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Design and performance predictions of plus energy neighbourhoods – Case studies of demonstration projects in four different European climates

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ABSTRACT

The article presents the design of four plus energy neighbourhood demonstration projects located in different climate zones in Europe. The demo projects are a part of the Horizon 2020 project 'syn.ikia', which aims to enable the development of sustainable plus energy neighbourhoods in different climates and contexts. In this article, we describe the active and passive building strategies and analyse the robustness of the designs with respect to different scenarios of climate change, user behaviour, and energy flexibility. Analyses were performed based on the primary energy balance, including space heating and cooling, ventilation, domestic hot water, and lighting.

The performance predictions indicate that all demonstration projects may attain the plus energy balance according to the syn.ikia definition. This was achieved with high performing envelopes, efficient HVAC systems, and onsite renewable energy systems to cover the energy demand. The analysis shows that there is a significant potential for increased self-consumption of photovoltaic energy by adjusting the heating schedules and including electric vehicle charging. Testing of the designs with respect to varying climates and user-behaviours showed that there could be an increased risk of overheating, and that some of the designs may not achieve the positive energy balance in case of 'worst case' user behaviour scenarios.

1. Introduction

Emissions from the construction sector are not on the trajectory of reaching carbon neutrality by 2050. According to the IEA all new buildings and 20 % of the existing building stock need to be "zero-carbon-ready" by 2030 to meet the 2050 goal. The electricity demand of the building sector continues to increase, and IEA projects that the energy intensity for each square meter needs to be reduced by 45 % from 2020 to 2030 [7]. A strategy to reduce operational emissions is to implement energy efficiency measures in buildings along with on-site renewable energy generation. Further, demand-side flexibility and energy efficiency can reduce the power demand and stress on the power grid [8].

Abbreviations: BC, Base Case; CDD, Cooling Degree Days [1]; DH, District Heating; DHW, Domestic Hot Water; EPB, Building services as defined in the Energy Performance for Buildings Directive (EPB), i.e. heating, cooling, lighting, ventilation, domestic hot water, [2]; EPBD, Energy Performance of Buildings Directive; GSHP, Ground Source Heat Pump; HP, Heat Pump; nEPB, Non EPB services, energy use not covered in EPB services, i.e. plug loads such as appliances, elevators, TV, computers [2]; NZEB, Nearly Zero-Energy Building; PMV, Predicted Mean Vote [3]; PV, Photovoltaics; RES, Renewable Energy Sources; SCOP, Seasonal Coefficient of Performance [4]; SPEN, Sustainable Plus Energy Neighbourhood [5]; Supply Cover Factor, The relationship between the energy produced on-site and directly used for EPB purposes, and the total on-site produced energy [6].

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As of December 2020 the Energy Performance of Buildings Directive requires all European Member States to apply the Nearly Zero Energy Building (NZEB) target for new buildings [9]. A study of the development of NZEB definitions in Europe in 2020 showed that 23 Member States had a definition for NZEB, while only half of them have U-value requirements and 12 Member States include a requirement to cover parts of the energy demand with renewable energy sources [10]. The scope and ambition of the NZEB definition varies between the European countries, with a generally less stringent policy and lower energy efficiency for buildings in Eastern Europe [11]. Addressing similarities, the most common energy balance for the NZEB target is demand/generation at the building level on an annual basis with on-site renewable energy sources [10].

There is no common European definition of a plus energy buildings (PEB). A joint workshop on a consolidated PEB definition, co-organized by syn.ikia, Cultural E and EXCESS EU funded projects, outlined the key discussion factors; system boundary, energy balance, embodied energy, energy flexibility and interaction with the grid, and renewable energy sources [12]. Further, social aspects were considered important for the achievement of PEB and the "Positive Energy User" concept was presented as an ideal user who would improve the energy balance.

Concepts like plus energy buildings and positive energy neighbourhoods and districts [13] are gaining interest and momentum in the research society and by practitioners, politicians, and governments as strategies to meet the climate goals [14]. A recent review article on Plus Energy Buildings [15] found a total of 82 research papers on various issues related to this concept. Most of the reviewed studies focused on residential buildings (70 %) and investigated the potential to achieve the plus energy target using numerical simulations (70 %). Another recent review article on Zero Emission Neighbourhoods and Positive Energy Districts [13] found a total of 144 research papers related to these concepts. Most of the studies included case studies of building projects in the planning phase (60 %). Further, most of the reviewed articles focused on the energy systems and presented a new method, a framework, or a tool to assess the neighbourhood. Both reviews illustrate that these fields are still quite new and that there is a need for more real-life projects demonstrating the application of criteria, methods, tools, and solutions to test and validate the performance of these concepts.

