7	48.7	47.9	49.6	72.2	46.5	51.4	51.5	49.6
Environmental return [kWh/m ²]	41.6	41.6	49.0	47.9	29.2	44.4	40.3	41.9	41.6
Supply cover factor ¹	0.13	0.33	0.34	0.33	0.28	0.33	0.38	0.35	0.32
PMV>0.5 [%] ²	11.0	11.0	15.0	16.2	6.5	13.4	10.5	11.1	12.4
Current energy cost [€/apartment per year] ³	-16.1	-16.1	-2.80	-2.33	44.2	-21.5	-74.8	-8.62	-13.9

Future energy cost [€/apartment per year] ⁴	255	198	194	199	256	193	146	197	201
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Notes:

¹ Supply cover factor is the percentage of the EPB uses that is delivered by PV as located on the own building plot.

² Overheating within the period from 8 to 23 hours.

³ Difference between yearly costs for imported electricity and yearly compensation for exported electricity for an average apartment (useful floor area of 57.7 m²). Costs and compensation both based upon an electricity price of 0.22 €/kWh according to <https://www.milieucentraal.nl/energie-besparen/inzicht-in-je-energierekening/energierekening/>.

⁴ No compensation for exported electricity (this will be the future scenario in the Netherlands).

Table 58. Simulation results for the different scenarios including non-EPB uses

Main KPI	Base case	Final design	Climate change		User behavior			Energy flexibility	
			Cl1	Cl2	Ub1	Ub2	Ub3	EpC2	EpC3
Imported uses incl. non-EPB [kWh/m ²]	56.9	54.7	54.1	54.4	59.5	54.3	50.3	55.2	51.9
Exported uses incl. non-EPB [kWh/m ²]	9.9	7.4	5.7	5.9	7.4	7.3	7.5	7.3	4.4
Supply cover factor ¹	0.21	0.24	0.25	0.25	0.22	0.24	0.25	0.24	0.28
Current energy cost [€/apartment per year] ²	601	601	614	615	661	596	542	609	603
Future energy cost [€/apartment per year] ³	722	694	686	690	755	689	638	701	659

Notes:

¹ Supply cover factor is the percentage of the EPB uses that is delivered by PV as located on the own building plot.

² Difference between yearly costs for imported electricity and yearly compensation for exported electricity for an average apartment (useful floor area of 57.7 m²). Costs and compensation both based upon an electricity price of 0.22 €/kWh according to <https://www.milieucentraal.nl/energie-besparen/inzicht-in-je-energierekening/energierekening/>.

³ No compensation for exported electricity (this will be the future scenario in the Netherlands).

Discussion of energy flexibility scenarios

Hot water boiler filled during the day (scenario EpC1 (final design)):

In case the hot water boiler for domestic hot water preparation is filled during the day (12-14h) instead of during the night, the electricity produced by the PV-panels can be used for this purpose. The supply cover factor of PV in EPB energy uses increases significantly from 0.13 (base case, see Table 57) to 0.33 (final design, see table 4). Both the imported EPB and exported EPB energy uses decrease with a similar amount (4.5 kWh/m²), as might be expected compared to the base case. The figures including non-EPB energy uses (see Table 58) show a similar trend, but the changes are smaller. Due to the higher electricity use when non-EPB energy uses are included, more on-site PV production is used in the final design scenario.

The energy costs for the current situation does not change, because both the imported and exported energy uses decrease in the same manner and the costs for imported electricity equal the compensation for exported electricity. In the future when there will be no compensation for exported energy anymore, the energy costs decrease when heating the hot water boiler during the day.

Heating setpoint during the day increased with 1K (scenario EpC2):

Due to the higher setpoint for heating, the heating demand increases (compared to the final design, see Table 57). The exported EPB energy use decreases with 0.6 kWh/m². This decrease equals the additional electricity use for heating, namely $(35.7 - 32.3) / 5.7 = 0.6 \text{ kWh/m}^2$ (COP=5.7). Thus, the extra electricity use needed by increasing the heating setpoint is delivered by the PV-panels. But at the same time the imported EPB energy use does not change. Thus, increasing the setpoint for heating is, under the given circumstances

in these model simulations with the occurring combination of heat losses and gains, not an effective energy flexibility scenario. Beside the fact that it results in an increase of the supply cover factor of PV in EPB energy uses from 0.33 to 0.35, it would only be effective in case the imported EPB energy uses would decrease. However, this does not happen due to the fact that the heating energy is reduced in periods when there is little or no energy produced by the PV-panels.

The figures including the non-EPB energy uses, also don't show that raising the heating setpoint is an effective flexibility scenario (see Table 58). The exported electricity is reduced only slightly, while the imported electricity is increased.

The energy costs, either excluding non-EPB uses (Table 57) or including non-EPB uses (Table 58), are comparable to the final design.

Note that the results of this scenario are highly influenced by the actual circumstances (actual energy demand during operation), so it could still be an attractive flexibility scenario to explore further.

Use of household appliances shifted to the day period (scenario EpC3):

The electricity used by appliances is not part of the EPB uses. The small changes (compared with the final design, see Table 57) in imported EPB, exported EPB and supply cover factor of PV are a consequence of the changes in the heating demand. Due to the small changes in the imported and exported EPB uses, the energy costs for EPB uses are similar to the final design.

The supply cover factor of PV including non-EPB uses increases from 0.24 to 0.28 (see Table 58). Thus, more on-site PV production can be used effectively. The decrease in imported electricity and increase in exported electricity is, as might be expected, similar, and equals roughly 2.8 to 3 kWh/m². In the current situation, in which the costs for imported electricity equal the compensation for exported electricity, this has hardly any effect on the energy costs. In the future cost scenario, the energy costs will decrease to some extent (see Table 58).

Conclusions

Based upon the results in the previous sections, a pessimistic and optimistic scenario are defined.

For the pessimistic scenario, the following scenarios are combined:

- Hot water boiler filled during the night (base case)
- Active window use (scenario Ub1)

For the optimistic scenario, the following scenarios are combined:

- Hot water boiler filled during the day (scenario Ub1 (final design))
- Use of energy efficient lighting (scenario Ub3)
- Use of household appliances shifted to the day period (scenario EpC3)

The results of the pessimistic and optimistic scenarios, as well as the results of the final design are given in table 59 and 60. The energy balances of both scenarios are given in Figures 60 and 61, respectively.

Table 59. Simulation results for the pessimistic and optimistic scenarios (exported and imported energy use, supply cover factor and energy costs based upon EPB uses only).

Main KPI	Final design	Pessimistic scenario	Optimistic scenario
Heating demand [kWh/m ²]	32.3	60.8	36.7
Cooling demand [kWh/m ²]	40.8	28.6	39.5
DHW demand [kWh/m ²]	30.6	30.6	30.6
Lighting [kWh/m ²]	5.2	5.2	0
COP – Heating	5.7	5.7	5.7
COP – Cooling	50	50	50
COP – DHW	3.6	3.6	3.6
PV production [kWh/m ²]	24.5	24.5	24.5
Total primary energy consumption [kWh/m ²]	82.4	112.7	79.6
Non-renewable primary energy consumption [kWh/m ²] (A)	33.6	40.5	27.2
Renewable primary energy delivered by PV [kWh/m ²] (B)	35.5	35.5	35.5
Non-renewable primary energy consumption [kWh/m ²]	-1.84	5.05	-8.25
Imported EPB uses [kWh/m ²]	15.6	24.6	11.8
Exported EPB uses [kWh/m ²]	16.8	21.1	17.5
Environmental use [kWh/m ²]	48.7	72.2	52.4
Environmental return [kWh/m ²]	41.6	29.2	40.3
Supply cover factor ¹	0.33	0.12	0.37
PMV>0.5 [%] ²	11.0	6.5	12.0
Current energy cost [€/apartment per year] ³	-16.1	44.2	-72.2
Future energy cost [€/apartment per year] ⁴	198	321	150

Note:

¹ Supply cover factor is the percentage of the EPB uses that is delivered by PV as located on the own building plot

² Overheating within the period from 8 to 23 hours

³ Difference between costs for imported electricity and compensation for exported electricity for an average apartment (useful floor area of 57.7 m²). Costs and compensation both based upon an electricity price of 0.22 €/kWh according to <https://www.milieucentraal.nl/energie-besparen/inzicht-in-je-energierekening/energierekening/>.

⁴ No compensation for exported electricity (this will be the future scenario in the Netherlands).

Table 60. Simulation results for the pessimistic and optimistic scenario including non EPB uses.

Main KPI	Final design	Pessimistic scenario	Optimistic scenario
Imported uses incl. nonEPB [kWh/m ²]	54.7	61.7	47.4
Exported uses incl. nonEPB [kWh/m ²]	7.4	9.6	4.4
Supply cover factor ¹	0.24	0.19	0.30
Current energy cost [€/app] ²	601	661	545
Future energy cost [€/app] ³	694	783	601

Notes:

¹ Supply cover factor is the percentage of the EPB uses that is delivered by PV as located on the own building plot

² Difference between yearly costs for imported electricity and yearly compensation for exported electricity for an average apartment (useful floor area of 57.7 m²). Costs and compensation both based upon an electricity price of 0.22 €/kWh according to <https://www.milieucentraal.nl/energie-besparen/inzicht-in-je-energierekening/energierekening/>.

³ No compensation for exported electricity (this will be the future scenario in the Netherlands).

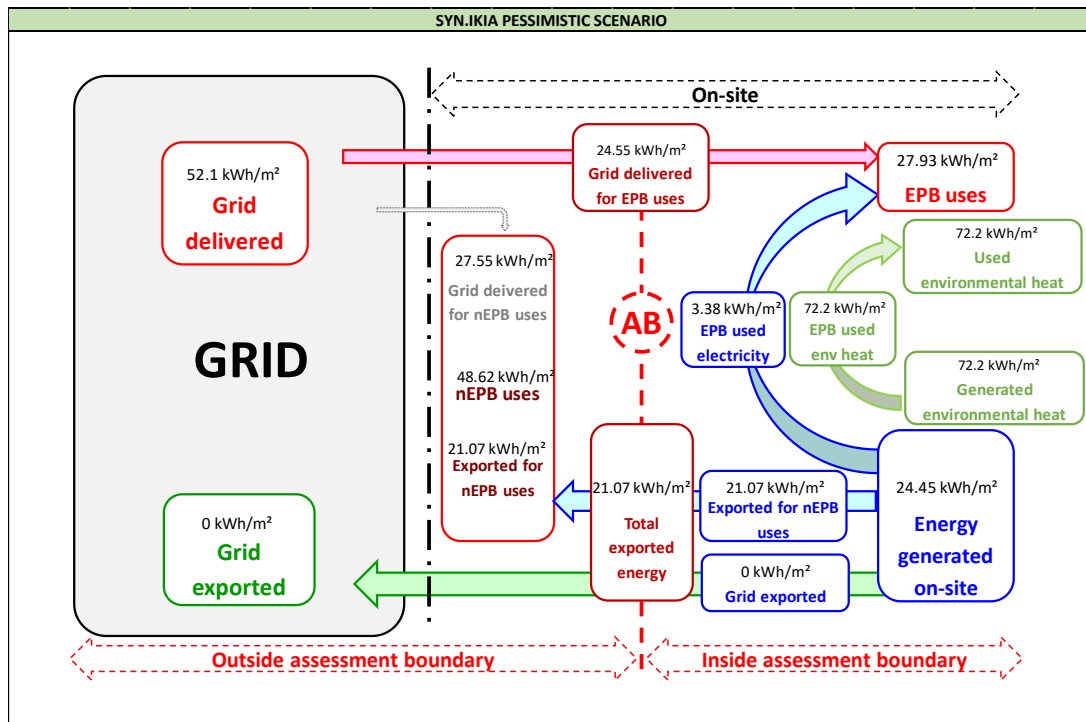


Figure 60. Energy balance of the pessimistic scenario.

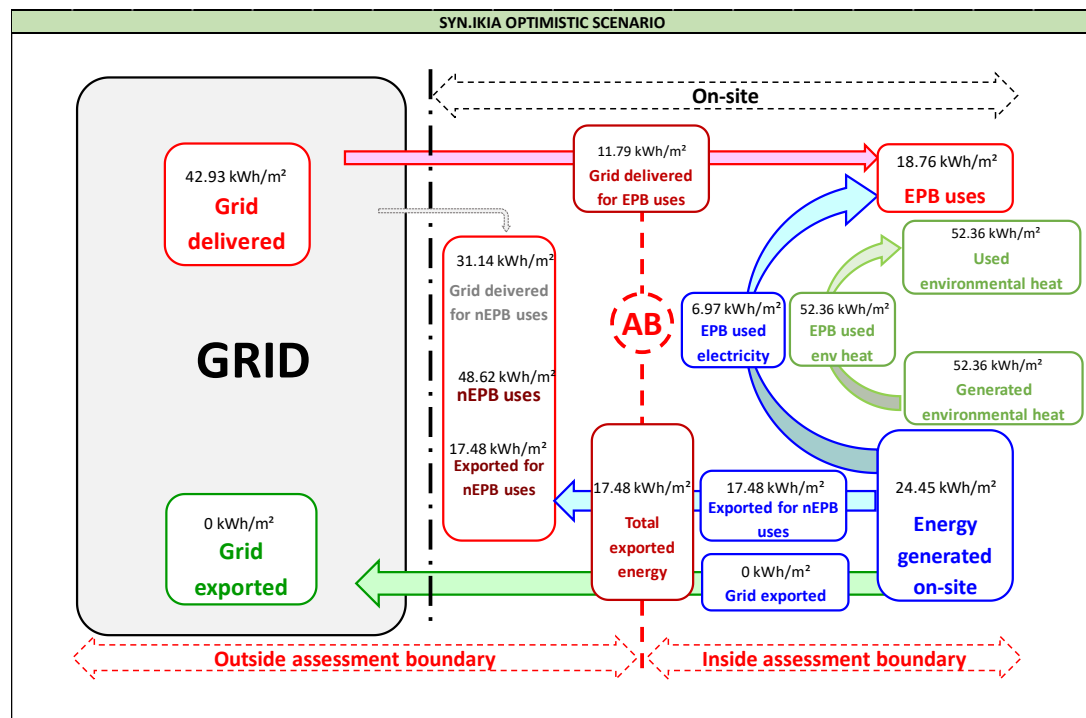


Figure 61. Energy balance of the optimistic scenario.

Based on the results showed above. the following conclusions may be drawn:

- The yearly heating energy demand is reduced from 60.8 to 36.7 kWh/m² when going from the pessimistic to the optimistic scenario.
- the yearly cooling energy demand is increased from 28.6 to 39.5 kWh/m² when going from the pessimistic to the optimistic scenario
- the yearly total imported electricity use is reduced from 24.6 to 11.8 kWh/m² when going from the pessimistic to the optimistic scenario.

- the yearly total exported electricity use is reduced from 21.1 to 17.5 kWh/m² when going from the pessimistic to the optimistic scenario.
- the supply cover factor of PV is increased from 0.12 to 0.37 when going from the pessimistic to the optimistic scenario. which means more effective use of on-site PV production.
- the yearly energy costs are reduced from 44.2 to -72.2 €/apartment in the current cost situation.

The final design of the Dutch demo lies in between the optimistic and the pessimistic scenario and is considered to be a robust design with respect to achieving the energy performance goals (plus energy and flexibility), a good indoor climate, and low life cycle costs.

Continental climate demonstration project

Description of scenarios

Future scenarios are evaluated for the proposed design case to assess the resilience of the design under different circumstances. The aim is to find a design that is resilient for future scenarios in a way that it will still comply with the Syn.ikia goals. Impacts of future scenarios related to climate change, user behaviour, and energy and flexibility have been evaluated.

The base case for the scenario analysis is the optimal design selected previously. Here we have considered a combination of scenario POS2 considering optimal passive envelope values, HV2 considering geothermal heat pumps, and low temperature heating and high temperature cooling, and R1 assuming façade mounted PV panels. Results for this POS2HV2R1 scenario can be seen in Figure 62.

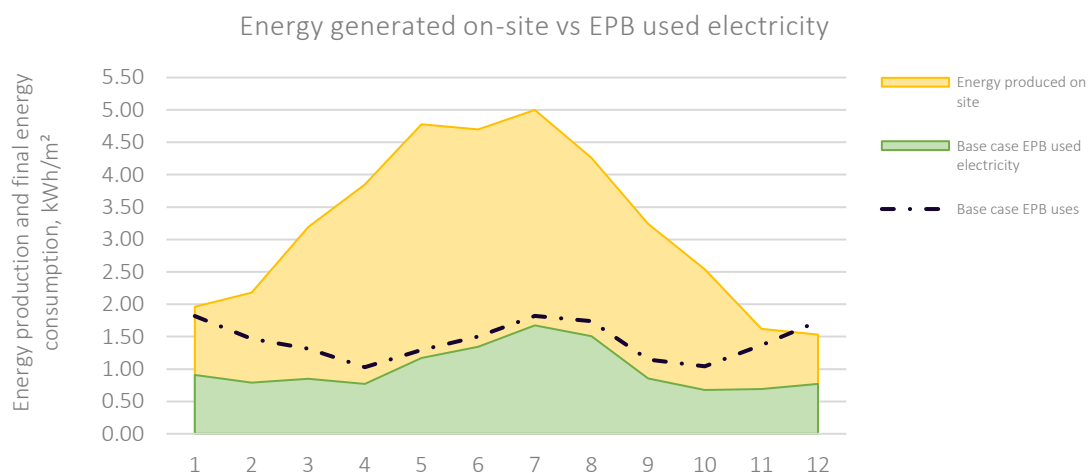


Figure 62. Results of scenario POS1HV2R1 used here as base case scenario.

Climate change

Two different IPCC scenarios for climate change are considered and simulated for the Austrian case described below in Table 61.

Table 61. Description of climate scenarios.

Scenario	Description
Cl1	Optimistic climate scenario based on IPCC B1 for 2050
Cl2	Pessimistic climate scenario based on IPCC A2 for 2050

The actual data files are created with Meteonorm software. Scenarios are based upon two concentration pathways RCP2.6 and RCP8.5 and are considering the year 2050.

The following figures show the differences between these scenarios. The base case presented here is the Meteonorm data for 2020 in Salzburg. In Figure 63 **Error! Reference source not found.** the cumulative distribution function of the three climate scenarios are given. This shows the percentage chance of the weather being under a certain temperature throughout a year. Figure 64 shows the monthly average dry bulb temperatures by scenario. It is clearly visible that A2 is the scenario with the warmest days, and B1 is somewhere in between A2 and the base case scenario.

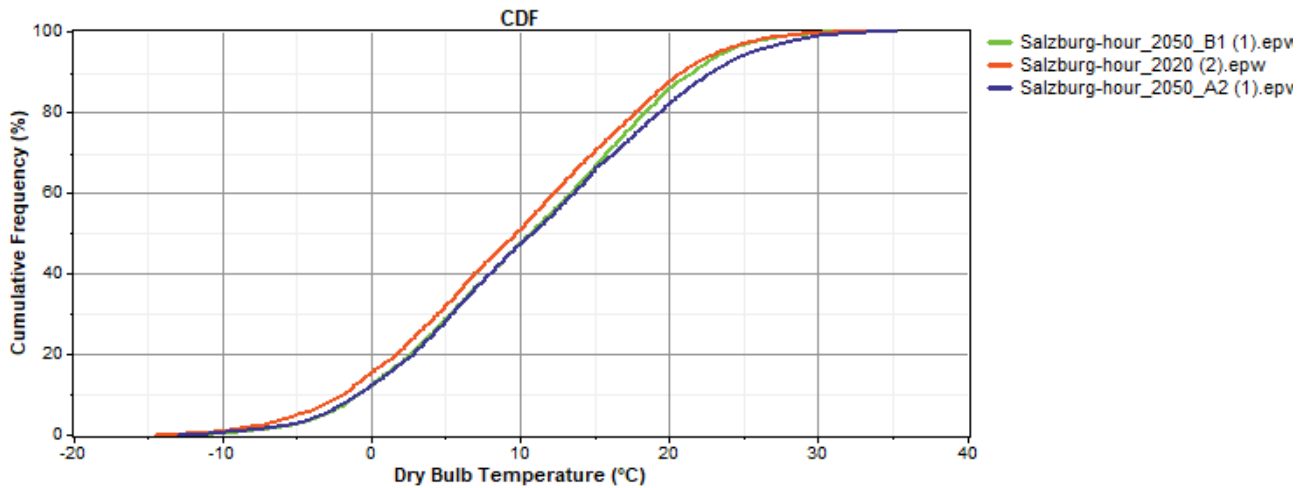


Figure 63. Cumulative distribution function of the three discussed weather scenarios

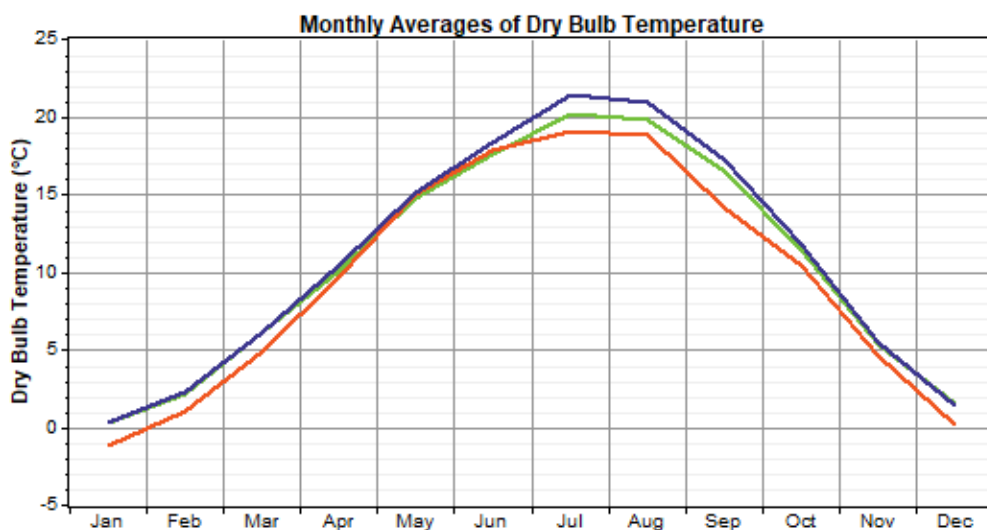


Figure 64. Monthly average dry bulb temperature of the previously mentioned scenarios.

User behavior

Regarding user behavior, the scenarios described below are simulated:

Table 62. Description of user behaviour scenarios

Scenario	Description
Ub1	Pandemic or home office scenario. where the occupants spend their days at home. These extreme occupancy measures can become more and more relevant in the coming years with the uncertainties around pandemics and epidemics. In this scenario occupancy was raised to maximum even during work hours. Subsequently appliance usage and peak sensible heat loads from people was also raised with 20% with the possibility of people exercising at home.
Ub2	Scenario where energy conscious lighting is assumed. This scenario aims to model energy awareness through lighting schedules. Lighting usage is halved. and considered to be completely switched off during work hours(9-17) on weekdays.

Energy flexibility

Regarding energy flexibility, the scenario described below is simulated.

Table 63. Description of flexibility scenarios

Scenario	Description
Ef1	This scenario considers the effect of increased setback points for heating and cooling. Setpoints for heating and cooling are respectively 20°C and 26°C with setback points of 18°C and 28°C. Here setback point of 19°C for heating and 27°C for cooling is used to evaluate the effect of the building's thermal capacity on energy usage.

Results

Climate change

The energy performance of the proposed design for the two climate scenarios are shown in Figures 65 and 66. The results show a slightly greater final energy demand for scenario A2 than for scenario B1 (21.6 kWh/m² instead of 21.0 kWh/m²). The greatest difference between the two scenarios is the cooling load. In scenario A2 the cooling load is 5.78 kWh/m² while in the B1 scenario it is 4.96 kWh/m². The end delivered energy and the total GHG emissions are lower in the scenario A2 which is due to higher solar radiation. The PV generation in scenario A2 is 37.17 kWh/m² while in B1 it is 35.43 kWh/m².

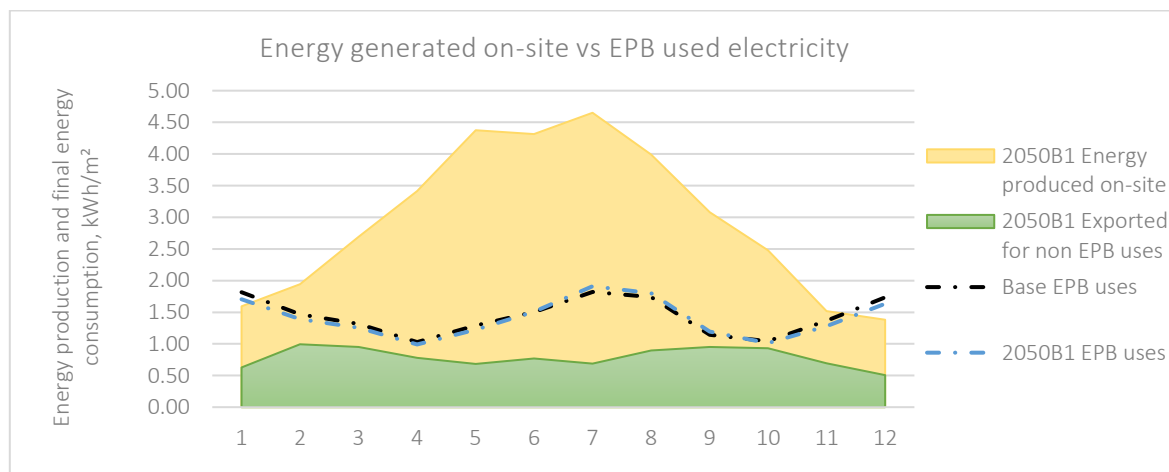


Figure 65. CL1 Energy performance of the proposed design case with climate data of 2050 B1.

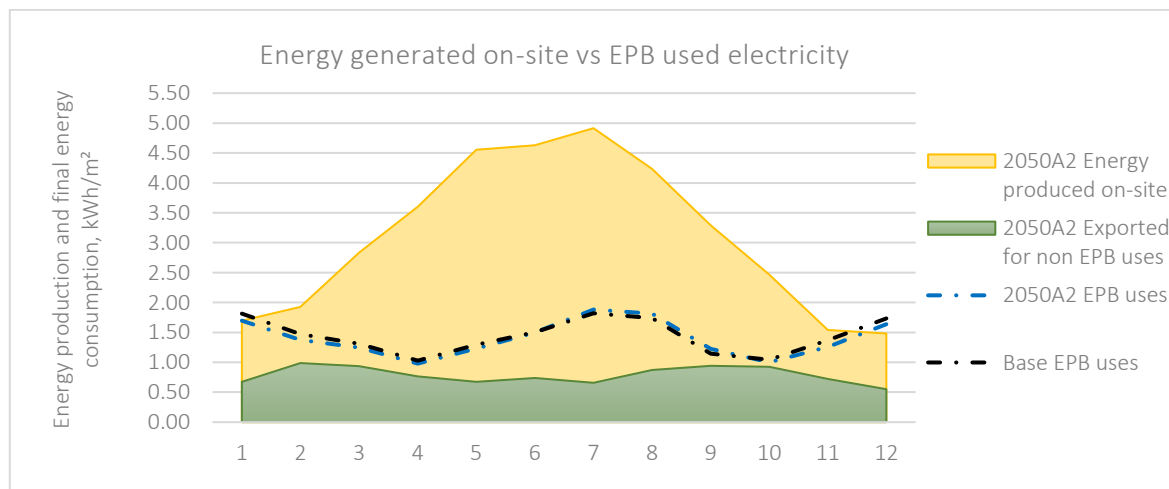


Figure 66. CL2 Energy performance of the proposed design case with climate data of 2050 A2.

User behavior

Energy performance considering the user behavior scenarios is shown in Figures 67 and 68.

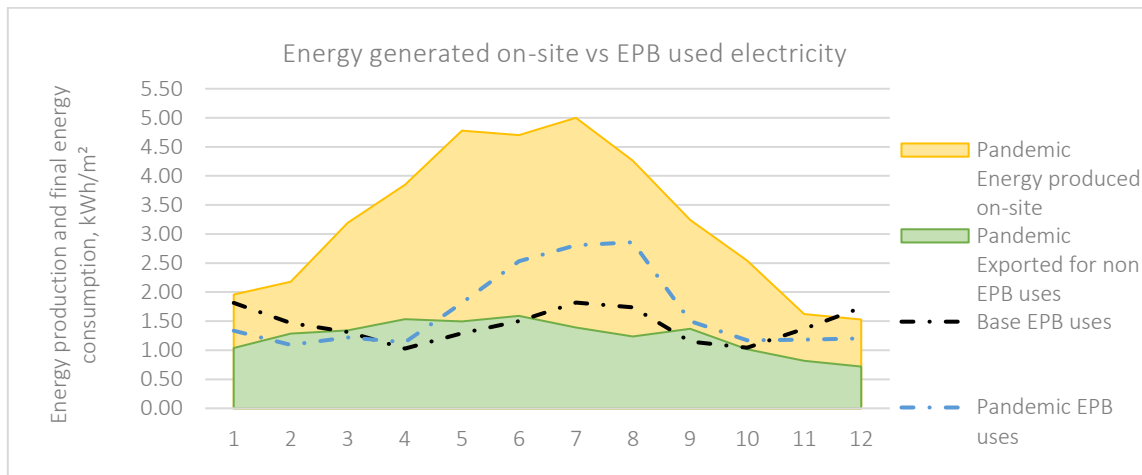


Figure 67. Ub1 Energy performance of the proposed case under the pandemic or home office scenario

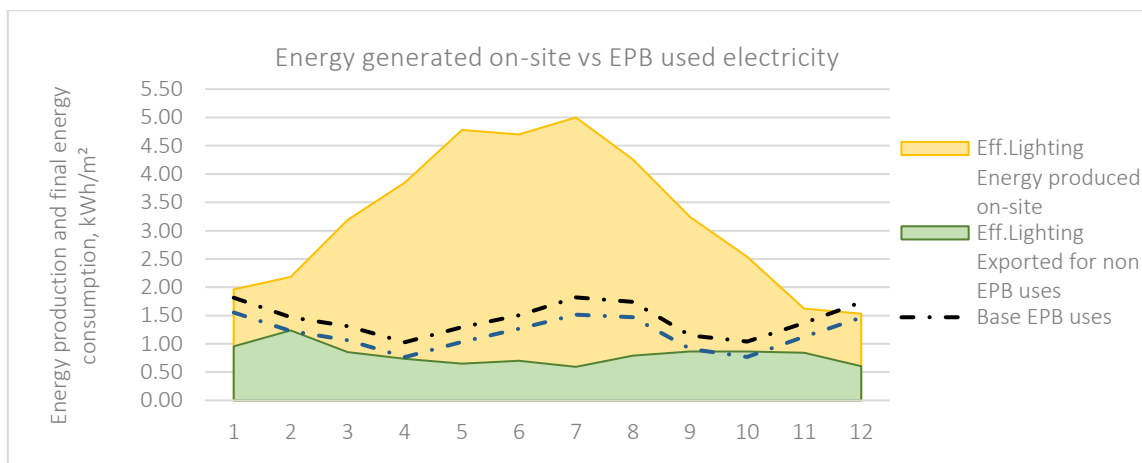


Figure 68. Ub2 Scenario where more energy conscious lighting is assumed

Pandemic scenario:

With residents being at home almost all the time, the heating needs are significantly lowered due to the higher heat load coming from people and appliances. Appliance usage is also significantly raised due to the higher occupancy and therefore non EPB uses are significantly higher. Here, with such high internal loads the ratio of heating and cooling demands completely flips. Supply cover factor is the highest for this scenario with 0.30 while non-renewable primary energy consumption is also the highest.

Energy conscious lighting scenario:

This scenario only concerns the lighting demand, which is significantly lowered with conscious energy usage and the assumption of energy efficient lighting. Lighting needs are lowered from 5.28 kWh/m² to 2.17 kWh/m². This scenario has the lowest non-renewable primary energy consumption.

Energy flexibility

Figure 69 shows the result for increased setpoint for heating during the day with 1K. As the buildings have relatively high thermal capacity, keeping the setpoints closer to each other, reduces the energy usage both with cooling and heating. The energy reduction, however, is not significant (around 0.41 kWh/m²) in this scenario.

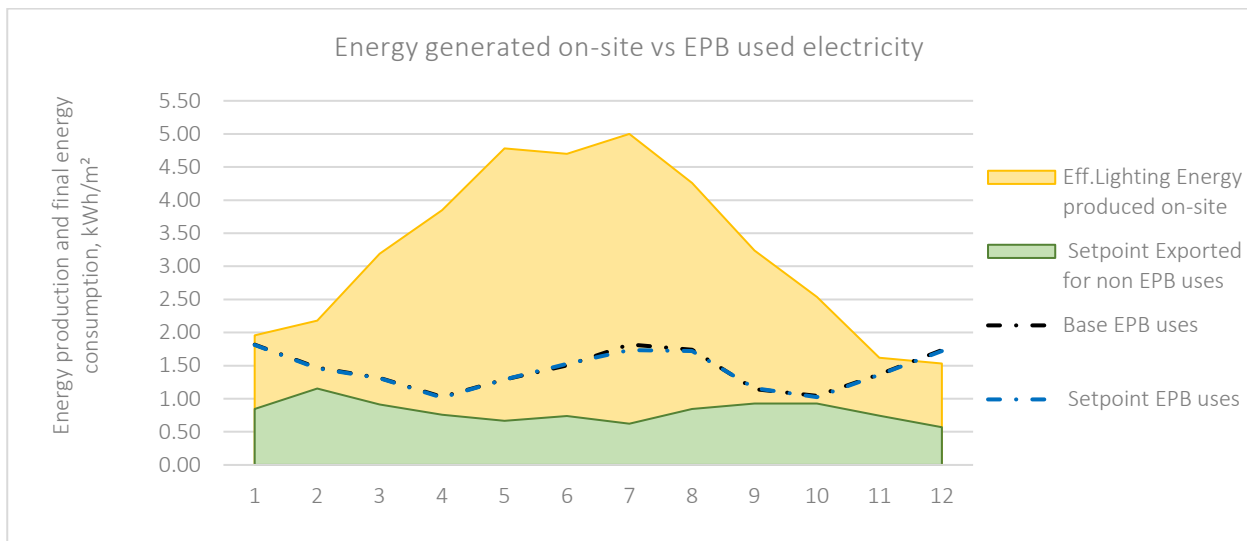


Figure 69. Ef1 Energy performance of scenario where 1°C higher setback points are assumed.

Table 64. Summarizing the result of the different scenarios.

Main KPI	BC	Cl1	Cl2	Ub1	Ub2	Ef1
Heating demand [kWh/m ²]	10.2	8.62	8.53	0.61	10.2	10.2
Cooling demand [kWh/m ²]	4.62	5.46	6.35	16.3	4.62	4.56
DHW demand [kWh/m ²]	18.4	18.4	18.4	18.4	18.4	18.4
Lighting [kWh/m ²]	5.28	5.28	5.28	7.14	2.17	5.28
COP – Heating	4	4	4	4	4	4
COP – Cooling	4	4	4	4	4	4
COP – DHW	2.7	2.7	2.7	2.7	2.7	2.7
PV production [kWh/m ²]	38.9	35.4	37.2	38.9	38.9	38.9
Total primary energy consumption [kWh/m ²]	41.03	38.63	38.16	37.53	35.33	39.84
Non-renewable primary energy consumption [kWh/m ²] (A)	-22.01	-18.89	-20.75	-19.38	-21.66	-22.14
Supply cover factor	0.28	0.29	0.28	0.30	0.27	0.29

Conclusions

The resilience and vulnerability of the design can be evaluated only when the combined effect of the above-mentioned scenarios are taken into account. For the sake of simplicity, the worst performing set of parameters was used to create a pessimistic scenario. and a set of the best performing parameters to create an optimistic scenario. Ideally, the result of any other combination would fall between these two scenarios.

For the pessimistic scenario the following scenarios are combined:

- 2050B1 weather file
- Pandemic or home office situation (everybody always at home)

For the optimistic scenario the following scenarios are combined:

- 2050A2 weather file
- Use of energy efficient lighting
- Use of higher setpoints

In Table 65 and Figures 70 and 71, the energy performance and energy balance of the pessimistic and optimistic scenarios are given. The results show that even with the combination of the worst and the best scenarios, the proposed design is able to maintain the positive energy status, meaning that the chosen design is robust.

Table 65. Results for pessimistic and optimistic scenario.

Main KPI	Optimistic	Pessimistic
Heating demand [kWh/m ²]	9.96	1.35
Cooling demand [kWh/m ²]	4.61	16.7
DHW demand [kWh/m ²]	18.4	18.4
Lighting [kWh/m ²]	2.17	5.28
COP – Heating	4	4
COP – Cooling	4	4
COP – DHW	2.7	2.7
PV production [kWh/m ²]	37.2	35.4
Total primary energy consumption [kWh/m ²]	34.58	36.17
Non-renewable primary energy consumption [kWh/m ²]	9.17	9.77
Supply cover factor	0.28	0.29

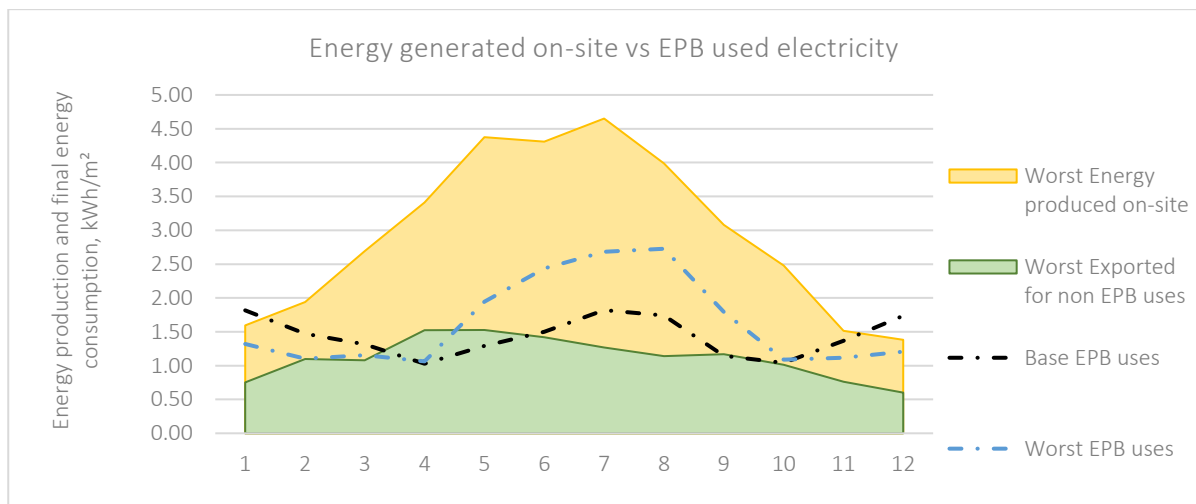


Figure 70. Energy performance of the pessimistic scenario.

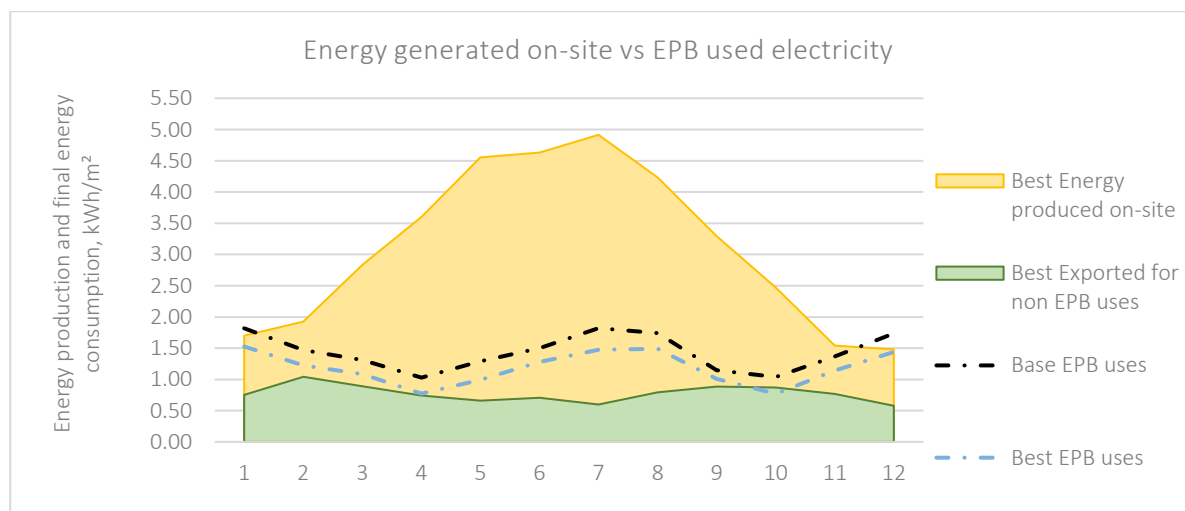


Figure 71. Energy performance of the optimistic scenario

The resulting energy balances are shown in Figures 72 and 73. It is shown that even in the pessimistic scenario, the demonstration project is able to uphold a positive energy balance with a considerable margin.

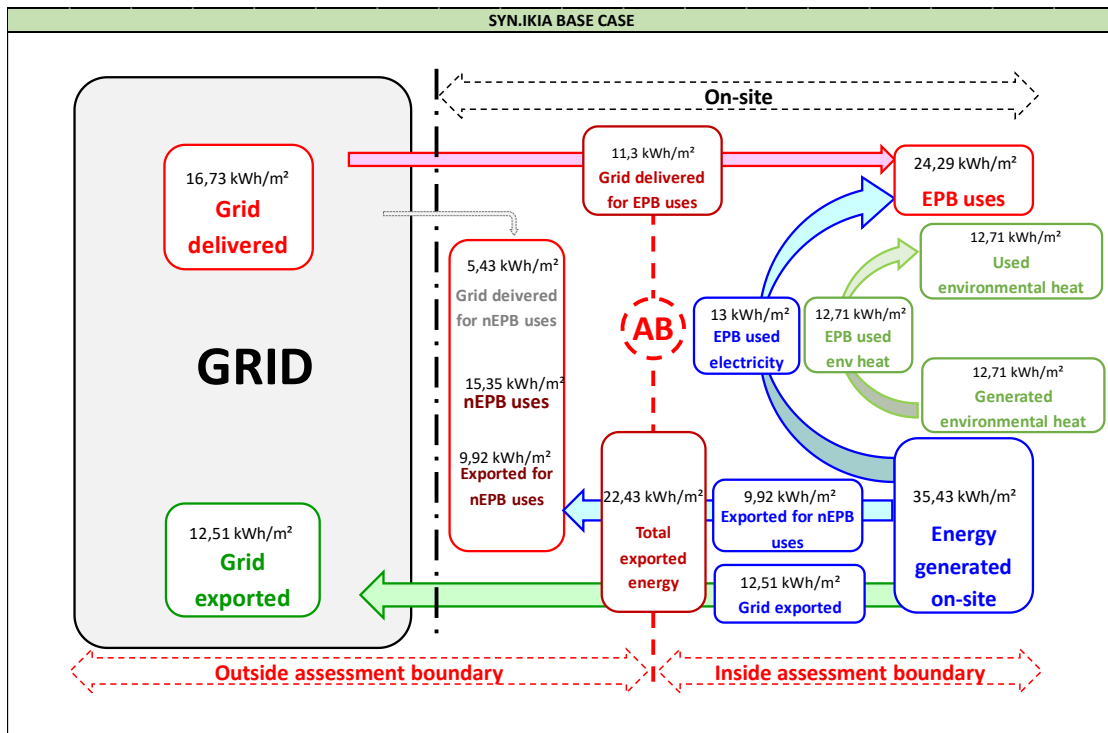


Figure 72. Energy balance of the pessimistic scenario.