Onsite renewable energy sources (RES) are significant to achieve an energy performance target ranging from NZEB to PEB. Data collected on nearly zero energy buildings (NZEB) in Europe found that the RES contribution ranged from 21 % to 105 % of the energy demand, where PV was included in 34 out of 50 projects [16]. Further, the primary energy demand of the NZEB best practice example buildings ranged from -7.5 kWh/m^{2}y to 152 kWh/m^{2}y, with large variations between countries and projects in colder climates had higher energy demand. A renovation project in Southern Europe used an integrated design approach to achieve the nearly zero energy building standard, where onsite RES (PV and solar thermal) improved the primary energy performance [17].

Li et al. [18] argue that the heat capacity of the building should be accounted for in heating load calculations of NZEB, and thermal inertia could be used in demand response. Monitoring and post evaluations of both new buildings and renovation projects to NZEB, ZEB and PEB standards are crucial to ensure initial performance targets are met. Moreover, Li et al. [18] developed a model-based evaluation method for the envelope performance, and successfully implemented the method on a renovation case study.

Buildings are affected by societal changes and expectations to buildings are changing. Electrical vehicles charging, economic viability, comfort, and consideration of climate change, among others, are mentioned as significant in the new development of NZEBs [10]. Studies of how buildings respond to these factors are emerging [19–24]. Ascione et al. found that the reduction of heating demand due to climate change could compensate for the increase in the cooling demand [20]. For an NZEB case study in Sweden, historic climate files gave significantly different results for cooling demand compared to future and extreme climate files [24]. A smart control of a PV system slightly reduced the primary energy consumption and CO$_2$ emissions compared to having no intelligent control system. Further, grid connected PV systems were recommended due to critical issues with standalone PV systems in terms of cost and excess energy storage in the summer seasons [25]. Lastly, D'Agostino et al. [10] argue that the focus will shift from NZEB at a building level to the neighbourhood or district level, and possibly further to city level in the future.

The research presented in this paper has been performed within the EU Horizon 2020 project 'Sustainable Plus Energy Neighbourhoods (short name 'syn.ikia', https://www.synikia.eu/). The overall aim of the syn.ikia project is to deliver innovations in energy and construction by developing new designs, tools, methods, and processes that will enable large-scale deployment of sustainable plus energy buildings and neighbourhoods in Europe. An important part of the project is to design, construct, and evaluate real-life demonstration projects in four different climates and contexts in Europe. The syn.ikia project also aims to design and test strategies and tools to maximize the utilization of renewable energy in the neighbourhoods by real-time matching of energy demand and production through flexibility optimization. In the next stages of the project, the demo neighbourhoods will be constructed, commissioned, and their performance in use will be evaluated.

This paper provides a summary of energy performance and indoor comfort analyses that were done during the design phases of the four real-life demonstration projects. The research addresses the following research questions:

1) *What are the perceived 'best designs' of the buildings in the four climates and contexts with respect to achieving the plus energy balance, while ensuring indoor comfort, minimizing costs, and sustaining high architectural qualities?* The research takes as a starting point (base case) the results of the current designs from the local design teams in the four projects. At the time of the research, the four demonstration projects were in different phases of the design; two of the projects were in early design phases (the Austrian and the Norwegian projects), while two of the projects were in the late design phases (the Spanish and the Dutch project). In cooperation with the local design teams, the syn.ikia researchers analysed different design options applying a set of passive and active energy measures. These analyses are described in chapters 3.4 to 3.7. The perceived 'best design' of each of the demonstration projects was chosen based on an integrated assessment of energy performance, comfort, costs, and architectural qualities.
2) *How robust are the designs with respect to changes in climate conditions and user behaviour?* This research question was addressed by testing the perceived 'best designs' with respect to different future climate scenarios and user behaviour patterns. The scenarios were also combined into 'best case' and 'worst case' scenarios to find the most optimistic and pessimistic outcomes with respect to a combination of energy performance, indoor comfort, and operational costs. These analyses are described in chapter 3.8.
3) *How to utilize energy flexibility measures to increase the self-consumption of on-site renewable energy?* In this article, this research question is addressed by studying the effect of different user behaviours as well as different setpoint sched-

ules for space and DHW heating, and also the introduction of electric vehicle charging. The background for this analysis may be found in chapters 3.4 to 3.8.

The research approach taken in this paper may be described as a 'practical' approach to find the 'best' design options, where researchers have generated alternatives and found solutions in close cooperation with the different stakeholders in the real-life design teams. We have used detailed computer simulations to predict the performance of different designs to find the options considered by the team to be the best compared to a set of criteria. We have also tested them against different scenarios to evaluate their sensitivity to changing weather conditions, use patterns, and energy costs. Thus, our research does not adhere to the theoretical approaches described in literature as 'parametric design' [26], 'optimization' [27], 'robustness assessment' [28] or 'uncertainty analysis' [29]. In our case, such theoretical methods were considered to be too time-consuming and difficult to communicate to the design teams in the real-life development projects. However, in Section 4 we will compare our results to results reported in research within these related fields.