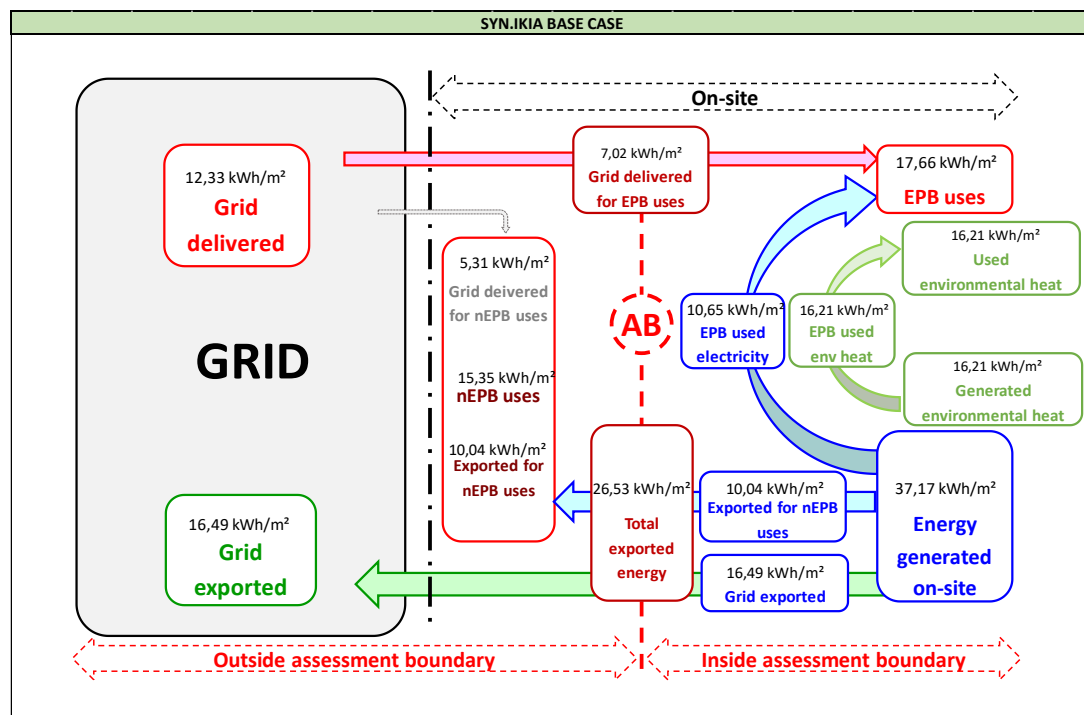


Figure 73. Energy balance of the optimistic scenario.

Sub-arctic climate demonstration project

Description of scenarios

Scenario Hv1 was used as best case as it guarantees low energy consumption (and high indoor comfort) while ensuring a good occupants' comfort. In particular, the scenario involves the use of floor heating distribution and no ventilative heating. The district heating Hv1 has been assumed as base case for analysing the impact of future scenarios related to climate change, user behaviour, and energy and power cost.

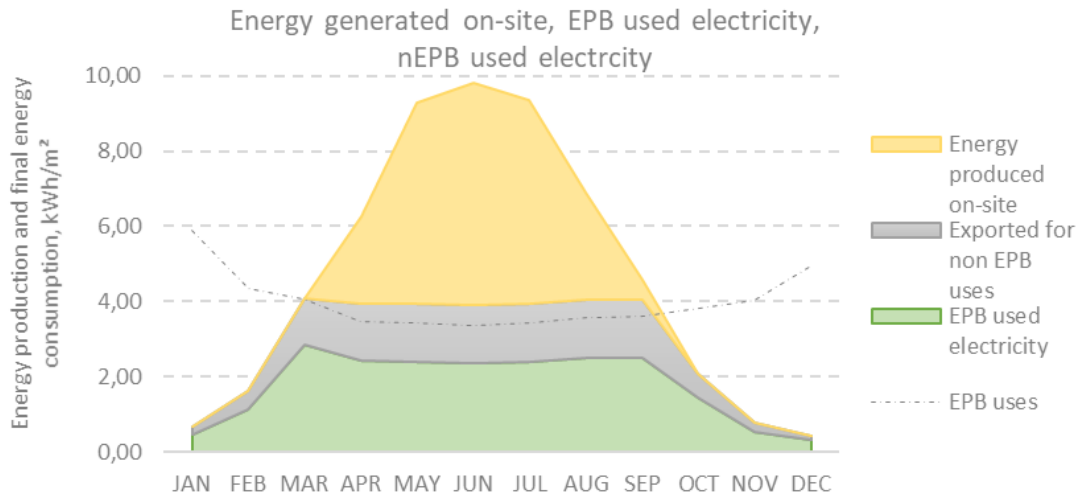


Figure 74. Hv1 energy budget, used as base case for scenario planning.

Climate change

In the last years, average temperatures in Norway have constantly increased, with exception of 2010 that was the coldest year since 1900. A peak was recorded in 2014, with temperatures 2.2 degrees over what is considered as being normal. Within 2100, average temperatures are expected to increase up to 4.5 degrees. Norwegian climate will be characterized by warmer winters (especially in the north) and more frequent and abundant precipitations. Unpredictable wind patterns, frequent precipitation, and higher temperatures will make our built environment more vulnerable, increasing the risk for rotting and mold related damages and will therefore require more stringent characteristics of the whole building envelope, floods, avalanches, storm surges, landslides, and sea level rise, will become more frequent. Uncertainties are larger locally than globally.

Depending on emissions released due to anthropogenic activities, the temperature increase can be included between 3.3 and 6.4 degrees. There are also relatively large uncertainties about how wind patterns will change in the near future. We should however consider strong winds. Climate adaptive strategies, involving form-giving processes, localization and orientation, together with detailing and material choice – of a building or a neighbourhood – will assume an even larger importance for protecting the building construction from exposure to adverse climatic factors.

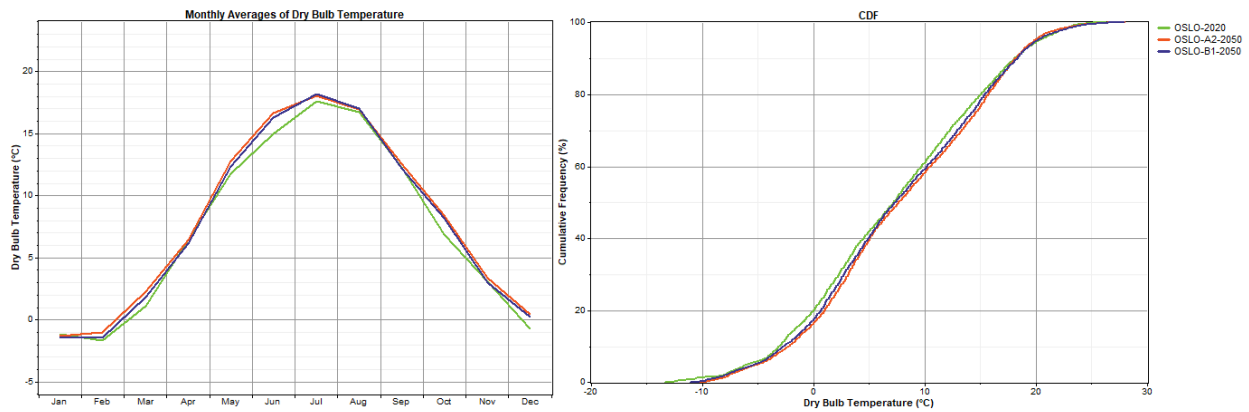


Figure 75. Weather conditions for the three scenarios: current climate (2020). IPCC A2 – 2050 and IPCC B1 – 2050. Left: monthly average temperature. Right: cumulative frequency of temperature.

User behaviour

Two typologies of users have been determined for this scenario; active and passive user. The active user has a simple understanding of how a technical system works and has awareness of how and to what extent his behaviour influences the performance of the building. In addition, the user has the will to adopt the behaviour that he or she understands to be the best. To simulate the impact of the active user, the DHW is heated during night following a lower power cost, the setpoint for the ventilation is 0.6 ach, and the room temperature setpoint is lowered. In this scenario, the lights and the appliance have a higher efficiency since the user chooses to invest in more efficient products. Same thing for the utilisation schedule, the active user uses light and appliances for a shorter time and turns them off when they are not necessary. The passive user does not take these measures, uses a higher setpoint for the ventilation and the heating (see Table 66), and does not invest in more efficient lighting or appliances. The setpoint for the ventilation rate is higher, and an automatic opening of one window per apartment is implemented in the simulation. The window is opened at the same time of the day for one hour disregarding the outdoor weather conditions.

Table 66. Description of user behaviour scenarios.

Scenario		Parameters describing user behaviour considered as input in the model	
Ub1	Active User	DHW	DHW is heated in the night when energy price is lower (valuable for later analyses related to energy and power cost)
		Ventilation rate	0.6 ACH (as base case)
		Temperature setpoint	19 °C
		Artificial lighting	Efficient LED (moving from 60 to 75 lm/watt) Adjusted schedule Lux target: 200 lux (as base case)
		Appliances use	Weekend same schedule as working days Power > 10 % less (efficient appliances)
Ub2	Passive User	DHW	35 kWh/(m ² yr)
		Ventilation rate	0.8 ACH (as base case) Windows are opened 1 hour per day independently from outdoor temperature
		Temperature setpoint	21 °C
		Artificial lighting	Relation to lux-requirement is removed Lighting on from 8:00 to 23:00
		Appliances use	Same schedule as for lighting Same power as base case

Energy and power costs

Two scenarios were simulated to introduce some energy flexibility features, see Table 67. This includes the local use of the renewable energy produced. This can be achieved by storing the energy in electrical

(batteries) or thermal (PCM or water tanks) storage facilities specifically built for this reason. Storing energy allows to adopt peak shaving strategies, that translate into lower energy cost. Instead of building expensive systems, it is possible to use systems that are already present in modern building, namely the thermal capacity of tanks or structure for the thermal energy storage and the battery of the electric vehicles for the electric energy. The scenarios adopted in the simulations are summarized in the table below.

The first scenario involves storing excess of energy into thermal energy using the concrete and the water tanks as thermal batteries. Therefore, the setpoint of the heating system and the DHW tank is increased ideally in the time interval when there is excess of renewable energy production.

The second scenario considers the presence of EVs. Currently, Norway has the largest marked incident of EV over traditional vehicles. Considering this, the scenario considers 5 EVs for the model in the simulations, 1 per floor, 1 every 4 apartments. The association between local energy production and EV charging was simulated as follows: According to literature, the average charging process of an EV in Norway requires 20 kWh. The charging process is carried out 30 times per months. This translates into a maximum energy request of 2.30 kWh/m² per month. In the months where there is a surplus of locally produced electricity, this surplus is entirely used for EV charging up to the maximum previously indicated. The rest of the energy is exported towards the central energy grid.

Table 67. Description of energy and power cost scenarios.

Scenario		Parameters describing scenario
EpC1	Increase of heating setpoint	heating setpoint of the building is increased by 1 C during the whole day
		the DHW setpoint increased by 5 C during the whole day
EpC2	Electric car use	EV charging, amount of electric work required by the average charging process of the average EV in Norway is 20 kWh (reference)
		We suppose the presence of 5 EV in the model (1 per floor. 1 every 4 apartments)
		They are charged 30 times per month each time using 20 kWh resulting in an energy demand of 2.38 kWh/m ² per month.
		When the local energy production is higher than the consumption a part of this surplus is used for EV charging up to the limit of 2.38 kWh/m ² per month.

Results

Figure 76 illustrates the comparison between the results obtained in the two scenarios Cl1 and Cl2 and the base case scenario. Case Cl2 is calculated considering a worse scenario for climate change. This means that the pattern of renewable energy produced on-site is slightly different from the base case (i.e. the yellow area). This situation does not happen in the other scenarios. The amount of energy for EPB uses is very similar between the two scenarios. This result was expected since the demo building is not equipped with a cooling system. With respect to the best-case scenario (HV1) the EPB use is slightly higher. Both scenarios demonstrate an increase in the consumption for cooling.

Figure 77 presents the results of the two scenario Ub1 and Ub2 which take into account different user behaviour. The increase of energy consumption associated to the passive user (scenario Ub2) is consistent. This result was expected. The decrease in energy consumption with respect to the base case in the scenario Ub1 is related to the assumption that an active user would have both reduce the use of energy in time and invested in more efficient systems.

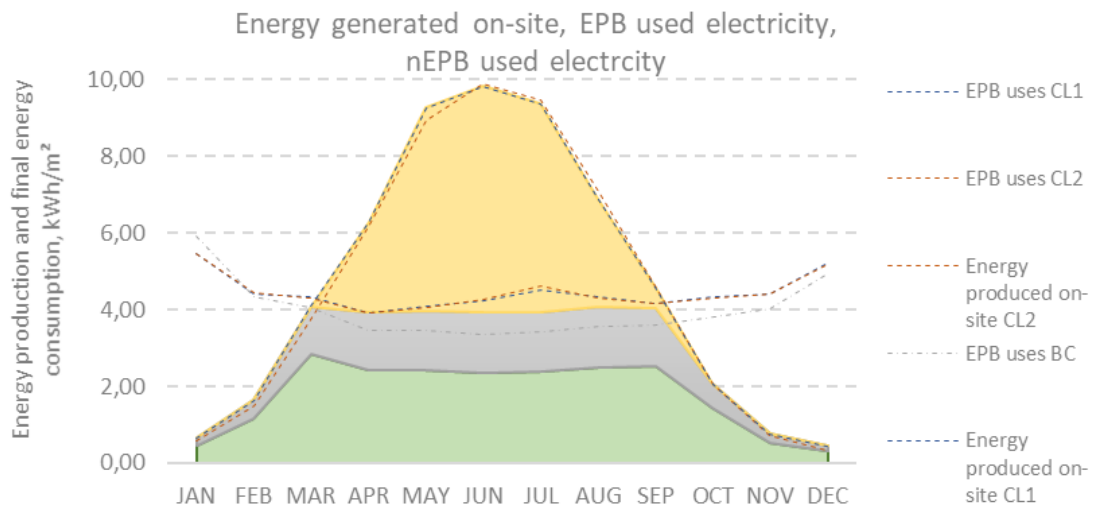


Figure 76. CL1 and CL2 - Climate change results

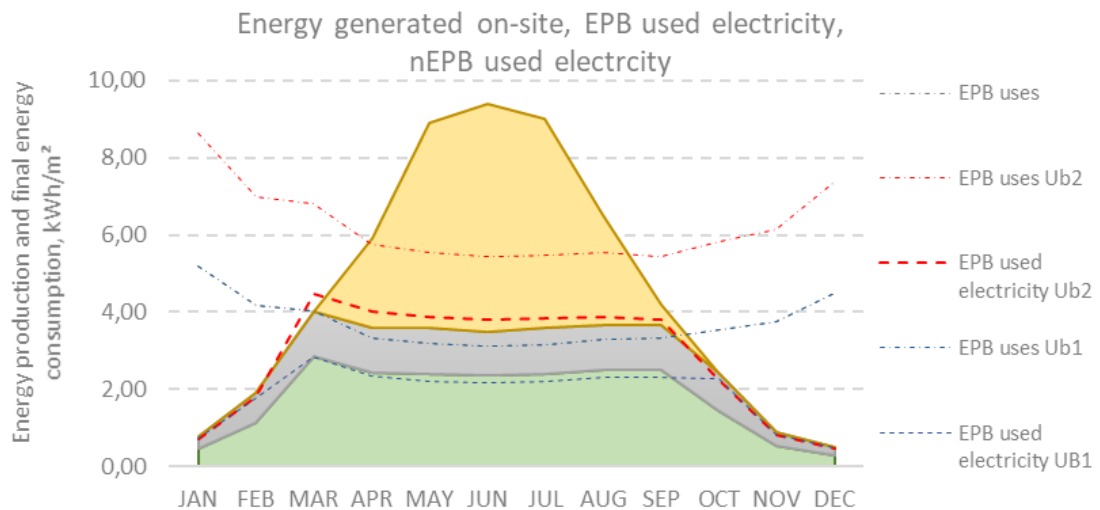


Figure 77. Ub1 and Ub2 final energy diagram.

The results reported in Figure 78 illustrate the scenario Ef1. The hypothesis considered here are only the increase of setpoint for the heating system and the DHW. The second scenario concerning energy flexibility and costs is reported in Figure79. In this case a part of the on-site produced energy is used for charging the EV. In the graph this is represented by the blue area. The results present an increase in the EPB used electricity.

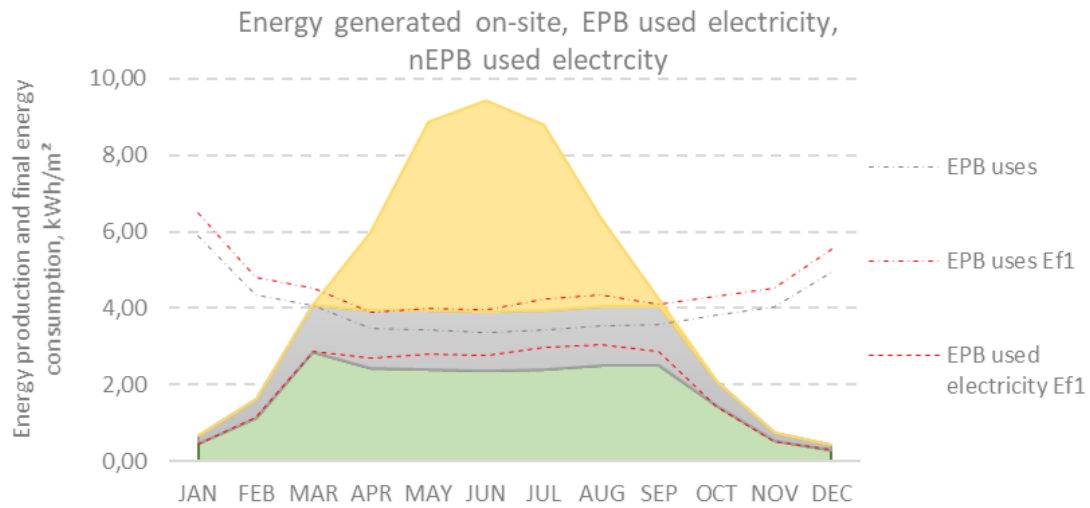


Figure 78. Ef1 _ Energy flexibility and cost 1

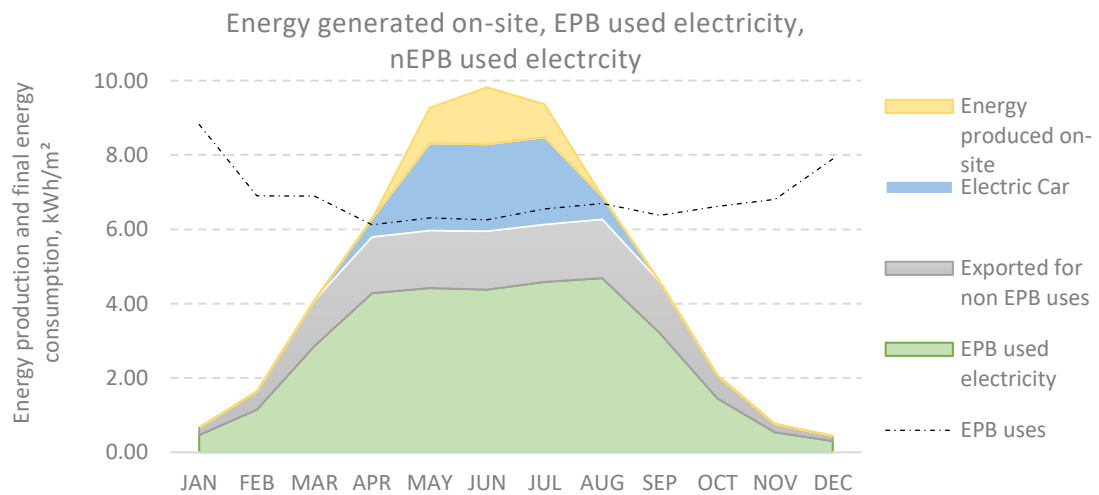


Figure 79. Ef2 _ Energy flexibility and cost 2 considers the use of electric car. In this case all areas are representative for the energy balance of this scenario. The blue area indicates the amount of energy that is directly used for charging the vehicle.

Table 68. Summary of results

Main KPI	HV1(BC)	CL1	CL2	UB1	UB2	Hf1	Hf2
Heating Demand [kWh/m ²]	3.99	5.25	5.21	4.27	9.07	7.61	7.61
Cooling Demand [kWh/m ²]	0	0	0	0	0	2.51	2.51
DHW Demand [kWh/m ²]	25	25	25	25	25	25	25
Lighting	13	13.5	13.6	10.1	23.5	13	13
COP-Heating	1	1	1	1	1	1	1
COP-Cooling	1	1	1	1	1	1	1
COP-DHW	1	1	1	1	1	1	1
PV production	55.85	55.85	55.09	55.85	55.85	55.85	55.85
Total primary energy consumption	59.97	63.83	63.89	65.10	63.28	66.09	90.96
Non-renewable primary energy consumption	-7.08	-3.29	-3.27	-2.45	6.24	-2.13	14.38
Supply cover factor	0.49	0.056	0.056	0.56	0.66	0.55	0.74
PMV>0.5 [%]	0.4	0.83	1.35	0.39	0.31	0.47	0.47

Conclusions

Pessimistic and optimistic scenarios

The different scenarios previously described were analysed, and for each typology it was spotted the scenario that gives the best results in terms of energy consumption and the one that gives the worst results. Two additional scenarios were then identified by combining all the worst results in a pessimistic scenario and the best results in an optimistic.

The pessimistic scenario involves the climate A2, a passive user and the increase of the setpoints in the flexibility strategy, while the optimistic scenario is the one involving an active user, EV charging and whose climate overlook is B1.

Table 69. Description of energy and power cost scenarios.

Scenario	Parameters describing scenario
Pessimistic: Cl2 + Ub2 + Ef1	Climate: Oslo-A2 Non-responsible use behaviour (passive user) Higher setpoints for heating
Optimistic: Cl1 + Ub1 + Ef2	Climate: Oslo-B1 Responsible use behaviour (active user) Electric car use

The final energy balance for the pessimistic and optimistic scenarios are shown in Figures 80 and 81. It is clear that even in the pessimistic scenario, the demo project is likely to meet the positive energy balance as defined in the syn.ikia project.

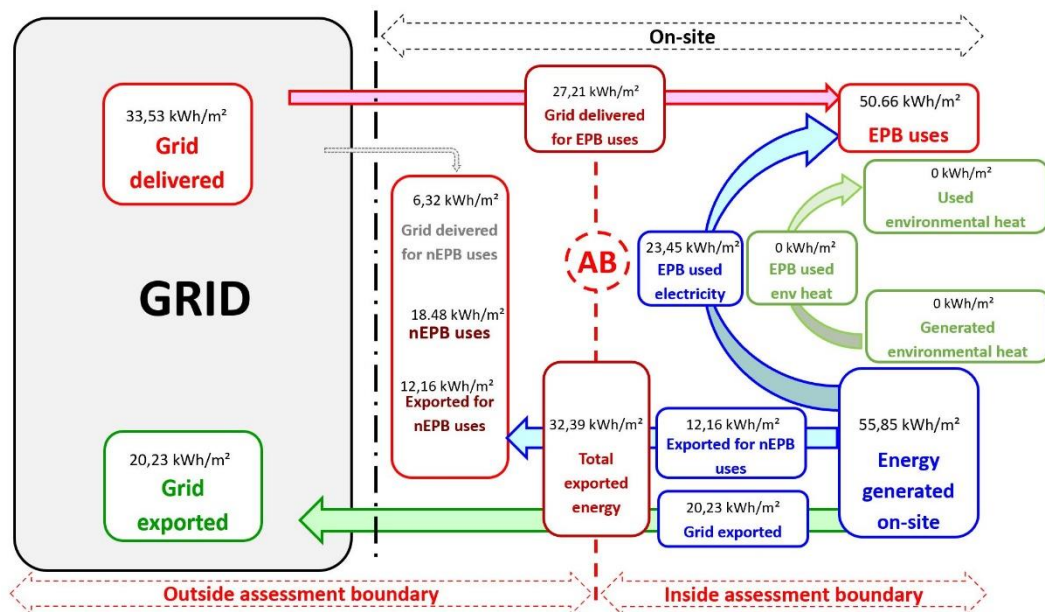


Figure 80. Energy balance of the pessimistic scenario.

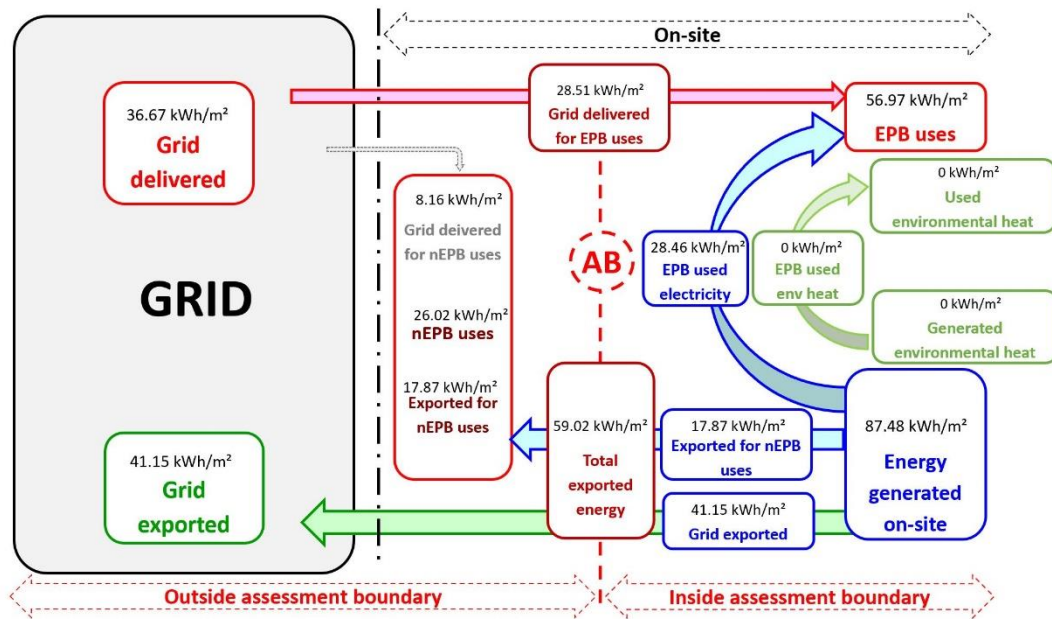


Figure 81. Energy balance of the optimistic scenario.

10. Conclusions

This report has shown the comprehensive results of integrated energy design of four demonstration projects in different climates around Europe.

Each of the demonstration projects have tested a wide range of design strategies including passive and active strategies tailored to the individual local contexts and climates. Using state-of-the-art computer simulation tools, the design teams have estimated the energy and environmental performance of the different strategies and chosen the most optimal ones in each case.

In addition, the robustness of the designs against changes in future conditions such as climate, user behaviour and costs, have been tested. The results show that all of the demonstration projects are likely to uphold the plus energy balance, even in the most pessimistic scenarios.

During the remaining time period of the syn.ikia project, the demonstration projects will be constructed, commissioned, and monitoring during their actual operation. These processes will be closely followed-up to ensure the performance with respect to energy, indoor environment, and costs. Ultimately, this will result in guidelines for the design, construction, and operation of plus energy neighbourhoods across Europe.

11. References

- [1] United Nations (2015). Paris Agreement.
https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf
- [2] United Nations(2015). The 17 Goals, [h\[3\] ttps://sdgs.un.org/goals](https://sdgs.un.org/goals)
- [3] United Nations (2018). News: 68% of the world population projected to live in urban areas by 2050, says UN. <https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html>
- [4] Salom and Tamm (2020). D31 Methodology Framework for Plus Energy Buildings and Neighbourhoods. Report of the EU-project syn.ikia, www.synikia.eu.
- [5] Hestnes et al. (2017). Zero Emission Buildings. Fagbokforlaget, Oslo, ISBN 978-82-450-2055-7.
- [6] Van Dijk and Hogeling (2019). The new EN ISO 52000 family of standards to assess the energy performance of buildings put in practice. E3S Web Conf., vol. 111, no. 201 9, 2019, doi: 10.1051/e3sconf/201911104047.
- [7] Fanger (1967). Calculation of thermal comfort: Introduction of a basic comfort equation. ASHRAE Trans., 73, III.4.1– III.4.20.
- [8] de Dear and Brager (1998). Developing an adaptive model of thermal comfort and preference. ASHRAE 663 Transactions. 1998;104:145-67.
- [9] WMO and UNEP (2000). Intergovernmental Panel on Climate Change. Summary for Policymakers. Emissions Scenarios. <https://www.ipcc.ch/site/assets/uploads/2018/03/sres-en.pdf>
- [10] Delzendeh et al. (2017). The impact of occupants’ behaviours on building energy analysis: A research review. Renewable and Sustainable Energy Reviews, vol. 80. Elsevier Ltd, pp. 1061–1071, Dec. 2017, doi: 10.1016/j.rser.2017.05.264.
- [11] Ministerio de Fomento (2019). Documento Básico HE Ahorro de Energía 2019. *Código Técnico la Edif.* pp. 1–129. 2019.
- [12] Solar Energy Laboratory (2017). TRNSYS 18. Madison: Solar Energy Laboratory. University of Wisconsin.
- [13] Trace Software International (2020). Archelios Pro, Software for the design of solar installations. <https://www.trace-software.com/archelios-pro/solar-design-software/>
- [14] Ortiz, Russo, and Salom (2015). Impact of natural ventilation in energy demand and thermal comfort of residential buildings in Catalonia. *Proceedings of the 36th AIVC-5th TightVent-3rd venticool Conference*. Madrid. pp. 320–330, 2015.
- [15] UNE (2019). EN 52000-1:2019 Energy performance of buildings - Overarching EPB assessment - Part 1: General framework and procedures (ISO 52000-1:2017).
- [16] UNE (2019). EN 16798-2:2019 Energy performance of buildings - Ventilation for buildings - Part 2: Interpretation of the requirements in EN 16798-1 - Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor, 2019.
- [16] Bouwbesluit (2012). <https://rijksoverheid.bouwbesluit.com/Inhoud/docs/wet/bb2012> (website visited 25 November 2020).
- [17] www.klimaktiv.at
- [18] www.oib.or.at/en/oib-guidelines
- [19] <https://cityenergyanalyst.com/>

[20] <https://www.equa.se/en/ida-ice>

[21] Altava-Ortiz et al (2016). Efectes del canvi climàtic a l'Àrea Metropolitana de Barcelona. Temperatura.

[22] METEOTEST Genossenschaft. Meteonorm 7 [Online], www.meteonorm.com

[23] Chen et al (2021). The impacts of occupant behavior on building energy consumption: A review. *Sustain. Energy Technol. Assessments*. vol. 45. p. 101212. Jun. 2021. doi: 10.1016/j.seta.2021.101212.

[24] Denholm et al (2015). Overgeneration from Solar Energy in California: A Field Guide to the Duck Chart. National Renewable Energy Laboratory, Technical Report NREL/TP-GA20-65023, California.

12. Appendix – Detailed results tables

Mediterranean climate

Climate change scenario Cl0/User behaviour scenario Ub0/ Energy flexibility Ef0/ Optimistic scenario

SYN.IKIA BASE CASE. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	18.19	2.73	2.12	1.65	1.15	1.12	0.97	0.96	0.99	1.06	1.19	1.59	2.67
non EPB uses	kWh/m ²	39.87	3.43	2.97	3.33	3.32	3.33	3.28	3.34	3.41	3.28	3.40	3.31	3.48
EPB used electricity	kWh/m ²	3.75	0.53	0.61	0.39	0.24	0.20	0.17	0.15	0.16	0.21	0.21	0.35	0.54
Energy produced on-site	kWh/m ²	23.42	0.98	1.37	2.20	2.27	2.56	2.63	2.72	2.58	2.06	2.00	1.08	1.00
Environmental energy	kWh/m ²	32.01	5.05	3.91	2.65	2.01	1.96	1.78	1.82	1.79	1.77	1.88	2.41	4.97
Exported electricity	kWh/m ²	19.67	0.45	0.76	1.81	2.04	2.36	2.46	2.57	2.42	1.85	1.78	0.72	0.45
Exported for non EPB uses	kWh/m ²	12.46	0.34	0.61	1.09	1.33	1.37	1.57	1.53	1.46	1.24	1.06	0.53	0.33
Grid exported	kWh/m ²	7.21	0.11	0.15	0.72	0.70	0.99	0.90	1.04	0.96	0.61	0.72	0.19	0.12
Grid delivered, (EPB uses)	kWh/m ²	14.44	2.20	1.51	1.26	0.92	0.91	0.80	0.81	0.83	0.85	0.97	1.23	2.13
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-1.87	0.62	0.27	-0.19	-0.40	-0.51	-0.59	-0.63	-0.57	-0.36	-0.29	0.18	0.60

Climate change scenario Cl1

SYN.IKIA BASE CASE. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	16.01	2.22	1.80	1.51	1.12	1.09	0.96	0.92	0.95	1.01	1.14	1.28	2.00
non EPB uses	kWh/m ²	39.87	3.43	2.97	3.33	3.32	3.33	3.28	3.34	3.41	3.28	3.40	3.31	3.48
EPB used electricity	kWh/m ²	3.26	0.46	0.52	0.34	0.23	0.19	0.16	0.14	0.15	0.19	0.20	0.28	0.41
Energy produced on-site	kWh/m ²	23.42	0.98	1.37	2.20	2.27	2.56	2.63	2.72	2.58	2.06	2.00	1.08	1.00
Environmental energy	kWh/m ²	28.15	4.10	3.22	2.44	2.00	1.95	1.78	1.82	1.79	1.77	1.88	1.90	3.49
Exported electricity	kWh/m ²	20.16	0.52	0.84	1.86	2.04	2.36	2.47	2.59	2.43	1.87	1.80	0.79	0.59
Exported for non EPB uses	kWh/m ²	12.80	0.40	0.67	1.13	1.34	1.37	1.57	1.53	1.46	1.25	1.07	0.58	0.43
Grid exported	kWh/m ²	7.35	0.13	0.18	0.73	0.70	0.99	0.90	1.05	0.97	0.61	0.72	0.22	0.15
Grid delivered, (EPB uses)	kWh/m ²	12.74	1.76	1.28	1.18	0.90	0.90	0.79	0.79	0.81	0.82	0.94	1.00	1.59
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-2.65	0.44	0.16	-0.24	-0.41	-0.52	-0.60	-0.64	-0.58	-0.38	-0.31	0.07	0.36

Climate change scenario Cl2

SYN.IKIA BASE CASE. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	16.31	2.31	1.83	1.52	1.13	1.10	0.96	0.93	0.96	1.02	1.15	1.32	2.08
non EPB uses	kWh/m ²	39.87	3.43	2.97	3.33	3.32	3.33	3.28	3.34	3.41	3.28	3.40	3.31	3.48
EPB used electricity	kWh/m ²	3.34	0.47	0.52	0.33	0.23	0.20	0.16	0.14	0.15	0.19	0.21	0.29	0.44
Energy produced on-site	kWh/m ²	23.42	0.98	1.37	2.20	2.27	2.56	2.63	2.72	2.58	2.06	2.00	1.08	1.00
Environmental energy	kWh/m ²	28.68	4.28	3.28	2.45	2.00	1.95	1.78	1.82	1.79	1.77	1.88	1.97	3.71
Exported electricity	kWh/m ²	20.09	0.51	0.85	1.86	2.04	2.36	2.47	2.58	2.43	1.86	1.79	0.78	0.56
Exported for non EPB uses	kWh/m ²	12.74	0.38	0.67	1.12	1.34	1.37	1.56	1.53	1.46	1.25	1.07	0.57	0.41
Grid exported	kWh/m ²	7.34	0.13	0.18	0.74	0.70	0.99	0.90	1.05	0.97	0.61	0.72	0.21	0.15
Grid delivered, (EPB uses)	kWh/m ²	12.97	1.83	1.31	1.19	0.90	0.90	0.80	0.79	0.81	0.82	0.95	1.03	1.64
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-2.54	0.47	0.17	-0.24	-0.41	-0.52	-0.60	-0.64	-0.58	-0.37	-0.30	0.09	0.39

User behaviour scenario Ub1

SYN.IKIA BASE CASE. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	18.71	2.89	2.27	1.71	1.15	1.11	0.97	0.96	0.99	1.06	1.19	1.62	2.80
non EPB uses	kWh/m ²	39.87	3.43	2.97	3.33	3.32	3.33	3.28	3.34	3.41	3.28	3.40	3.31	3.48
EPB used electricity	kWh/m ²	4.15	0.61	0.74	0.45	0.23	0.20	0.17	0.15	0.16	0.21	0.21	0.39	0.63
Energy produced on-site	kWh/m ²	23.42	0.98	1.37	2.20	2.27	2.56	2.63	2.72	2.58	2.06	2.00	1.08	1.00
Environmental energy	kWh/m ²	33.49	5.56	4.38	2.77	1.98	1.93	1.78	1.82	1.80	1.77	1.88	2.49	5.34
Exported electricity	kWh/m ²	19.28	0.36	0.63	1.74	2.04	2.36	2.46	2.57	2.42	1.85	1.78	0.68	0.37
Exported for non EPB uses	kWh/m ²	12.22	0.28	0.55	1.06	1.33	1.37	1.57	1.53	1.46	1.24	1.06	0.51	0.27
Grid exported	kWh/m ²	7.05	0.09	0.08	0.68	0.70	0.99	0.90	1.04	0.96	0.61	0.72	0.18	0.10
Grid delivered, (EPB uses)	kWh/m ²	14.56	2.28	1.53	1.26	0.92	0.91	0.80	0.81	0.83	0.85	0.97	1.23	2.17
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-1.68	0.68	0.32	-0.17	-0.40	-0.52	-0.59	-0.63	-0.57	-0.36	-0.29	0.19	0.64

User behaviour scenario Ub2

SYN.IKIA BASE CASE. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	19.17	2.82	2.21	1.73	1.26	1.20	1.04	1.01	1.04	1.14	1.26	1.70	2.77
non EPB uses	kWh/m ²	42.08	3.61	3.23	3.47	3.44	3.63	3.49	3.55	3.59	3.52	3.58	3.41	3.56
EPB used electricity	kWh/m ²	3.90	0.52	0.61	0.42	0.27	0.23	0.19	0.15	0.17	0.23	0.23	0.36	0.51
Energy produced on-site	kWh/m ²	23.42	0.98	1.37	2.20	2.27	2.56	2.63	2.72	2.58	2.06	2.00	1.08	1.00
Environmental energy	kWh/m ²	34.11	5.20	4.06	2.80	2.26	2.17	1.98	1.96	1.94	1.98	2.02	2.62	5.12
Exported electricity	kWh/m ²	19.53	0.46	0.76	1.77	2.00	2.33	2.44	2.57	2.41	1.83	1.77	0.71	0.49
Exported for non EPB uses	kWh/m ²	12.75	0.34	0.63	1.09	1.38	1.42	1.59	1.55	1.49	1.28	1.09	0.55	0.36
Grid exported	kWh/m ²	6.78	0.12	0.13	0.68	0.63	0.91	0.85	1.01	0.92	0.55	0.68	0.17	0.13
Grid delivered, (EPB uses)	kWh/m ²	15.27	2.30	1.61	1.30	0.99	0.97	0.84	0.86	0.87	0.91	1.03	1.34	2.26
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-1.52	0.66	0.30	-0.17	-0.36	-0.49	-0.57	-0.61	-0.55	-0.33	-0.26	0.22	0.63

User behaviour scenario Ub3

SYN.IKIA BASE CASE. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	19.64	2.97	2.35	1.78	1.26	1.19	1.04	1.01	1.04	1.14	1.26	1.72	2.89
non EPB uses	kWh/m ²	42.08	3.61	3.23	3.47	3.44	3.63	3.49	3.55	3.59	3.52	3.58	3.41	3.56
EPB used electricity	kWh/m ²	4.32	0.61	0.75	0.49	0.27	0.22	0.19	0.15	0.17	0.23	0.23	0.40	0.61
Energy produced on-site	kWh/m ²	23.42	0.98	1.37	2.20	2.27	2.56	2.63	2.72	2.58	2.06	2.00	1.08	1.00
Environmental energy	kWh/m ²	35.47	5.68	4.49	2.90	2.22	2.13	1.98	1.96	1.94	1.98	2.02	2.67	5.50
Exported electricity	kWh/m ²	19.10	0.36	0.62	1.70	2.01	2.33	2.44	2.57	2.41	1.83	1.77	0.68	0.39
Exported for non EPB uses	kWh/m ²	12.50	0.27	0.56	1.06	1.38	1.42	1.59	1.55	1.49	1.28	1.09	0.52	0.30
Grid exported	kWh/m ²	6.60	0.09	0.06	0.65	0.63	0.92	0.85	1.01	0.92	0.55	0.68	0.16	0.09
Grid delivered, (EPB uses)	kWh/m ²	15.32	2.36	1.60	1.29	0.99	0.97	0.84	0.86	0.87	0.91	1.03	1.32	2.28
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-1.35	0.71	0.35	-0.15	-0.36	-0.49	-0.57	-0.61	-0.55	-0.33	-0.26	0.23	0.67

Flexibility scenario FI1

SYN.IKIA BASE CASE. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	19.64	2.97	2.35	1.78	1.26	1.19	1.04	1.01	1.04	1.14	1.26	1.72	2.89
non EPB uses	kWh/m ²	42.08	3.61	3.23	3.47	3.44	3.63	3.49	3.55	3.59	3.52	3.58	3.41	3.56
EPB used electricity	kWh/m ²	4.32	0.61	0.75	0.49	0.27	0.22	0.19	0.15	0.17	0.23	0.23	0.40	0.61
Energy produced on-site	kWh/m ²	23.42	0.98	1.37	2.20	2.27	2.56	2.63	2.72	2.58	2.06	2.00	1.08	1.00
Environmental energy	kWh/m ²	35.47	5.68	4.49	2.90	2.22	2.13	1.98	1.96	1.94	1.98	2.02	2.67	5.50
Exported electricity	kWh/m ²	19.10	0.36	0.62	1.70	2.01	2.33	2.44	2.57	2.41	1.83	1.77	0.68	0.39
Exported for non EPB uses	kWh/m ²	12.50	0.27	0.56	1.06	1.38	1.42	1.59	1.55	1.49	1.28	1.09	0.52	0.30
Grid exported	kWh/m ²	6.60	0.09	0.06	0.65	0.63	0.92	0.85	1.01	0.92	0.55	0.68	0.16	0.09
Grid delivered, (EPB uses)	kWh/m ²	15.32	2.36	1.60	1.29	0.99	0.97	0.84	0.86	0.87	0.91	1.03	1.32	2.28
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-1.35	0.71	0.35	-0.15	-0.36	-0.49	-0.57	-0.61	-0.55	-0.33	-0.26	0.23	0.67

Pessimistic scenario

SYN.IKIA BASE CASE. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	18.45	2.53	2.08	1.81	1.31	1.25	1.11	1.05	1.08	1.15	1.26	1.51	2.30
non EPB uses	kWh/m ²	42.08	3.61	3.23	3.47	3.44	3.63	3.49	3.55	3.59	3.52	3.58	3.41	3.56
EPB used electricity	kWh/m ²	4.82	0.61	0.76	0.62	0.34	0.29	0.25	0.19	0.22	0.28	0.28	0.42	0.59
Energy produced on-site	kWh/m ²	23.42	0.98	1.37	2.20	2.27	2.56	2.63	2.72	2.58	2.06	2.00	1.08	1.00
Environmental energy	kWh/m ²	33.16	4.89	3.90	2.99	2.31	2.22	2.09	2.06	2.03	2.07	2.08	2.30	4.23
Exported electricity	kWh/m ²	18.60	0.37	0.60	1.58	1.93	2.27	2.38	2.53	2.36	1.78	1.72	0.66	0.40
Exported for non EPB uses	kWh/m ²	12.48	0.29	0.56	1.00	1.36	1.42	1.59	1.57	1.49	1.28	1.08	0.52	0.32
Grid exported	kWh/m ²	6.12	0.08	0.05	0.58	0.57	0.86	0.79	0.96	0.87	0.50	0.64	0.14	0.09
Grid delivered, (EPB uses)	kWh/m ²	13.62	1.92	1.32	1.20	0.97	0.96	0.87	0.86	0.87	0.87	0.98	1.09	1.71
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-1.78	0.55	0.26	-0.14	-0.34	-0.47	-0.54	-0.60	-0.53	-0.33	-0.26	0.15	0.47