2. Introduction of the demo projects

As defined in the syn.ikia's evaluation framework [5], a Sustainable Plus Energy Neighbourhood (SPEN) is a highly energy-efficient neighbourhood with a surplus of energy from renewable sources that 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 covering the building energy needs.

The design of the syn.ikia demonstration projects have been based on the concept of Integrated Energy Design (IED) for buildings [30–33], but in this case applied to the neighbourhood scale. The process involves multi-disciplinary actors, the application of advanced simulation tools from the early design phases, and the consideration of a range of related design issues (energy, comfort, architecture, and costs), considering the neighbourhood as a whole. Illustrations of the four demonstration projects are given in Fig. 1, and key data for the projects are given in Table 1.

2.1. Spanish demo

The Spanish demonstration case is located in Santa Coloma de Gramenet, a city located 4 km from Barcelona, and is placed in a neighbourhood that is involved in an urban regeneration process (Fig. 1, upper left). The climate is classified as Mediterranean according to the Köppen Geiger classification system [34]. The demonstration site includes a 7-storey building with 38 dwellings, 2 commercial premises, and 38 parking spaces (below ground) (Fig. 4). The project provides housing to people that have economic difficulties accessing a house in the open market.

2.2. Austrian demo

The Austrian demo is a new greenfield development in Salzburg, located on the outskirts of the city (Fig. 1, lower right). The climate is classified as Continental according to the Köppen Geiger classification system [34]. The plot includes a greenfield and a neighbourhood with 17 buildings including mostly 2–4 storey res-

Fig. 1. Illustrations of the four demonstration projects, from the left upper Spanish and Dutch demo. Below: Norwegian and Austrian demo.

Table 1
Key data for the demonstration projects ('Best Case').

	Demo 1	Demo 2	Demo 3	Demo 4
Name and location of the project	Santa Coloma de Gramenet, Barcelona, Spain	Gewin Gneis, Salzburg, Austria	Loopkantstraat, Uden, The Netherlands	Oen, Oslo, Norway
Climate data	Mediterranean HDD: 1438 h CDD: 75 h	Continental HDD: 3211 h CDD: 2 h	Marine HDD: 2814 h CDD: 20 h	Sub-arctic HDD: 4112 h CDD: 2 h
Building envelope				
U-values walls	0.27 W/m^{2}K	0.13 W/m^{2}K	0.16 W/m^{2}K	0.10 W/m^{2}K
U-values glazing	1.10 W/m^{2}K	0.65 W/m^{2}K	1.0 W/m^{2}K	0.80 W/m^{2}K
U-values roof	0.33 W/m^{2}K	0.10 W/m^{2}K	0.12 W/m^{2}K	0.11 W/m^{2}K
U-values floorAir leakage	0.46 W/m^{2}K	0.14 W/m^{2}K	0.19 W/m^{2}K	0.08 W/m^{2}K
(n50)	0.4 h^{-1}	0.6 h^{-1}	0.3 h^{-1}	0.6 h^{-1}
*	38 %	35 %	37 %	50 %
Glass to wall ratio				
Neighbourhood layout				
No. of housing units				
No. of floors	38 dwellings	250 dwellings	39 dwellings	150 dwellings
Conditioned floor area	7 floors	2–4 floors	3 floors	4–5 floors
	2 154 m^2	22 000 m^2	2 360 m^2	14 450 m^2
	Air-to-Water HP	Ground-Source HP	Ground-Source HP	District Heating (55 °C)
Heating/Cooling system	w. 4 pipes			
	Radiators (35/30) No cooling	Floor heating (40/35), Floor cooling (18/21)	Floor heating (40/35) Floor cooling	Floor heating No cooling
Ventilation system	Natural Cross Ventilation	Heat Recovery and Economizer Ventilation	Mechanical Exhaust Ventilation w. CO$_2$ sensor	Balanced Ventilation w. 80 % Heat Recovery
SCOP* heating / cooling / DHW	4.98 / - / 2.96	4.0 / 4.0 / 2.7	5.7 / 50 / 3.6	0.9 / - / 0.9
Heating setpoint	21/ 17 °C day/ night	21/ 18 °C setpoint/ setback	20/ 21/ 19 °C day/ evening/ night	21 °C
Cooling setpoint	n/a	26/ 28 °C setpoint/ setback	23 °C	n/a
Ventilation	Natural ventilation in summer: 4.0 h^{-1}	0.38 h^{-1} residential 1.15 h^{-1} kindergarten	1.4 m^3/(h-m^2)	2.2 m^3/(h-m^2) Natural ventilation in the summer.
SFP	–	0.45 kW/(m^3 s)	0.8 kW/(m^3 s)	1.3 W/(m^3 s)
Controls	Ventilation control based on operative and outdoor temperature, and occupancy.	PI controller with optimal tuning	–	Natural ventilation when the temperature exceeds 26 °C
Average lighting power	2.81 W/m^2	4.4 W/m^2	1.39 W/m^2	1.95 W/m^2
Photovoltaic system	39.1 kWp 200.5 m^2 Nominal efficiency = 19.9 %	667 kWp 5700 m^2 Nominal efficiency = 19 %	60.5 kWp 378 m^2 Nominal efficiency = 20 %	520 kWp 3500 m^2 Nominal efficiency = 21 %