Marine climate

SYN.IKIA BASE CASE. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	23.18	3.31	2.62	2.03	1.61	1.27	1.32	1.35	1.33	1.28	1.60	2.36	3.10
non EPB uses	kWh/m ²	48.62	4.01	4.08	4.04	4.04	4.08	4.02	4.09	4.01	4.06	4.07	4.03	4.09
EPB used electricity	kWh/m ²	3.12	0.24	0.28	0.28	0.33	0.26	0.32	0.31	0.26	0.20	0.23	0.21	0.18
Energy produced on-site	kWh/m ²	24.45	0.59	1.07	1.47	3.06	3.37	3.55	3.40	3.12	2.14	1.47	0.70	0.51
Environmental energy	kWh/m ²	48.74	10.10	6.77	4.07	1.96	1.82	1.82	1.88	1.82	1.89	1.96	5.58	9.07
Exported electricity	kWh/m ²	21.33	0.35	0.78	1.18	2.73	3.10	3.23	3.09	2.86	1.94	1.24	0.49	0.33
Exported for non EPB uses	kWh/m ²	11.77	0.31	0.58	0.82	1.37	1.46	1.52	1.50	1.44	1.20	0.86	0.41	0.29
Grid exported	kWh/m ²	9.56	0.04	0.20	0.36	1.36	1.64	1.72	1.58	1.42	0.74	0.39	0.08	0.03
Grid delivered, (EPB uses)	kWh/m ²	20.06	3.06	2.33	1.75	1.28	1.01	1.00	1.04	1.06	1.08	1.37	2.14	2.93
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-0.45	0.97	0.55	0.20	-0.52	-0.75	-0.80	-0.73	-0.64	-0.31	0.05	0.59	0.93

Case 1

SYN.IKIA FINAL DESIGN. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	23.18	3.31	2.62	2.03	1.61	1.27	1.32	1.35	1.33	1.28	1.60	2.36	3.10
non EPB uses	kWh/m ²	48.62	4.01	4.08	4.04	4.04	4.08	4.02	4.09	4.01	4.06	4.07	4.03	4.09
EPB used electricity	kWh/m ²	7.61	0.39	0.51	0.62	0.86	0.83	0.88	0.89	0.83	0.60	0.55	0.36	0.29
Energy produced on-site	kWh/m ²	24.45	0.59	1.07	1.47	3.06	3.37	3.55	3.40	3.12	2.14	1.47	0.70	0.51
Environmental energy	kWh/m ²	48.74	10.10	6.77	4.07	1.96	1.82	1.82	1.88	1.82	1.89	1.96	5.58	9.07
Exported electricity	kWh/m ²	16.84	0.21	0.55	0.85	2.21	2.54	2.67	2.51	2.29	1.54	0.92	0.34	0.22
Exported for non EPB uses	kWh/m ²	9.49	0.18	0.41	0.60	1.16	1.26	1.35	1.29	1.19	0.95	0.63	0.28	0.19
Grid exported	kWh/m ²	7.36	0.03	0.14	0.25	1.05	1.27	1.32	1.22	1.10	0.59	0.29	0.06	0.02
Grid delivered, (EPB uses)	kWh/m ²	15.58	2.92	2.11	1.41	0.75	0.45	0.44	0.46	0.50	0.68	1.05	2.00	2.82
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-0.45	0.97	0.55	0.20	-0.52	-0.75	-0.80	-0.73	-0.64	-0.31	0.05	0.59	0.93

Case 2

SYN.IKIA FINAL DESIGN. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	37.47	5.08	3.79	2.78	2.42	2.46	2.82	2.90	2.86	2.30	2.20	3.29	4.58
non EPB uses	kWh/m ²	48.62	4.01	4.08	4.04	4.04	4.08	4.02	4.09	4.01	4.06	4.07	4.03	4.09
EPB used electricity	kWh/m ²	10.58	0.40	0.53	0.64	1.12	1.32	1.55	1.53	1.39	0.85	0.59	0.36	0.29
Energy produced on-site	kWh/m ²	24.45	0.59	1.07	1.47	3.06	3.37	3.55	3.40	3.12	2.14	1.47	0.70	0.51
Environmental energy	kWh/m ²	39.08	8.32	5.60	3.33	1.43	1.32	1.32	1.36	1.32	1.37	1.45	4.65	7.60
Exported electricity	kWh/m ²	13.87	0.19	0.54	0.83	1.94	2.04	2.00	1.87	1.73	1.28	0.88	0.34	0.21
Exported for non EPB uses	kWh/m ²	8.03	0.16	0.40	0.58	1.01	1.01	1.03	1.00	0.95	0.83	0.60	0.28	0.19
Grid exported	kWh/m ²	5.84	0.03	0.14	0.25	0.93	1.03	0.97	0.87	0.79	0.46	0.27	0.06	0.03
Grid delivered, (EPB uses)	kWh/m ²	26.88	4.68	3.26	2.15	1.30	1.14	1.27	1.36	1.47	1.45	1.60	2.92	4.28
Total greenhouse gas emissions	kg CO ₂ eq/m ²	4.65	1.60	0.97	0.47	-0.23	-0.32	-0.26	-0.18	-0.09	0.06	0.26	0.92	1.45

Case 3

SYN.IKIA FINAL DESIGN. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	36.26	5.22	4.03	3.01	2.25	2.01	2.35	2.53	2.45	2.01	2.24	3.47	4.69
non EPB uses	kWh/m ²	48.62	4.01	4.08	4.04	4.04	4.08	4.02	4.09	4.01	4.06	4.07	4.03	4.09
EPB used electricity	kWh/m ²	9.60	0.43	0.60	0.69	0.98	1.05	1.30	1.36	1.22	0.68	0.57	0.40	0.32
Energy produced on-site	kWh/m ²	24.45	0.59	1.07	1.47	3.06	3.37	3.55	3.40	3.12	2.14	1.47	0.70	0.51
Environmental energy	kWh/m ²	42.10	8.63	6.18	3.97	1.79	1.34	1.32	1.37	1.32	1.38	1.79	5.14	7.87
Exported electricity	kWh/m ²	14.85	0.16	0.47	0.78	2.09	2.32	2.25	2.04	1.90	1.45	0.90	0.30	0.19
Exported for non EPB uses	kWh/m ²	8.19	0.14	0.34	0.54	1.04	1.10	1.10	1.04	0.98	0.89	0.61	0.25	0.17
Grid exported	kWh/m ²	6.66	0.02	0.12	0.24	1.05	1.22	1.15	1.00	0.92	0.57	0.29	0.06	0.02
Grid delivered, (EPB uses)	kWh/m ²	26.65	4.79	3.43	2.32	1.27	0.96	1.04	1.17	1.23	1.33	1.67	3.07	4.37
Total greenhouse gas emissions	kg CO ₂ eq/m ²	4.21	1.65	1.06	0.55	-0.29	-0.48	-0.43	-0.31	-0.24	-0.04	0.28	0.99	1.49

Case 4

SYN.IKIA FINAL DESIGN. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	23.08	3.27	2.65	2.03	1.58	1.26	1.32	1.37	1.33	1.26	1.58	2.33	3.10
non EPB uses	kWh/m ²	48.62	4.01	4.08	4.04	4.04	4.08	4.02	4.09	4.01	4.06	4.07	4.03	4.09
EPB used electricity	kWh/m ²	8.33	0.53	0.73	0.74	0.84	0.82	0.89	0.91	0.84	0.59	0.55	0.46	0.43
Energy produced on-site	kWh/m ²	24.45	0.59	1.07	1.47	3.06	3.37	3.55	3.40	3.12	2.14	1.47	0.70	0.51
Environmental energy	kWh/m ²	46.70	9.41	6.59	3.93	1.90	1.82	1.82	1.88	1.82	1.88	1.86	5.21	8.61
Exported electricity	kWh/m ²	16.13	0.07	0.34	0.73	2.22	2.54	2.66	2.49	2.28	1.55	0.92	0.24	0.08
Exported for non EPB uses	kWh/m ²	8.95	0.06	0.26	0.50	1.16	1.27	1.35	1.29	1.19	0.95	0.63	0.20	0.08
Grid exported	kWh/m ²	7.18	0.00	0.08	0.23	1.06	1.28	1.31	1.20	1.09	0.59	0.29	0.03	0.00
Grid delivered, (EPB uses)	kWh/m ²	14.76	2.74	1.92	1.29	0.74	0.44	0.43	0.46	0.49	0.67	1.03	1.86	2.68
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-0.49	0.96	0.56	0.20	-0.53	-0.75	-0.80	-0.73	-0.64	-0.31	0.04	0.58	0.93

Case 5

SYN.IKIA FINAL DESIGN. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	25.39	2.75	2.29	2.08	2.17	1.80	1.85	1.88	1.85	1.81	2.14	2.17	2.61
non EPB uses	kWh/m ²	48.62	4.01	4.08	4.04	4.04	4.08	4.02	4.09	4.01	4.06	4.07	4.03	4.09
EPB used electricity	kWh/m ²	9.46	0.39	0.57	0.73	1.11	1.08	1.15	1.15	1.07	0.80	0.69	0.41	0.31
Energy produced on-site	kWh/m ²	24.45	0.59	1.07	1.47	3.06	3.37	3.55	3.40	3.12	2.14	1.47	0.70	0.51
Environmental energy	kWh/m ²	29.42	5.10	2.86	1.86	1.88	1.83	1.82	1.88	1.82	1.88	1.83	2.30	4.36
Exported electricity	kWh/m ²	14.99	0.20	0.49	0.74	1.95	2.28	2.40	2.25	2.06	1.34	0.78	0.30	0.20
Exported for non EPB uses	kWh/m ²	8.71	0.17	0.38	0.54	1.05	1.17	1.26	1.20	1.11	0.85	0.55	0.25	0.18
Grid exported	kWh/m ²	6.27	0.03	0.12	0.20	0.90	1.12	1.14	1.05	0.95	0.48	0.23	0.05	0.01
Grid delivered, (EPB uses)	kWh/m ²	15.93	2.35	1.72	1.36	1.05	0.72	0.69	0.73	0.78	1.01	1.44	1.76	2.30
Total greenhouse gas emissions	kg CO ₂ eq/m ²	0.34	0.77	0.44	0.22	-0.32	-0.56	-0.61	-0.54	-0.45	-0.12	0.24	0.52	0.75

Cl1

SYN.IKIA FINAL DESIGN. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m²	23.14	3.04	2.77	2.04	1.64	1.29	1.34	1.39	1.33	1.30	1.66	2.37	2.97
non EPB uses	kWh/m²	48.62	4.01	4.08	4.04	4.04	4.08	4.02	4.09	4.01	4.06	4.07	4.03	4.09
EPB used electricity	kWh/m²	7.84	0.36	0.48	0.70	0.92	0.84	0.88	0.88	0.76	0.69	0.65	0.40	0.28
Energy produced on-site	kWh/m²	23.29	0.87	1.72	3.01	3.08	3.38	3.24	2.68	2.14	1.51	0.71	0.44	0.51
Environmental energy	kWh/m²	47.87	8.86	7.49	4.11	2.04	1.82	1.82	1.88	1.82	1.89	2.11	5.61	8.42
Exported electricity	kWh/m²	15.45	0.51	1.25	2.31	2.16	2.53	2.37	1.80	1.38	0.82	0.06	0.03	0.23
Exported for non EPB uses	kWh/m²	9.85	0.20	0.33	0.79	1.24	1.34	1.36	1.33	1.15	1.04	0.66	0.26	0.14
Grid exported	kWh/m²	5.61	0.31	0.92	1.53	0.92	1.19	1.00	0.47	0.23	-0.22	-0.60	-0.23	0.09
Grid delivered, (EPB uses)	kWh/m²	15.31	2.68	2.29	1.34	0.72	0.45	0.46	0.51	0.57	0.61	1.02	1.96	2.69
Total greenhouse gas emissions	kg CO2eq/m²	-0.05	0.77	0.37	-0.35	-0.52	-0.74	-0.68	-0.46	-0.29	-0.07	0.34	0.69	0.88

Cl2

SYN.IKIA FINAL DESIGN. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	23.48	3.11	2.91	2.11	1.63	1.30	1.32	1.40	1.34	1.30	1.66	2.39	3.01
non EPB uses	kWh/m ²	48.62	4.01	4.08	4.04	4.04	4.08	4.02	4.09	4.01	4.06	4.07	4.03	4.09
EPB used electricity	kWh/m ²	7.80	0.36	0.48	0.66	0.93	0.84	0.86	0.91	0.78	0.68	0.62	0.42	0.26
Energy produced on-site	kWh/m ²	23.66	0.57	0.92	1.60	3.14	3.22	3.36	3.30	2.70	2.29	1.45	0.75	0.37
Environmental energy	kWh/m ²	49.55	9.19	8.15	4.42	2.05	1.83	1.82	1.88	1.82	1.88	2.17	5.74	8.62
Exported electricity	kWh/m ²	15.86	0.22	0.44	0.94	2.21	2.38	2.49	2.39	1.92	1.61	0.83	0.33	0.11
Exported for non EPB uses	kWh/m ²	9.95	0.20	0.36	0.71	1.28	1.35	1.36	1.39	1.20	1.08	0.62	0.29	0.11
Grid exported	kWh/m ²	5.92	0.02	0.08	0.22	0.93	1.04	1.13	1.00	0.72	0.53	0.21	0.04	0.00
Grid delivered, (EPB uses)	kWh/m ²	15.68	2.76	2.43	1.45	0.70	0.46	0.46	0.48	0.56	0.62	1.04	1.97	2.75
Total greenhouse gas emissions	kg CO2eq/m ²	-0.07	0.91	0.71	0.18	-0.54	-0.69	-0.73	-0.68	-0.48	-0.35	0.08	0.59	0.94

Ub1

SYN.IKIA FINAL DESIGN. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	27.93	4.34	3.50	2.78	1.83	1.23	1.28	1.32	1.30	1.24	1.90	3.15	4.08
non EPB uses	kWh/m ²	48.62	4.01	4.08	4.04	4.04	4.08	4.02	4.09	4.01	4.06	4.07	4.03	4.09
EPB used electricity	kWh/m ²	7.77	0.45	0.58	0.66	0.85	0.81	0.87	0.88	0.82	0.58	0.57	0.38	0.33
Energy produced on-site	kWh/m ²	24.45	0.59	1.07	1.47	3.06	3.37	3.55	3.40	3.12	2.14	1.47	0.70	0.51
Environmental energy	kWh/m ²	72.20	14.94	10.90	7.59	3.13	1.85	1.83	1.88	1.83	1.90	3.41	9.29	13.66
Exported electricity	kWh/m ²	16.69	0.14	0.49	0.81	2.21	2.56	2.69	2.52	2.30	1.56	0.90	0.32	0.18
Exported for non EPB uses	kWh/m ²	9.30	0.12	0.36	0.56	1.15	1.27	1.35	1.30	1.20	0.96	0.61	0.26	0.16
Grid exported	kWh/m ²	7.39	0.02	0.13	0.25	1.06	1.29	1.33	1.23	1.11	0.60	0.29	0.06	0.02
Grid delivered, (EPB uses)	kWh/m ²	20.17	3.88	2.92	2.12	0.98	0.42	0.42	0.45	0.47	0.66	1.33	2.77	3.75
Total greenhouse gas emissions	kg CO2eq/m ²	1.24	1.34	0.87	0.47	-0.44	-0.76	-0.81	-0.74	-0.65	-0.32	0.15	0.87	1.28

Ub2

SYN.IKIA FINAL DESIGN. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	22.76	3.20	2.53	1.96	1.61	1.28	1.33	1.36	1.34	1.29	1.60	2.26	3.01
non EPB uses	kWh/m ²	48.62	4.01	4.08	4.04	4.04	4.08	4.02	4.09	4.01	4.06	4.07	4.03	4.09
EPB used electricity	kWh/m ²	7.57	0.37	0.50	0.61	0.86	0.83	0.89	0.89	0.83	0.60	0.56	0.35	0.28
Energy produced on-site	kWh/m ²	24.45	0.59	1.07	1.47	3.06	3.37	3.55	3.40	3.12	2.14	1.47	0.70	0.51
Environmental energy	kWh/m ²	46.49	9.62	6.36	3.72	1.91	1.82	1.82	1.88	1.82	1.88	1.90	5.11	8.63
Exported electricity	kWh/m ²	16.88	0.22	0.57	0.86	2.20	2.53	2.66	2.51	2.29	1.53	0.92	0.35	0.23
Exported for non EPB uses	kWh/m ²	9.53	0.19	0.42	0.61	1.15	1.26	1.35	1.29	1.19	0.94	0.63	0.29	0.21
Grid exported	kWh/m ²	7.34	0.03	0.14	0.25	1.05	1.27	1.32	1.22	1.10	0.59	0.29	0.06	0.02
Grid delivered, (EPB uses)	kWh/m ²	15.18	2.83	2.03	1.35	0.75	0.45	0.44	0.47	0.50	0.68	1.04	1.91	2.74
Total greenhouse gas emissions	kg CO2eq/m ²	-0.61	0.93	0.52	0.17	-0.52	-0.74	-0.79	-0.73	-0.64	-0.30	0.04	0.56	0.89

Ub3

SYN.IKIA FINAL DESIGN. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	18.56	2.82	2.12	1.53	1.05	1.07	1.13	1.15	1.13	1.06	1.02	1.87	2.61
non EPB uses	kWh/m ²	48.62	4.01	4.08	4.04	4.04	4.08	4.02	4.09	4.01	4.06	4.07	4.03	4.09
EPB used electricity	kWh/m ²	7.07	0.36	0.45	0.53	0.73	0.82	0.86	0.87	0.83	0.59	0.47	0.31	0.26
Energy produced on-site	kWh/m ²	24.45	0.59	1.07	1.47	3.06	3.37	3.55	3.40	3.12	2.14	1.47	0.70	0.51
Environmental energy	kWh/m ²	51.40	10.59	7.24	4.52	2.04	1.83	1.82	1.88	1.82	1.89	2.08	6.10	9.59
Exported electricity	kWh/m ²	17.38	0.24	0.61	0.94	2.33	2.55	2.69	2.53	2.30	1.55	1.01	0.40	0.25
Exported for non EPB uses	kWh/m ²	9.86	0.20	0.45	0.66	1.22	1.27	1.37	1.31	1.20	0.95	0.69	0.32	0.22
Grid exported	kWh/m ²	7.52	0.04	0.16	0.28	1.11	1.27	1.32	1.22	1.10	0.59	0.32	0.07	0.03
Grid delivered, (EPB uses)	kWh/m ²	11.49	2.46	1.66	1.00	0.32	0.26	0.27	0.28	0.30	0.47	0.55	1.57	2.35
Total greenhouse gas emissions	kg CO2eq/m ²	-2.10	0.79	0.37	0.02	-0.72	-0.82	-0.87	-0.80	-0.71	-0.38	-0.16	0.42	0.75

EpC1 (final design similar case 1)

SYN.IKIA FINAL DESIGN. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	23.18	3.31	2.62	2.03	1.61	1.27	1.32	1.35	1.33	1.28	1.60	2.36	3.10
non EPB uses	kWh/m ²	48.62	4.01	4.08	4.04	4.04	4.08	4.02	4.09	4.01	4.06	4.07	4.03	4.09
EPB used electricity	kWh/m ²	7.61	0.39	0.51	0.62	0.86	0.83	0.88	0.89	0.83	0.60	0.55	0.36	0.29
Energy produced on-site	kWh/m ²	24.45	0.59	1.07	1.47	3.06	3.37	3.55	3.40	3.12	2.14	1.47	0.70	0.51
Environmental energy	kWh/m ²	48.74	10.10	6.77	4.07	1.96	1.82	1.82	1.88	1.82	1.89	1.96	5.58	9.07
Exported electricity	kWh/m ²	16.84	0.21	0.55	0.85	2.21	2.54	2.67	2.51	2.29	1.54	0.92	0.34	0.22
Exported for non EPB uses	kWh/m ²	9.49	0.18	0.41	0.60	1.16	1.26	1.35	1.29	1.19	0.95	0.63	0.28	0.19
Grid exported	kWh/m ²	7.36	0.03	0.14	0.25	1.05	1.27	1.32	1.22	1.10	0.59	0.29	0.06	0.02
Grid delivered, (EPB uses)	kWh/m ²	15.58	2.92	2.11	1.41	0.75	0.45	0.44	0.46	0.50	0.68	1.05	2.00	2.82
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-0.45	0.97	0.55	0.20	-0.52	-0.75	-0.80	-0.73	-0.64	-0.31	0.05	0.59	0.93

EpC2

SYN.IKIA FINAL DESIGN. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	23.77	3.41	2.72	2.13	1.63	1.27	1.32	1.35	1.33	1.28	1.66	2.49	3.18
non EPB uses	kWh/m ²	48.62	4.01	4.08	4.04	4.04	4.08	4.02	4.09	4.01	4.06	4.07	4.03	4.09
EPB used electricity	kWh/m ²	8.22	0.49	0.67	0.74	0.88	0.83	0.88	0.89	0.83	0.60	0.57	0.44	0.39
Energy produced on-site	kWh/m ²	24.45	0.59	1.07	1.47	3.06	3.37	3.55	3.40	3.12	2.14	1.47	0.70	0.51
Environmental energy	kWh/m ²	51.49	10.59	7.25	4.53	2.06	1.82	1.82	1.88	1.82	1.89	2.22	6.20	9.43
Exported electricity	kWh/m ²	16.24	0.10	0.39	0.73	2.19	2.54	2.67	2.51	2.29	1.54	0.90	0.26	0.11
Exported for non EPB uses	kWh/m ²	8.98	0.09	0.28	0.49	1.14	1.26	1.35	1.29	1.19	0.95	0.61	0.21	0.10
Grid exported	kWh/m ²	7.26	0.02	0.11	0.24	1.05	1.27	1.32	1.22	1.10	0.59	0.29	0.05	0.01
Grid delivered, (EPB uses)	kWh/m ²	15.56	2.92	2.05	1.39	0.76	0.44	0.44	0.46	0.50	0.68	1.09	2.05	2.79
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-0.24	1.01	0.59	0.24	-0.51	-0.75	-0.80	-0.73	-0.64	-0.31	0.07	0.64	0.95

EpC3

SYN.IKIA FINAL DESIGN. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	23.36	3.33	2.65	2.07	1.62	1.27	1.32	1.35	1.33	1.28	1.62	2.39	3.13
non EPB uses	kWh/m ²	48.62	4.01	4.09	4.02	4.08	4.05	4.04	4.08	4.00	4.09	4.03	4.05	4.07
EPB used electricity	kWh/m ²	7.57	0.36	0.50	0.61	0.86	0.84	0.89	0.89	0.83	0.61	0.56	0.35	0.28
Energy produced on-site	kWh/m ²	24.45	0.59	1.07	1.47	3.06	3.37	3.55	3.40	3.12	2.14	1.47	0.70	0.51
Environmental energy	kWh/m ²	49.58	10.20	6.91	4.26	2.02	1.82	1.82	1.88	1.82	1.88	2.03	5.74	9.21
Exported electricity	kWh/m ²	16.89	0.23	0.57	0.86	2.20	2.53	2.67	2.51	2.29	1.53	0.91	0.35	0.23
Exported for non EPB uses	kWh/m ²	12.54	0.23	0.52	0.75	1.54	1.75	1.83	1.76	1.62	1.20	0.78	0.33	0.23
Grid exported	kWh/m ²	4.35	0.01	0.05	0.11	0.66	0.78	0.84	0.74	0.67	0.33	0.14	0.02	0.00
Grid delivered, (EPB uses)	kWh/m ²	15.80	2.97	2.15	1.46	0.76	0.44	0.43	0.46	0.49	0.67	1.06	2.04	2.86
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-0.39	0.98	0.57	0.22	-0.51	-0.75	-0.80	-0.73	-0.64	-0.31	0.05	0.60	0.94

Pessimistic scenario

SYN.IKIA BASE CASE. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	27.93	4.36	3.47	2.80	1.80	1.23	1.31	1.30	1.32	1.21	1.91	3.14	4.08
non EPB uses	kWh/m ²	48.62	4.01	4.08	4.04	4.04	4.08	4.02	4.09	4.01	4.06	4.07	4.03	4.09
EPB used electricity	kWh/m ²	3.38	0.36	0.37	0.34	0.32	0.24	0.31	0.30	0.26	0.17	0.25	0.24	0.24
Energy produced on-site	kWh/m ²	24.45	0.59	1.07	1.47	3.06	3.37	3.55	3.40	3.12	2.14	1.47	0.70	0.51
Environmental energy	kWh/m ²	72.20	15.00	10.84	7.65	3.07	1.85	1.89	1.82	1.89	1.84	3.44	9.26	13.66
Exported electricity	kWh/m ²	21.07	0.23	0.70	1.13	2.75	3.13	3.24	3.10	2.87	1.96	1.23	0.46	0.27
Exported for non EPB uses	kWh/m ²	11.49	0.21	0.51	0.78	1.36	1.47	1.52	1.51	1.45	1.20	0.84	0.39	0.24
Grid exported	kWh/m ²	9.58	0.02	0.19	0.35	1.38	1.66	1.72	1.60	1.42	0.76	0.39	0.08	0.02
Grid delivered, (EPB uses)	kWh/m ²	24.55	4.00	3.10	2.47	1.49	0.99	1.00	1.01	1.06	1.04	1.67	2.90	3.84
Total greenhouse gas emissions	kg CO ₂ eq/m ²	1.24	1.34	0.86	0.48	-0.45	-0.76	-0.80	-0.75	-0.64	-0.33	0.16	0.87	1.28

Optimistic scenario

SYN.IKIA BASE CASE. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	18.76	2.84	2.15	1.58	1.08	1.07	1.12	1.15	1.13	1.06	1.05	1.91	2.63
non EPB uses	kWh/m ²	48.62	4.01	4.09	4.02	4.08	4.05	4.04	4.08	4.00	4.09	4.03	4.05	4.07
EPB used electricity	kWh/m ²	6.97	0.32	0.42	0.51	0.73	0.82	0.86	0.88	0.83	0.60	0.47	0.29	0.24
Energy produced on-site	kWh/m ²	24.45	0.59	1.07	1.47	3.06	3.37	3.55	3.40	3.12	2.14	1.47	0.70	0.51
Environmental energy	kWh/m ²	52.36	10.67	7.40	4.75	2.14	1.82	1.82	1.88	1.82	1.89	2.21	6.28	9.70
Exported electricity	kWh/m ²	17.48	0.28	0.64	0.96	2.33	2.54	2.69	2.52	2.30	1.54	1.01	0.41	0.27
Exported for non EPB uses	kWh/m ²	13.05	0.27	0.58	0.83	1.63	1.76	1.85	1.78	1.63	1.21	0.85	0.39	0.26
Grid exported	kWh/m ²	4.43	0.01	0.06	0.13	0.70	0.78	0.84	0.74	0.67	0.33	0.15	0.02	0.01
Grid delivered, (EPB uses)	kWh/m ²	11.79	2.52	1.73	1.07	0.34	0.25	0.26	0.28	0.30	0.46	0.58	1.62	2.39
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-2.03	0.80	0.39	0.04	-0.71	-0.82	-0.87	-0.80	-0.71	-0.38	-0.15	0.43	0.76

Continental climate

Scenario1 POS1- Stricter U-values and infiltration rates with manually controlled internal shading

SYN.IKIA BASE CASE. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	27,55	2,10	1,89	2,07	1,97	2,20	2,59	3,09	2,95	2,00	2,03	2,57	2,08
non EPB uses	kWh/m ²	15,35	1,30	1,18	1,30	1,26	1,30	1,26	1,30	1,30	1,26	1,30	1,26	1,30
EPB used electricity	kWh/m ²	12,15	0,52	0,66	1,05	1,10	1,31	1,45	1,66	1,52	1,03	0,82	0,57	0,45
Energy produced on-site	kWh/m ²	30,35	0,77	1,21	2,41	3,31	4,35	4,35	4,61	3,76	2,55	1,61	0,79	0,62
Environmental energy	kWh/m ²	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Exported electricity	kWh/m ²	18,20	0,25	0,55	1,36	2,21	3,04	2,90	2,95	2,24	1,52	0,78	0,22	0,17
Exported for non EPB uses	kWh/m ²	7,35	0,17	0,42	0,58	1,05	0,89	1,06	0,97	0,93	0,78	0,28	0,13	0,09
Grid exported	kWh/m ²	10,85	0,08	0,13	0,78	1,15	2,15	1,84	1,98	1,31	0,74	0,51	0,09	0,08
Grid delivered, (EPB uses)	kWh/m ²	15,40	1,57	1,23	1,03	0,86	0,88	1,14	1,43	1,43	0,97	1,20	2,01	1,64
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-1,00	0,47	0,24	-0,12	-0,48	-0,77	-0,63	-0,54	-0,29	-0,20	0,15	0,64	0,52

Scenario2 POS2 – Best practice U values and infiltration rates with manually controlled internal shading.

SYN.IKIA BASE CASE. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	27,12	2,07	1,86	2,05	1,97	2,39	2,61	3,06	3,01	2,03	2,02	1,99	2,06
non EPB uses	kWh/m ²	15,35	1,31	1,18	1,30	1,26	1,30	1,26	1,30	1,30	1,26	1,30	1,26	1,31
EPB used electricity	kWh/m ²	12,19	0,52	0,66	1,04	1,10	1,38	1,46	1,65	1,54	1,04	0,82	0,52	0,45
Energy produced on-site	kWh/m ²	30,35	0,77	1,21	2,41	3,31	4,35	4,35	4,61	3,76	2,55	1,61	0,79	0,62
Environmental energy	kWh/m ²	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Exported electricity	kWh/m ²	18,16	0,25	0,56	1,37	2,21	2,97	2,89	2,96	2,22	1,51	0,78	0,27	0,17
Exported for non EPB uses	kWh/m ²	7,43	0,17	0,42	0,59	1,06	0,94	1,07	0,97	0,91	0,77	0,28	0,18	0,09
Grid exported	kWh/m ²	10,73	0,08	0,13	0,78	1,15	2,03	1,83	1,99	1,31	0,74	0,51	0,09	0,08
Grid delivered, (EPB uses)	kWh/m ²	14,94	1,55	1,20	1,01	0,87	1,01	1,15	1,41	1,47	0,99	1,19	1,47	1,62
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-1,15	0,46	0,23	-0,13	-0,48	-0,70	-0,62	-0,55	-0,27	-0,19	0,15	0,43	0,52

Scenario3 POS1HO1- Stricter U values and infiltration rates with manually controlled internal shading. heat pumps and floor heating and cooling.

SYN.IKIA Stricter U values and infiltration rates, shading and heat pumps with floor heating and cooling. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	18,63	2,09	1,69	1,51	1,13	1,25	1,47	1,87	1,78	1,14	1,12	1,57	1,99
non EPB uses	kWh/m ²	15,35	1,30	1,18	1,31	1,26	1,30	1,26	1,30	1,30	1,26	1,30	1,26	1,30
EPB used electricity	kWh/m ²	9,26	0,52	0,64	0,83	0,79	0,92	1,03	1,22	1,09	0,72	0,60	0,47	0,44
Energy produced on-site	kWh/m ²	30,35	0,77	1,21	2,41	3,31	4,35	4,35	4,61	3,76	2,55	1,61	0,79	0,62
Environmental energy	kWh/m ²	20,96	3,66	2,78	2,13	1,20	0,88	0,85	0,87	0,87	0,86	1,13	2,35	3,39
Exported electricity	kWh/m ²	21,09	0,25	0,58	1,58	2,53	3,43	3,33	3,39	2,67	1,83	1,01	0,32	0,17
Exported for non EPB uses	kWh/m ²	7,09	0,17	0,44	0,80	0,82	0,69	0,76	0,68	0,91	0,99	0,51	0,23	0,10
Grid exported	kWh/m ²	14,00	0,08	0,13	0,78	1,71	2,74	2,57	2,71	1,75	0,85	0,51	0,09	0,08
Grid delivered, (EPB uses)	kWh/m ²	9,37	1,57	1,05	0,68	0,35	0,33	0,45	0,65	0,69	0,43	0,53	1,10	1,55
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-4,18	0,47	0,17	-0,32	-0,78	-1,11	-1,03	-0,98	-0,71	-0,50	-0,17	0,28	0,49

Scenario4 POS2HO1 - Best practice U values and infiltration rates with manually controlled internal shading. heat pumps and floor heating and cooling.

SYN.IKIA Best practice U values and infiltration rates internal shading, heat pumps and floor heating and cooling. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	17,27	1,82	1,47	1,31	1,03	1,29	1,50	1,82	1,74	1,15	1,04	1,37	1,73
non EPB uses	kWh/m ²	15,35	1,31	1,18	1,30	1,26	1,30	1,26	1,30	1,30	1,26	1,30	1,26	1,31
EPB used electricity	kWh/m ²	9,02	0,49	0,62	0,76	0,74	0,94	1,04	1,20	1,08	0,72	0,57	0,45	0,42
Energy produced on-site	kWh/m ²	30,35	0,77	1,21	2,41	3,31	4,35	4,35	4,61	3,76	2,55	1,61	0,79	0,62
Environmental energy	kWh/m ²	17,48	2,94	2,20	1,61	0,94	0,88	0,85	0,87	0,87	0,85	0,93	1,81	2,72
Exported electricity	kWh/m ²	21,33	0,28	0,60	1,65	2,58	3,41	3,31	3,41	2,68	1,83	1,04	0,34	0,20
Exported for non EPB uses	kWh/m ²	7,25	0,20	0,46	0,87	0,79	0,69	0,76	0,67	0,90	0,99	0,54	0,25	0,12
Grid exported	kWh/m ²	14,09	0,08	0,13	0,78	1,78	2,72	2,55	2,74	1,78	0,84	0,51	0,09	0,08
Grid delivered, (EPB uses)	kWh/m ²	8,25	1,32	0,85	0,55	0,29	0,35	0,46	0,62	0,66	0,43	0,48	0,92	1,31
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-4,67	0,37	0,09	-0,39	-0,82	-1,09	-1,02	-1,00	-0,72	-0,50	-0,20	0,21	0,40

Scenario5 POS1HOVAC1- Stricter U values and infiltration rates with manually controlled internal shading. heat pumps and floor heating and cooling with heat recovery ventilation and automatic control.

SYN.IKIA Stricter U values and infiltration rates with internal shading, heat pumps and floor heating and cooling with heat recovery ventilation and automatic control. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	17,79	2,05	1,66	1,49	1,13	1,16	1,39	1,62	1,55	1,12	1,12	1,55	1,95
non EPB uses	kWh/m ²	15,35	1,30	1,18	1,31	1,26	1,30	1,26	1,30	1,30	1,26	1,30	1,26	1,30
EPB used electricity	kWh/m ²	8,95	0,52	0,64	0,82	0,78	0,87	0,99	1,11	1,01	0,71	0,59	0,47	0,44
Energy produced on-site	kWh/m ²	30,35	0,77	1,21	2,41	3,31	4,35	4,35	4,61	3,76	2,55	1,61	0,79	0,62
Environmental energy	kWh/m ²	20,52	3,56	2,70	2,07	1,18	0,88	0,85	0,87	0,87	0,86	1,12	2,28	3,30
Exported electricity	kWh/m ²	21,40	0,26	0,58	1,59	2,53	3,48	3,36	3,50	2,75	1,84	1,01	0,32	0,18
Exported for non EPB uses	kWh/m ²	6,97	0,17	0,44	0,80	0,81	0,68	0,74	0,64	0,85	0,98	0,51	0,23	0,10
Grid exported	kWh/m ²	14,43	0,08	0,13	0,78	1,72	2,80	2,62	2,86	1,90	0,86	0,51	0,09	0,08
Grid delivered, (EPB uses)	kWh/m ²	8,84	1,53	1,02	0,67	0,34	0,29	0,41	0,51	0,55	0,41	0,52	1,08	1,51
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-4,48	0,46	0,16	-0,33	-0,78	-1,14	-1,06	-1,07	-0,79	-0,51	-0,17	0,27	0,48

Scenario6 POS2HOVAC1 – Best practice U values and infiltration rates with manually controlled internal shading. heat pumps and floor heating and cooling with heat recovery ventilation and automatic control.

SYN.IKIA Best practice U values and infiltration rates with internal shading, heat pumps and floor heating and cooling with heat recovery ventilation and automatic control. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	16,56	1,77	1,43	1,29	1,02	1,17	1,42	1,66	1,60	1,12	1,04	1,34	1,69
non EPB uses	kWh/m ²	15,35	1,31	1,18	1,30	1,26	1,30	1,26	1,30	1,30	1,26	1,30	1,26	1,31
EPB used electricity	kWh/m ²	8,76	0,49	0,62	0,75	0,74	0,88	1,00	1,13	1,02	0,71	0,56	0,44	0,42
Energy produced on-site	kWh/m ²	30,35	0,77	1,21	2,41	3,31	4,35	4,35	4,61	3,76	2,55	1,61	0,79	0,62
Environmental energy	kWh/m ²	17,01	2,82	2,11	1,56	0,93	0,88	0,85	0,87	0,87	0,85	0,92	1,75	2,61
Exported electricity	kWh/m ²	21,59	0,28	0,60	1,66	2,58	3,47	3,35	3,48	2,74	1,84	1,04	0,34	0,20
Exported for non EPB uses	kWh/m ²	7,16	0,20	0,46	0,87	0,79	0,68	0,75	0,64	0,87	0,98	0,54	0,26	0,12
Grid exported	kWh/m ²	14,43	0,08	0,13	0,78	1,79	2,79	2,61	2,84	1,87	0,86	0,51	0,09	0,08
Grid delivered, (EPB uses)	kWh/m ²	7,80	1,28	0,82	0,54	0,29	0,29	0,42	0,53	0,57	0,41	0,47	0,90	1,27
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-4,92	0,36	0,08	-0,40	-0,82	-1,13	-1,05	-1,06	-0,77	-0,51	-0,20	0,20	0,38

Scenario7 POS1R1- Stricter U-values and infiltration rates with manually controlled internal shading

SYN.IKIA Stricter U values and infiltration rates with internal shading. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	27,55	2,10	1,89	2,07	1,97	2,20	2,59	3,09	2,95	2,00	2,03	2,57	2,08
non EPB uses	kWh/m ²	15,35	1,30	1,18	1,30	1,26	1,30	1,26	1,30	1,30	1,26	1,30	1,26	1,30
EPB used electricity	kWh/m ²	14,21	0,98	0,95	1,13	1,17	1,36	1,50	1,71	1,57	1,11	1,04	0,89	0,80
Energy produced on-site	kWh/m ²	38,85	1,96	2,18	3,19	3,85	4,78	4,70	5,00	4,26	3,24	2,54	1,62	1,53
Environmental energy	kWh/m ²	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Exported electricity	kWh/m ²	24,64	0,98	1,23	2,06	2,68	3,42	3,20	3,29	2,69	2,13	1,50	0,73	0,73
Exported for non EPB uses	kWh/m ²	10,73	0,77	0,99	1,03	0,99	0,84	1,02	0,93	1,20	1,19	0,70	0,55	0,54
Grid exported	kWh/m ²	13,92	0,21	0,24	1,04	1,69	2,58	2,19	2,36	1,49	0,94	0,80	0,18	0,19
Grid delivered, (EPB uses)	kWh/m ²	13,34	1,11	0,93	0,95	0,80	0,83	1,10	1,38	1,38	0,90	0,99	1,68	1,28
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-4,03	0,05	-0,10	-0,40	-0,67	-0,92	-0,75	-0,68	-0,47	-0,44	-0,18	0,34	0,20

Scenario8 POS2R1 – Best practice U values and infiltration rates with manually controlled internal shading.

SYN.IKIA Best practice U values and infiltration rates with manually controlled internal shading. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	27,12	2,07	1,86	2,05	1,97	2,39	2,61	3,06	3,01	2,03	2,02	1,99	2,06
non EPB uses	kWh/m ²	15,35	1,31	1,18	1,30	1,26	1,30	1,26	1,30	1,30	1,26	1,30	1,26	1,31
EPB used electricity	kWh/m ²	14,22	0,98	0,94	1,12	1,17	1,43	1,50	1,70	1,59	1,12	1,03	0,83	0,80
Energy produced on-site	kWh/m ²	38,85	1,96	2,18	3,19	3,85	4,78	4,70	5,00	4,26	3,24	2,54	1,62	1,53
Environmental energy	kWh/m ²	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Exported electricity	kWh/m ²	24,63	0,98	1,24	2,07	2,68	3,35	3,20	3,30	2,67	2,12	1,51	0,79	0,73
Exported for non EPB uses	kWh/m ²	10,84	0,77	1,00	1,03	0,99	0,89	1,02	0,92	1,18	1,18	0,71	0,61	0,54
Grid exported	kWh/m ²	13,79	0,21	0,24	1,04	1,69	2,46	2,17	2,38	1,49	0,94	0,80	0,18	0,19
Grid delivered, (EPB uses)	kWh/m ²	12,91	1,08	0,92	0,93	0,80	0,96	1,11	1,37	1,42	0,91	0,98	1,16	1,27
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-4,19	0,04	-0,11	-0,41	-0,67	-0,85	-0,75	-0,69	-0,45	-0,43	-0,19	0,13	0,19

Scenario9 POS1HO1R1- Stricter U values and infiltration rates with manually controlled internal shading. heat pumps and floor heating and cooling. PV on walls and roof.

SYN.IKIA Stricter U values and infiltration rates with manually controlled internal shading, heat pumps and floor heating and cooling, PV on walls and roof.														
ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	22,24	2,09	1,69	1,51	1,13	1,58	2,08	3,22	2,96	1,29	1,12	1,57	1,99
non EPB uses	kWh/m ²	15,35	1,30	1,18	1,31	1,26	1,30	1,26	1,30	1,30	1,26	1,30	1,26	1,30
EPB used electricity	kWh/m ²	12,49	0,98	0,87	0,93	0,83	1,11	1,31	1,76	1,57	0,85	0,71	0,79	0,79
Energy produced on-site	kWh/m ²	38,85	1,96	2,18	3,19	3,85	4,78	4,70	5,00	4,26	3,24	2,54	1,62	1,53
Environmental energy	kWh/m ²	20,96	3,66	2,78	2,13	1,20	0,88	0,85	0,87	0,87	0,86	1,13	2,35	3,39
Exported electricity	kWh/m ²	26,36	0,98	1,31	2,26	3,02	3,67	3,39	3,24	2,69	2,39	1,83	0,83	0,74
Exported for non EPB uses	kWh/m ²	10,44	0,77	1,07	0,98	0,78	0,70	0,87	0,96	1,20	0,96	0,96	0,65	0,55
Grid exported	kWh/m ²	15,93	0,21	0,24	1,29	2,25	2,97	2,52	2,29	1,49	1,43	0,88	0,18	0,19
Grid delivered, (EPB uses)	kWh/m ²	9,76	1,11	0,82	0,59	0,31	0,47	0,77	1,47	1,39	0,44	0,41	0,79	1,20
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-5,93	0,05	-0,18	-0,60	-0,97	-1,14	-0,93	-0,63	-0,46	-0,70	-0,51	-0,02	0,16

Scenario10 POS2HO1R1 - Best practice U values and infiltration rates with manually controlled internal shading. heat pumps and floor heating and cooling PV on walls and roof.

SYN.IKIA Best practice U values and infiltration rates with manually controlled internal shading, heat pumps and floor heating and cooling PV on walls and roof.														
ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	20,74	1,82	1,47	1,31	1,03	1,71	2,17	2,99	2,78	1,31	1,04	1,37	1,73
non EPB uses	kWh/m ²	15,35	1,31	1,18	1,30	1,26	1,30	1,26	1,30	1,30	1,26	1,30	1,26	1,31
EPB used electricity	kWh/m ²	12,01	0,91	0,79	0,85	0,77	1,17	1,34	1,67	1,51	0,86	0,68	0,69	0,77
Energy produced on-site	kWh/m ²	38,85	1,96	2,18	3,19	3,85	4,78	4,70	5,00	4,26	3,24	2,54	1,62	1,53
Environmental energy	kWh/m ²	17,48	2,94	2,20	1,61	0,94	0,88	0,85	0,87	0,87	0,85	0,93	1,81	2,72
Exported electricity	kWh/m ²	26,84	1,05	1,39	2,34	3,08	3,61	3,36	3,33	2,75	2,38	1,86	0,93	0,76
Exported for non EPB uses	kWh/m ²	10,55	0,84	1,15	0,92	0,76	0,73	0,89	0,90	1,15	0,97	0,93	0,74	0,57
Grid exported	kWh/m ²	16,29	0,21	0,24	1,42	2,32	2,88	2,46	2,42	1,60	1,42	0,93	0,18	0,19
Grid delivered, (EPB uses)	kWh/m ²	8,72	0,91	0,68	0,46	0,26	0,54	0,82	1,32	1,27	0,46	0,37	0,67	0,96
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-6,47	-0,05	-0,25	-0,67	-1,01	-1,10	-0,90	-0,72	-0,53	-0,69	-0,54	-0,09	0,07

Scenario11 POS1HOVAC1R1- Stricter U values and infiltration rates with manually controlled internal shading. heat pumps and floor heating and cooling with heat recovery ventilation and automatic control PV on walls and roof.

SYN.IKIA Stricter U values and infiltration rates with manually controlled internal shading, heat pumps and floor heating and cooling with heat recovery ventilation and automatic control PV on walls and roof.														
ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	20,08	2,05	1,66	1,49	1,13	1,24	1,91	2,46	2,28	1,24	1,12	1,55	1,95
non EPB uses	kWh/m ²	15,35	1,30	1,18	1,31	1,26	1,30	1,26	1,30	1,30	1,26	1,30	1,26	1,30
EPB used electricity	kWh/m ²	11,68	0,98	0,86	0,92	0,82	0,94	1,24	1,49	1,33	0,82	0,71	0,77	0,79
Energy produced on-site	kWh/m ²	38,85	1,96	2,18	3,19	3,85	4,78	4,70	5,00	4,26	3,24	2,54	1,62	1,53
Environmental energy	kWh/m ²	20,52	3,56	2,70	2,07	1,18	0,88	0,85	0,87	0,87	0,86	1,12	2,28	3,30
Exported electricity	kWh/m ²	27,17	0,98	1,32	2,27	3,03	3,84	3,46	3,51	2,93	2,42	1,83	0,85	0,74
Exported for non EPB uses	kWh/m ²	9,97	0,77	1,08	0,97	0,77	0,66	0,83	0,77	1,00	0,95	0,95	0,66	0,55
Grid exported	kWh/m ²	17,21	0,21	0,24	1,30	2,25	3,18	2,63	2,74	1,93	1,47	0,88	0,18	0,19
Grid delivered, (EPB uses)	kWh/m ²	8,40	1,07	0,80	0,57	0,30	0,30	0,67	0,98	0,95	0,41	0,41	0,77	1,17
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-6,70	0,03	-0,19	-0,61	-0,97	-1,26	-1,00	-0,91	-0,71	-0,72	-0,51	-0,03	0,15

Scenario12 POS2HOVAC1R1 – Best practice U values and infiltration rates with manually controlled internal shading. heat pumps and floor heating and cooling with heat recovery ventilation and automatic control PV on walls and roof.

SYN.IKIA Best practice U values and infiltration rates with internal shading, heat pumps and floor heating and cooling with heat recovery ventilation and automatic control PV on walls and roof														
ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	19,18	1,77	1,43	1,29	1,02	1,28	2,00	2,60	2,44	1,26	1,04	1,34	1,69
non EPB uses	kWh/m ²	15,35	1,31	1,18	1,30	1,26	1,30	1,26	1,30	1,30	1,26	1,30	1,26	1,31
EPB used electricity	kWh/m ²	11,40	0,89	0,78	0,84	0,77	0,96	1,28	1,54	1,39	0,83	0,67	0,68	0,77
Energy produced on-site	kWh/m ²	38,85	1,96	2,18	3,19	3,85	4,78	4,70	5,00	4,26	3,24	2,54	1,62	1,53
Environmental energy	kWh/m ²	17,01	2,82	2,11	1,56	0,93	0,88	0,85	0,87	0,87	0,85	0,92	1,75	2,61
Exported electricity	kWh/m ²	27,45	1,07	1,40	2,35	3,08	3,82	3,42	3,46	2,87	2,41	1,87	0,94	0,76
Exported for non EPB uses	kWh/m ²	10,27	0,86	1,16	0,91	0,76	0,66	0,85	0,80	1,05	0,95	0,93	0,75	0,57
Grid exported	kWh/m ²	17,18	0,21	0,24	1,44	2,32	3,15	2,57	2,66	1,83	1,45	0,94	0,18	0,19
Grid delivered, (EPB uses)	kWh/m ²	7,77	0,88	0,66	0,45	0,25	0,32	0,72	1,07	1,05	0,43	0,36	0,66	0,92
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-7,02	-0,07	-0,27	-0,68	-1,01	-1,25	-0,96	-0,86	-0,65	-0,71	-0,54	-0,10	0,06

CL1 Energy performance of the proposed design case with climate data of 2050 B1

SYN.IKIA proposed design 2050_B1. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	21,00	1,70	1,39	1,25	0,99	1,46	2,25	3,40	3,07	1,56	1,01	1,28	1,63
non EPB uses	kWh/m ²	15,35	1,31	1,18	1,30	1,26	1,30	1,26	1,30	1,30	1,26	1,30	1,26	1,31
EPB used electricity	kWh/m ²	11,68	0,80	0,73	0,77	0,73	1,02	1,33	1,78	1,58	0,93	0,66	0,65	0,70
Energy produced on-site	kWh/m ²	35,43	1,59	1,94	2,69	3,41	4,38	4,31	4,65	3,99	3,08	2,48	1,52	1,38
Environmental energy	kWh/m ²	16,12	2,66	2,01	1,46	0,86	0,87	0,83	0,85	0,85	0,82	0,87	1,59	2,46
Exported electricity	kWh/m ²	23,75	0,80	1,21	1,92	2,69	3,35	2,99	2,87	2,40	2,15	1,82	0,87	0,68
Exported for non EPB uses	kWh/m ²	10,25	0,63	0,99	0,95	0,78	0,72	0,96	1,01	1,01	1,07	0,93	0,70	0,51
Grid exported	kWh/m ²	13,49	0,17	0,21	0,97	1,91	2,64	2,02	1,86	1,39	1,08	0,89	0,17	0,17
Grid delivered, (EPB uses)	kWh/m ²	9,31	0,91	0,66	0,48	0,27	0,44	0,92	1,62	1,48	0,63	0,35	0,63	0,93
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-5,15	0,04	-0,20	-0,51	-0,86	-1,04	-0,74	-0,45	-0,33	-0,54	-0,53	-0,08	0,09

CL2 Energy performance of the proposed design case with climate data of 2050 A2

SYN.IKIA proposed design 2050A2. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	21,60	1,69	1,37	1,24	0,98	1,53	2,35	3,50	3,31	1,72	1,00	1,26	1,64
non EPB uses	kWh/m ²	15,35	1,31	1,18	1,30	1,26	1,30	1,26	1,30	1,30	1,26	1,30	1,26	1,31
EPB used electricity	kWh/m ²	12,16	0,85	0,72	0,79	0,73	1,07	1,40	1,85	1,70	1,01	0,65	0,64	0,74
Energy produced on-site	kWh/m ²	37,17	1,70	1,92	2,83	3,60	4,56	4,63	4,91	4,23	3,29	2,47	1,54	1,48
Environmental energy	kWh/m ²	15,94	2,64	1,97	1,46	0,84	0,85	0,82	0,84	0,84	0,81	0,85	1,54	2,49
Exported electricity	kWh/m ²	25,01	0,85	1,20	2,04	2,87	3,49	3,23	3,07	2,53	2,28	1,82	0,90	0,74
Exported for non EPB uses	kWh/m ²	10,41	0,67	0,99	0,93	0,77	0,71	0,95	1,03	1,05	1,10	0,93	0,72	0,55
Grid exported	kWh/m ²	14,60	0,18	0,21	1,11	2,11	2,77	2,28	2,03	1,48	1,18	0,89	0,17	0,19
Grid delivered, (EPB uses)	kWh/m ²	9,44	0,85	0,65	0,46	0,25	0,46	0,95	1,66	1,61	0,70	0,35	0,62	0,89
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-5,56	0,00	-0,20	-0,57	-0,94	-1,08	-0,82	-0,50	-0,33	-0,56	-0,52	-0,10	0,06

Ub1 Energy performance of the proposed case under the pandemic or home office scenario

SYN.IKIA Proposed design Pandemic scenario. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	19,85	1,33	1,09	1,22	1,14	1,82	2,53	2,80	2,86	1,50	1,17	1,18	1,20
non EPB uses	kWh/m ²	29,25	2,49	2,23	2,51	2,39	2,49	2,44	2,41	2,47	2,44	2,47	2,43	2,47
EPB used electricity	kWh/m ²	11,73	0,71	0,65	0,81	0,83	1,21	1,48	1,61	1,54	0,93	0,73	0,62	0,62
Energy produced on-site	kWh/m ²	38,85	1,96	2,18	3,19	3,85	4,78	4,70	5,00	4,26	3,24	2,54	1,62	1,53
Environmental energy	kWh/m ²	10,93	1,25	0,87	0,91	0,87	0,88	0,85	0,87	0,87	0,85	0,89	0,88	0,95
Exported electricity	kWh/m ²	27,12	1,25	1,53	2,38	3,02	3,57	3,22	3,39	2,72	2,31	1,81	1,00	0,91
Exported for non EPB uses	kWh/m ²	14,83	1,04	1,28	1,34	1,53	1,50	1,59	1,39	1,24	1,37	1,02	0,82	0,72
Grid exported	kWh/m ²	12,28	0,21	0,24	1,04	1,49	2,07	1,63	2,00	1,49	0,94	0,80	0,18	0,19
Grid delivered, (EPB uses)	kWh/m ²	8,12	0,62	0,44	0,41	0,31	0,60	1,06	1,20	1,32	0,57	0,44	0,56	0,58
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-6,78	-0,22	-0,39	-0,70	-0,97	-1,06	-0,77	-0,78	-0,50	-0,62	-0,49	-0,16	-0,12

Ub2 Scenario where more energy conscious lighting is assumed

SYN.IKIA Proposed scenario with energy conscious lighting. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	17,62	1,55	1,22	1,06	0,77	1,45	1,93	2,69	2,51	1,07	0,77	1,12	1,46
non EPB uses	kWh/m ²	15,35	1,31	1,18	1,30	1,26	1,30	1,26	1,30	1,30	1,26	1,30	1,26	1,31
EPB used electricity	kWh/m ²	10,78	0,80	0,70	0,74	0,62	1,05	1,25	1,57	1,41	0,75	0,56	0,60	0,73
Energy produced on-site	kWh/m ²	38,85	1,96	2,18	3,19	3,85	4,78	4,70	5,00	4,26	3,24	2,54	1,62	1,53
Environmental energy	kWh/m ²	17,48	2,94	2,20	1,61	0,94	0,88	0,85	0,87	0,87	0,85	0,93	1,81	2,72
Exported electricity	kWh/m ²	28,07	1,16	1,48	2,45	3,23	3,73	3,45	3,43	2,85	2,49	1,98	1,02	0,80
Exported for non EPB uses	kWh/m ²	10,40	0,96	1,24	0,85	0,73	0,68	0,83	0,83	1,07	0,90	0,87	0,84	0,61
Grid exported	kWh/m ²	17,66	0,21	0,24	1,59	2,50	3,05	2,62	2,61	1,77	1,58	1,12	0,18	0,19
Grid delivered, (EPB uses)	kWh/m ²	6,84	0,76	0,52	0,32	0,15	0,40	0,68	1,12	1,10	0,32	0,21	0,53	0,73
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-7,58	-0,15	-0,34	-0,76	-1,10	-1,19	-0,99	-0,83	-0,62	-0,77	-0,63	-0,18	-0,02

Ef1 Energy performance of scenario where 1°C higher setback points are assumed.

SYN.IKIA Proposed design with 1°C higher setback points. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	20,56	1,81	1,46	1,31	1,02	1,71	2,25	2,80	2,76	1,34	1,03	1,36	1,72
non EPB uses	kWh/m ²	15,35	1,31	1,18	1,30	1,26	1,30	1,26	1,30	1,30	1,26	1,30	1,26	1,31
EPB used electricity	kWh/m ²	11,95	0,91	0,78	0,85	0,77	1,17	1,37	1,61	1,50	0,87	0,67	0,69	0,77
Energy produced on-site	kWh/m ²	38,85	1,96	2,18	3,19	3,85	4,78	4,70	5,00	4,26	3,24	2,54	1,62	1,53
Environmental energy	kWh/m ²	17,27	2,93	2,18	1,59	0,93	0,87	0,86	0,80	0,85	0,86	0,91	1,79	2,69
Exported electricity	kWh/m ²	26,90	1,05	1,40	2,34	3,08	3,61	3,33	3,39	2,76	2,37	1,87	0,93	0,76
Exported for non EPB uses	kWh/m ²	10,53	0,84	1,15	0,91	0,76	0,73	0,91	0,85	1,14	0,98	0,93	0,75	0,57
Grid exported	kWh/m ²	16,37	0,21	0,24	1,43	2,33	2,89	2,41	2,54	1,62	1,39	0,94	0,18	0,19
Grid delivered, (EPB uses)	kWh/m ²	8,61	0,90	0,67	0,46	0,25	0,54	0,87	1,20	1,26	0,47	0,36	0,67	0,95
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-6,53	-0,05	-0,26	-0,67	-1,01	-1,10	-0,88	-0,78	-0,54	-0,68	-0,54	-0,09	0,07

Energy performance of the pessimistic scenario

SYN.IKIA proposed design worst case scenario. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	19,64	1,32	1,10	1,16	1,06	1,95	2,44	2,68	2,73	1,79	1,09	1,12	1,21
non EPB uses	kWh/m ²	29,25	2,49	2,23	2,51	2,39	2,49	2,44	2,41	2,47	2,44	2,47	2,43	2,47
EPB used electricity	kWh/m ²	11,29	0,67	0,63	0,74	0,76	1,22	1,39	1,52	1,46	1,01	0,69	0,58	0,61
Energy produced on-site	kWh/m ²	35,43	1,59	1,94	2,69	3,41	4,38	4,31	4,65	3,99	3,08	2,48	1,52	1,38
Environmental energy	kWh/m ²	10,18	1,29	0,96	0,81	0,75	0,78	0,75	0,75	0,77	0,75	0,77	0,78	1,03
Exported electricity	kWh/m ²	24,14	0,92	1,31	1,96	2,65	3,15	2,92	3,13	2,53	2,07	1,79	0,93	0,77
Exported for non EPB uses	kWh/m ²	13,35	0,75	1,10	1,08	1,52	1,53	1,42	1,27	1,14	1,17	1,01	0,76	0,60
Grid exported	kWh/m ²	10,79	0,17	0,21	0,88	1,13	1,63	1,50	1,86	1,39	0,90	0,78	0,17	0,17
Grid delivered, (EPB uses)	kWh/m ²	8,35	0,65	0,47	0,42	0,30	0,72	1,04	1,16	1,27	0,78	0,40	0,53	0,60
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-5,64	-0,10	-0,30	-0,55	-0,84	-0,87	-0,67	-0,70	-0,45	-0,46	-0,50	-0,14	-0,06

Energy performance of the optimistic scenario

SYN.IKIA proposed design best case scenario. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	14,21	1,53	1,22	1,08	0,78	0,99	1,28	1,47	1,49	1,01	0,77	1,14	1,44
non EPB uses	kWh/m ²	15,35	1,31	1,18	1,30	1,26	1,30	1,26	1,30	1,30	1,26	1,30	1,26	1,31
EPB used electricity	kWh/m ²	9,20	0,77	0,67	0,72	0,62	0,78	0,95	1,07	1,02	0,72	0,55	0,60	0,72
Energy produced on-site	kWh/m ²	37,17	1,70	1,92	2,83	3,60	4,56	4,63	4,91	4,23	3,29	2,47	1,54	1,48
Environmental energy	kWh/m ²	16,21	2,74	2,09	1,52	0,87	0,81	0,76	0,76	0,78	0,76	0,84	1,72	2,55
Exported electricity	kWh/m ²	27,97	0,93	1,25	2,11	2,99	3,77	3,68	3,85	3,21	2,57	1,92	0,94	0,76
Exported for non EPB uses	kWh/m ²	9,28	0,75	1,04	0,89	0,74	0,66	0,71	0,60	0,80	0,88	0,87	0,77	0,58
Grid exported	kWh/m ²	18,69	0,18	0,21	1,22	2,24	3,11	2,97	3,25	2,41	1,68	1,05	0,17	0,19
Grid delivered, (EPB uses)	kWh/m ²	5,01	0,76	0,55	0,36	0,16	0,21	0,33	0,41	0,47	0,28	0,22	0,55	0,72
Total greenhouse gas emissions	kg CO ₂ eq/m ²	-8,20	-0,06	-0,25	-0,62	-1,01	-1,27	-1,20	-1,23	-0,98	-0,82	-0,61	-0,14	-0,01

Sub-arctic climate

Tm1

		YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EPB uses without lighting	kWh/m ²	69.05	8.46	6.73	6.42	5.05	4.77	4.67	4.70	4.87	4.88	5.35	5.94	7.23
non EPB uses with lighting	kWh/m ²	13.05	1.35	1.14	1.14	0.98	0.88	0.80	0.85	0.95	1.07	1.22	1.30	1.38
EPB used electricity	kWh/m ²	30.81	0.72	1.79	4.47	3.53	3.34	3.27	3.29	3.41	3.41	2.27	0.83	0.48
Energy produced on-site	kWh/m ²	87.48	1.03	2.56	6.39	9.82	14.50	15.40	14.70	10.80	7.17	3.24	1.19	0.68
Environmental energy	kWh/m ²	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Exported electricity	kWh/m ²	56.67	0.31	0.77	1.92	6.29	11.16	12.13	11.41	7.39	3.76	0.97	0.36	0.20
Exported for non EPB uses	kWh/m ²	9.28	0.31	0.77	1.14	0.98	0.88	0.80	0.85	0.95	1.07	0.97	0.36	0.20
Grid exported	kWh/m ²	-47.39	0.00	0.00	-0.78	-5.31	-10.29	-11.33	-10.56	-6.44	-2.69	0.00	0.00	0.00
Grid delivered. (EPB uses)	kWh/m ²	38.24	7.74	4.94	1.95	1.51	1.43	1.40	1.41	1.46	1.46	3.08	5.10	6.75
Total greenhouse gas emissions		-6.58	2.65	1.49	0.01	-1.70	-3.48	-3.83	-3.57	-2.12	-0.82	0.75	1.69	2.34

Tm2

		YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EPB uses without lighting	kWh/m ²	50.14	6.68	4.69	4.25	3.55	3.45	3.37	3.42	3.56	3.60	3.79	4.19	5.62
non EPB uses with lighting	kWh/m ²	18.51	1.55	1.42	1.60	1.51	1.55	1.56	1.55	1.58	1.54	1.54	1.53	1.57
EPB used electricity	kWh/m ²	23.72	0.72	1.79	2.98	2.48	2.41	2.36	2.39	2.49	2.52	2.27	0.83	0.48
Energy produced on-site	kWh/m ²	87.48	1.03	2.56	6.39	9.82	14.50	15.40	14.70	10.80	7.17	3.24	1.19	0.68
Environmental energy	kWh/m ²	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Exported electricity	kWh/m ²	63.76	0.31	0.77	3.41	7.34	12.09	13.04	12.31	8.31	4.65	0.97	0.36	0.20
Exported for non EPB uses	kWh/m ²	13.51	0.31	0.77	1.60	1.51	1.55	1.56	1.55	1.58	1.54	0.97	0.36	0.20
Grid exported	kWh/m ²	-50.25	0.00	0.00	-1.81	-5.83	-10.54	-11.48	-10.76	-6.73	-3.12	0.00	0.00	0.00
Grid delivered. (EPB uses)	kWh/m ²	26.42	5.96	2.89	1.28	1.06	1.03	1.01	1.03	1.07	1.08	1.52	3.35	5.14
Total greenhouse gas emissions		-13.33	2.02	0.76	-0.76	-2.24	-3.95	-4.30	-4.03	-2.59	-1.28	0.20	1.07	1.76

Ss1

		YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EPB uses without lighting	kWh/m ²	55.22	7.42	5.77	5.32	4.03	3.46	3.37	3.42	3.56	3.61	4.18	4.90	6.18
non EPB uses with lighting	kWh/m ²	18.45	1.54	1.41	1.60	1.50	1.55	1.56	1.55	1.57	1.53	1.54	1.53	1.57
EPB used electricity	kWh/m ²	24.83	0.72	1.79	3.73	2.82	2.42	2.36	2.39	2.49	2.53	2.27	0.83	0.48
Energy produced on-site	kWh/m ²	87.48	1.03	2.56	6.39	9.82	14.50	15.40	14.70	10.80	7.17	3.24	1.19	0.68
Environmental energy	kWh/m ²	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Exported electricity	kWh/m ²	62.65	0.31	0.77	2.66	7.00	12.08	13.04	12.31	8.31	4.64	0.97	0.36	0.20
Exported for non EPB uses	kWh/m ²	13.47	0.31	0.77	1.60	1.50	1.55	1.56	1.55	1.57	1.53	0.97	0.36	0.20
Grid exported	kWh/m ²	-49.18	0.00	0.00	-1.06	-5.50	-10.53	-11.48	-10.76	-6.74	-3.11	0.00	0.00	0.00
Grid delivered. (EPB uses)	kWh/m ²	30.39	6.70	3.98	1.60	1.21	1.04	1.01	1.03	1.07	1.08	1.91	4.07	5.70
Total greenhouse gas emissions		-11.52	2.28	1.15	-0.38	-2.07	-3.94	-4.30	-4.03	-2.59	-1.27	0.34	1.32	1.96

Ss2

		YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EPB uses without lighting	kWh/m ²	58.80	7.72	6.09	5.69	4.38	3.82	3.75	3.80	3.84	3.79	4.37	5.14	6.40
non EPB uses with lighting	kWh/m ²	18.45	1.54	1.41	1.60	1.50	1.55	1.56	1.55	1.57	1.53	1.54	1.53	1.57
EPB used electricity	kWh/m ²	26.44	0.72	1.79	3.98	3.07	2.68	2.62	2.66	2.69	2.65	2.27	0.83	0.48
Energy produced on-site	kWh/m ²	87.48	1.03	2.56	6.39	9.82	14.50	15.40	14.70	10.80	7.17	3.24	1.19	0.68
Environmental energy	kWh/m ²	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Exported electricity	kWh/m ²	61.04	0.31	0.77	2.41	6.75	11.82	12.78	12.04	8.11	4.52	0.97	0.36	0.20
Exported for non EPB uses	kWh/m ²	13.47	0.31	0.77	1.60	1.50	1.55	1.56	1.55	1.57	1.53	0.97	0.36	0.20
Grid exported	kWh/m ²	-47.57	0.00	0.00	-0.81	-5.25	-10.28	-11.21	-10.49	-6.54	-2.99	0.00	0.00	0.00
Grid delivered. (EPB uses)	kWh/m ²	32.36	7.00	4.30	1.71	1.31	1.15	1.12	1.14	1.15	1.14	2.11	4.31	5.92
Total greenhouse gas emissions		-10.24	2.39	1.26	-0.25	-1.94	-3.81	-4.16	-3.89	-2.48	-1.21	0.40	1.41	2.04

Ss3

		YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EPB uses without lighting	kWh/m ²	55.27	7.42	5.78	5.33	4.04	3.46	3.37	3.42	3.56	3.61	4.19	4.91	6.18
non EPB uses with lighting	kWh/m ²	18.48	1.54	1.42	1.60	1.50	1.55	1.56	1.55	1.57	1.53	1.54	1.53	1.57
EPB used electricity	kWh/m ²	24.84	0.72	1.79	3.73	2.83	2.42	2.36	2.39	2.49	2.53	2.27	0.83	0.48
Energy produced on-site	kWh/m ²	87.48	1.03	2.56	6.39	9.82	14.50	15.40	14.70	10.80	7.17	3.24	1.19	0.68
Environmental energy	kWh/m ²	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Exported electricity	kWh/m ²	62.64	0.31	0.77	2.66	6.99	12.08	13.04	12.31	8.31	4.64	0.97	0.36	0.20
Exported for non EPB uses	kWh/m ²	13.48	0.31	0.77	1.60	1.50	1.55	1.56	1.55	1.57	1.53	0.97	0.36	0.20
Grid exported	kWh/m ²	-49.16	0.00	0.00	-1.05	-5.49	-10.53	-11.48	-10.76	-6.74	-3.11	0.00	0.00	0.00
Grid delivered. (EPB uses)	kWh/m ²	30.43	6.70	3.99	1.60	1.21	1.04	1.01	1.03	1.07	1.08	1.92	4.07	5.70
Total greenhouse gas emissions		-11.50	2.28	1.15	-0.38	-2.06	-3.94	-4.30	-4.03	-2.59	-1.27	0.34	1.33	1.96

Hv1

		YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EPB uses without lighting	kWh/m ²	47.95	5.90	4.35	4.06	3.47	3.44	3.37	3.42	3.56	3.59	3.81	4.04	4.95
non EPB uses with lighting	kWh/m ²	18.49	1.55	1.42	1.60	1.50	1.55	1.56	1.55	1.57	1.53	1.55	1.53	1.57
EPB used electricity	kWh/m ²	23.53	0.72	1.79	2.84	2.43	2.41	2.36	2.39	2.49	2.52	2.27	0.83	0.48
Energy produced on-site	kWh/m ²	87.48	1.03	2.56	6.39	9.82	14.50	15.40	14.70	10.80	7.17	3.24	1.19	0.68
Environmental energy	kWh/m ²	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Exported electricity	kWh/m ²	63.95	0.31	0.77	3.55	7.39	12.09	13.04	12.31	8.31	4.65	0.97	0.36	0.20

Exported for non EPB uses	kWh/m ²	13.48	0.31	0.77	1.60	1.50	1.55	1.56	1.55	1.57	1.53	0.97	0.36	0.20
Grid exported	kWh/m ²	-50.47	0.00	0.00	-1.95	-5.88	-10.54	-11.48	-10.76	-6.74	-3.12	0.00	0.00	0.00
Grid delivered. (EPB uses)	kWh/m ²	24.43	5.18	2.56	1.22	1.04	1.03	1.01	1.03	1.07	1.08	1.54	3.20	4.47
Total greenhouse gas emissions		-14.11	1.74	0.64	-0.83	-2.27	-3.95	-4.30	-4.03	-2.59	-1.28	0.20	1.02	1.52

Hv2

		YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EPB uses without lighting	kWh/m ²	47.68	5.80	4.31	4.03	3.47	3.44	3.37	3.42	3.56	3.59	3.80	4.00	4.88
non EPB uses with lighting	kWh/m ²	18.50	1.55	1.42	1.60	1.51	1.55	1.56	1.55	1.57	1.53	1.55	1.54	1.57
EPB used electricity	kWh/m ²	23.51	0.72	1.79	2.82	2.43	2.41	2.36	2.39	2.49	2.52	2.27	0.83	0.48
Energy produced on-site	kWh/m ²	87.48	1.03	2.56	6.39	9.82	14.50	15.40	14.70	10.80	7.17	3.24	1.19	0.68
Environmental energy	kWh/m ²	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Exported electricity	kWh/m ²	63.97	0.31	0.77	3.57	7.39	12.09	13.04	12.31	8.31	4.65	0.97	0.36	0.20
Exported for non EPB uses	kWh/m ²	13.48	0.31	0.77	1.60	1.51	1.55	1.56	1.55	1.57	1.53	0.97	0.36	0.20
Grid exported	kWh/m ²	-50.49	0.00	0.00	-1.96	-5.88	-10.54	-11.48	-10.76	-6.74	-3.12	0.00	0.00	0.00
Grid delivered. (EPB uses)	kWh/m ²	24.17	5.08	2.52	1.21	1.04	1.03	1.01	1.03	1.07	1.08	1.53	3.17	4.41
Total greenhouse gas emissions		-14.21	1.70	0.63	-0.84	-2.27	-3.95	-4.30	-4.03	-2.59	-1.28	0.20	1.00	1.50

Hp1

		YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EPB uses without lighting	kWh/m ²	20.18	3.49	2.20	1.66	1.23	1.14	1.06	1.11	1.22	1.32	1.49	1.73	2.54
non EPB uses with lighting	kWh/m ²	18.49	1.54	1.42	1.61	1.51	1.55	1.56	1.55	1.57	1.53	1.55	1.54	1.57
EPB used electricity	kWh/m ²	10.73	0.72	1.54	1.16	0.86	0.80	0.74	0.78	0.85	0.92	1.04	0.83	0.48
Energy produced on-site	kWh/m ²	87.48	1.03	2.56	6.39	9.82	14.50	15.40	14.70	10.80	7.17	3.24	1.19	0.68
Environmental energy	kWh/m ²	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Exported electricity	kWh/m ²	76.75	0.31	1.02	5.23	8.96	13.70	14.66	13.92	9.95	6.25	2.20	0.36	0.20
Exported for non EPB uses	kWh/m ²	14.31	0.31	1.02	1.61	1.51	1.55	1.56	1.55	1.57	1.53	1.55	0.36	0.20
Grid exported	kWh/m ²	-62.45	0.00	0.00	-3.62	-7.45	-12.16	-13.10	-12.37	-8.37	-4.72	-0.65	0.00	0.00
Grid delivered. (EPB uses)	kWh/m ²	9.46	2.77	0.66	0.50	0.37	0.34	0.32	0.33	0.37	0.40	0.45	0.89	2.07
Total greenhouse gas emissions		-24.02	0.88	-0.13	-1.69	-3.07	-4.77	-5.12	-4.85	-3.42	-2.09	-0.62	0.19	0.66

Cl1

		YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EPB uses without lighting	kWh/m ²	44.60	5.18	4.18	4.04	3.34	3.18	3.11	3.16	3.28	3.32	3.55	3.76	4.50
non EPB uses with lighting	kWh/m ²	14.02	1.19	1.08	1.19	1.15	1.19	1.15	1.19	1.19	1.15	1.19	1.15	1.19
EPB used electricity	kWh/m ²	22.49	0.72	1.79	2.83	2.34	2.22	2.18	2.21	2.30	2.32	2.27	0.83	0.48
Energy produced on-site	kWh/m ²	55.85	0.66	1.64	4.08	6.28	9.27	9.82	9.37	6.88	4.58	2.07	0.76	0.44
Environmental energy	kWh/m ²	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Exported electricity	kWh/m ²	64.99	0.31	0.77	3.56	7.48	12.28	13.22	12.49	8.50	4.85	0.97	0.36	0.20
Exported for non EPB uses	kWh/m ²	10.82	0.31	0.77	1.19	1.15	1.19	1.15	1.19	1.19	1.15	0.97	0.36	0.20
Grid exported	kWh/m ²	-54.17	0.00	0.00	-2.37	-6.33	-11.09	-12.07	-11.30	-7.31	-3.70	0.00	0.00	0.00
Grid delivered. (EPB uses)	kWh/m ²	22.11	4.46	2.39	1.21	1.00	0.95	0.93	0.95	0.99	1.00	1.29	2.92	4.02
Total greenhouse gas emissions		-15.31	1.48	0.58	-0.84	-2.31	-4.04	-4.39	-4.12	-2.68	-1.37	0.11	0.92	1.36

CI2

		YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EPB uses without lighting	kWh/m ²	49.29	5.61	4.81	4.32	3.54	3.49	3.40	3.46	3.61	3.62	3.86	4.32	5.25
non EPB uses with lighting	kWh/m ²	18.50	1.55	1.42	1.61	1.50	1.55	1.56	1.55	1.57	1.53	1.55	1.54	1.58
EPB used electricity	kWh/m ²	23.89	0.72	1.79	3.03	2.48	2.44	2.38	2.42	2.53	2.53	2.27	0.83	0.48
Energy produced on-site	kWh/m ²	87.48	1.03	2.56	6.39	9.82	14.50	15.40	14.70	10.80	7.17	3.24	1.19	0.68
Environmental energy	kWh/m ²	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Exported electricity	kWh/m ²	63.59	0.31	0.77	3.36	7.34	12.06	13.02	12.28	8.27	4.64	0.97	0.36	0.20
Exported for non EPB uses	kWh/m ²	13.48	0.31	0.77	1.61	1.50	1.55	1.56	1.55	1.57	1.53	0.97	0.36	0.20
Grid exported	kWh/m ²	-50.11	0.00	0.00	-1.76	-5.84	-10.51	-11.46	-10.73	-6.70	-3.11	0.00	0.00	0.00
Grid delivered. (EPB uses)	kWh/m ²	25.39	4.89	3.02	1.30	1.06	1.05	1.02	1.04	1.08	1.09	1.60	3.48	4.78
Total greenhouse gas emissions		-13.64	1.63	0.80	-0.74	-2.24	-3.93	-4.28	-4.01	-2.57	-1.27	0.22	1.12	1.63

Ub1

		YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EPB uses without lighting	kWh/m ²	44.60	5.18	4.18	4.04	3.34	3.18	3.11	3.16	3.28	3.32	3.55	3.76	4.50
non EPB uses with lighting	kWh/m ²	14.02	1.19	1.08	1.19	1.15	1.19	1.15	1.19	1.19	1.15	1.19	1.15	1.19
EPB used electricity	kWh/m ²	22.49	0.72	1.79	2.83	2.34	2.22	2.18	2.21	2.30	2.32	2.27	0.83	0.48
Energy produced on-site	kWh/m ²	55.85	0.66	1.64	4.08	6.28	9.27	9.82	9.37	6.88	4.58	2.07	0.76	0.44
Environmental energy	kWh/m ²	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Exported electricity	kWh/m ²	64.99	0.31	0.77	3.56	7.48	12.28	13.22	12.49	8.50	4.85	0.97	0.36	0.20
Exported for non EPB uses	kWh/m ²	10.82	0.31	0.77	1.19	1.15	1.19	1.15	1.19	1.19	1.15	0.97	0.36	0.20
Grid exported	kWh/m ²	-54.17	0.00	0.00	-2.37	-6.33	-11.09	-12.07	-11.30	-7.31	-3.70	0.00	0.00	0.00
Grid delivered. (EPB uses)	kWh/m ²	22.11	4.46	2.39	1.21	1.00	0.95	0.93	0.95	0.99	1.00	1.29	2.92	4.02
Total greenhouse gas emissions		-15.31	1.48	0.58	-0.84	-2.31	-4.04	-4.39	-4.12	-2.68	-1.37	0.11	0.92	1.36

Ub2

		YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EPB uses without lighting	kWh/m ²	74.95	8.63	6.99	6.81	5.75	5.55	5.44	5.49	5.54	5.43	5.81	6.15	7.36
non EPB uses with lighting	kWh/m ²	26.04	2.21	2.00	2.21	2.14	2.21	2.14	2.21	2.21	2.14	2.21	2.14	2.21
EPB used electricity	kWh/m ²	33.80	0.72	1.79	4.47	4.02	3.89	3.81	3.84	3.88	3.80	2.27	0.83	0.48
Energy produced on-site	kWh/m ²	55.85	0.66	1.64	4.08	6.28	9.27	9.82	9.37	6.88	4.58	2.07	0.76	0.44
Environmental energy	kWh/m ²	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Exported electricity	kWh/m ²	53.68	0.31	0.77	1.92	5.80	10.61	11.59	10.86	6.92	3.37	0.97	0.36	0.20
Exported for non EPB uses	kWh/m ²	17.57	0.31	0.77	1.92	2.14	2.21	2.14	2.21	2.21	2.14	0.97	0.36	0.20
Grid exported	kWh/m ²	-36.10	0.00	0.00	0.00	-3.66	-8.40	-9.46	-8.65	-4.71	-1.23	0.00	0.00	0.00
Grid delivered. (EPB uses)	kWh/m ²	41.15	7.91	5.20	2.34	1.72	1.67	1.63	1.65	1.66	1.63	3.54	5.32	6.88
Total greenhouse gas emissions		-4.47	2.71	1.58	0.15	-1.45	-3.19	-3.56	-3.29	-1.88	-0.62	0.92	1.77	2.38

Ef1

		YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EPB uses without lighting	kWh/m ²	54.74	6.51	4.79	4.52	3.88	4.00	3.95	4.24	4.35	4.10	4.31	4.53	5.55
non EPB uses with lighting	kWh/m ²	24.56	7.62	1.42	1.60	1.50	1.55	1.56	1.55	1.57	1.53	1.55	1.53	1.57
EPB used electricity	kWh/m ²	26.42	0.72	1.79	3.16	2.72	2.80	2.77	2.97	3.05	2.87	2.27	0.83	0.48
Energy produced on-site	kWh/m ²	87.48	1.03	2.56	6.39	9.82	14.50	15.40	14.70	10.80	7.17	3.24	1.19	0.68
Environmental energy	kWh/m ²	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Exported electricity	kWh/m ²	61.06	0.31	0.77	3.23	7.10	11.70	12.63	11.73	7.75	4.30	0.97	0.36	0.20
Exported for non EPB uses	kWh/m ²	13.48	0.31	0.77	1.60	1.50	1.55	1.56	1.55	1.57	1.53	0.97	0.36	0.20
Grid exported	kWh/m ²	-47.58	0.00	0.00	-1.62	-5.60	-10.15	-11.07	-10.19	-6.18	-2.77	0.00	0.00	0.00
Grid delivered. (EPB uses)	kWh/m ²	28.32	5.79	3.00	1.36	1.16	1.20	1.19	1.27	1.31	1.23	2.04	3.70	5.08
Total greenhouse gas emissions		-11.69	1.96	0.80	-0.67	-2.12	-3.75	-4.09	-3.73	-2.30	-1.10	0.38	1.19	1.74

Ef2

SYN.IKIA BASE CASE. ASSESSMENT BOUNDARY INCLUDES ONLY EPB USES														
Unweighted final energy														
EPB uses	kWh/m ²	82,24	8,82	6,90	6,89	6,12	6,31	6,26	6,55	6,70	6,37	6,62	6,81	7,89
non EPB uses	kWh/m ²	24,56	7,62	1,42	1,60	1,50	1,55	1,56	1,55	1,57	1,53	1,55	1,53	1,57
EPB used electricity	kWh/m ²	32,32	0,46	1,15	2,86	4,29	4,42	4,38	4,58	4,69	3,21	1,45	0,53	0,31
Energy produced on-site	kWh/m ²	55,85	0,66	1,64	4,08	6,28	9,27	9,82	9,37	6,88	4,58	2,07	0,76	0,44
Environmental energy	kWh/m ²	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Exported electricity	kWh/m ²	23,53	0,20	0,49	1,22	1,99	4,85	5,44	4,78	2,19	1,37	0,62	0,23	0,13
Exported for non EPB uses	kWh/m ²	12,00	0,20	0,49	1,22	1,50	1,55	1,56	1,55	1,57	1,37	0,62	0,23	0,13
Grid exported	kWh/m ²	-11,53	0,00	0,00	0,00	-0,49	-3,31	-3,88	-3,24	-0,62	0,00	0,00	0,00	0,00
Grid delivered. (EPB uses)	kWh/m ²	49,93	8,36	5,76	4,04	1,84	1,89	1,88	1,96	2,01	3,17	5,17	6,27	7,59
Total greenhouse gas emissions	kg CO ₂ eq/m ²	9,42	2,91	1,88	1,00	-0,06	-1,06	-1,27	-1,01	-0,07	0,64	1,62	2,16	2,66

Pessimistic Scenario

		YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EPB uses without lighting	kWh/m ²	56.97	5.59	4.54	4.65	4.24	4.42	4.61	4.96	4.64	4.45	4.68	4.76	5.43
non EPB uses with lighting	kWh/m ²	26.02	2.21	2.00	2.21	2.14	2.21	2.14	2.21	2.21	2.14	2.21	2.14	2.21
EPB used electricity	kWh/m ²	28.46	0.72	1.79	3.25	2.97	3.10	3.23	3.47	3.25	3.11	2.27	0.83	0.48
Energy produced on-site	kWh/m ²	87.48	1.03	2.56	6.39	9.82	14.50	15.40	14.70	10.80	7.17	3.24	1.19	0.68
Environmental energy	kWh/m ²	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Exported electricity	kWh/m ²	59.02	0.31	0.77	3.14	6.85	11.40	12.17	11.23	7.56	4.06	0.97	0.36	0.20
Exported for non EPB uses	kWh/m ²	17.87	0.31	0.77	2.21	2.14	2.21	2.14	2.21	2.21	2.14	0.97	0.36	0.20
Grid exported	kWh/m ²	-41.15	0.00	0.00	-0.93	-4.71	-9.19	-10.03	-9.02	-5.35	-1.92	0.00	0.00	0.00
Grid delivered. (EPB uses)	kWh/m ²	28.51	4.87	2.75	1.39	1.27	1.33	1.38	1.49	1.39	1.33	2.41	3.93	4.96
Total greenhouse gas emissions		-10.89	1.63	0.71	-0.62	-1.99	-3.60	-3.85	-3.48	-2.20	-0.97	0.51	1.28	1.70

Optimistic Scenario

		YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EPB uses without lighting	kWh/m ²	50.66	5.31	4.25	4.09	3.70	3.85	4.00	4.27	4.10	3.92	4.03	4.09	5.05
non EPB uses with lighting	kWh/m ²	18.48	1.55	1.42	1.60	1.50	1.55	1.56	1.55	1.57	1.53	1.55	1.53	1.57
EPB used electricity	kWh/m ²	25.65	0.72	1.79	2.86	2.59	2.70	2.80	2.99	2.87	2.75	2.27	0.83	0.48
Energy produced on-site	kWh/m ²	87.48	1.03	2.56	6.39	9.82	14.50	15.40	14.70	10.80	7.17	3.24	1.19	0.68
Environmental energy	kWh/m ²	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Exported electricity	kWh/m ²	61.83	0.31	0.77	3.53	7.23	11.80	12.60	11.71	7.93	4.42	0.97	0.36	0.20
Exported for non EPB uses	kWh/m ²	13.48	0.31	0.77	1.60	1.50	1.55	1.56	1.55	1.57	1.53	0.97	0.36	0.20
Grid exported	kWh/m ²	-48.36	0.00	0.00	-1.93	-5.73	-10.26	-11.04	-10.16	-6.36	-2.89	0.00	0.00	0.00
Grid delivered. (EPB uses)	kWh/m ²	25.02	4.59	2.46	1.23	1.11	1.16	1.20	1.28	1.23	1.18	1.76	3.26	4.57
Total greenhouse gas emissions		-13.14	1.53	0.61	-0.82	-2.19	-3.80	-4.07	-3.72	-2.39	-1.16	0.28	1.03	1.56



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