*n50: Air leakage number according to EN- ISO 9972:2015 Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method.
**SCOP: Seasonal Coefficient of Performance.

idential building blocks with a mix of services such as shops, churches, medical practices, and leisure facilities.

2.3. Dutch demo

The Dutch Demonstration case (Fig. 1, upper right) is a new residential development in a mid-sized town named Uden, in a marine climate as defined by the Köppen Geiger classification [34]. The development consists of a residential building block with 39 apartments spread over 3 floors. The total plot area of this development is 3 860 m^2 with a usable floor area of 2 394 m^2. The building development follows the "Social Beautiful" concept, which aims to provide suitable living and working conditions to vulnerable citizens.

2.4. Norwegian demo

The Norwegian Demonstration case is a new residential development in the outskirt of Oslo (Fig. 1, lower left). It is in a subarctic climate as defined by the Köppen Geiger classification [34] and the development consists of a neighbourhood of 150 apartments collected in a circular shaped building. A courtyard of 3000 m^2 lies in the centre of the building. The circular shape and the courtyard of the building emphasize the social dimension of a sustainable neighbourhood, stressing the overall concept of sharing spaces, functions, energy, and infrastructure.

3. Methods

3.1. The assessment framework

The assessment framework that has been developed in the syn.ikia project [5] defines key performance indicators considering energy and power performance, GHG emissions, indoor environmental quality, smartness, flexibility, life cycle costs, and social sustainability. The framework is designed to be implemented during integrated design processes aiming to select design options for a neighbourhood as well as during the operational phase for monitoring its performance. Fig. 2 illustrates the primary energy balance as defined by the syn.ikia assessment framework. The right side of the assessment boundary (AB) represents the energy balance inside the building and is the unweighted final energy. When moving to the left side of AB, the final energy is multiplied by primary energy conversion factors and therefore represents the

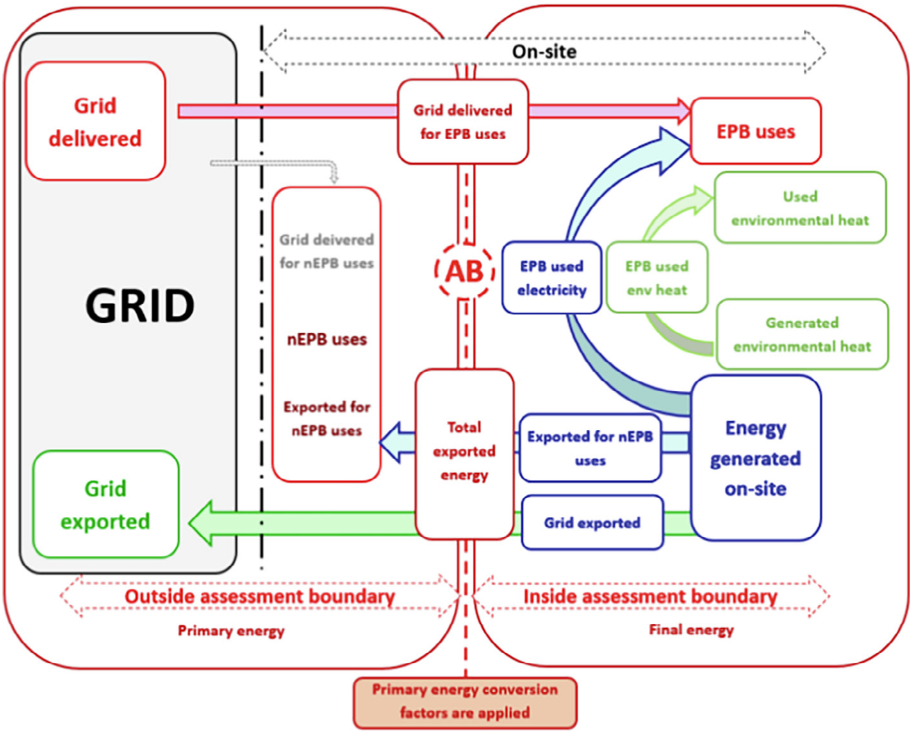

Fig. 2. Primary energy balance as defined in syn.ikia demonstration projects.

primary energy balance. The objective of a positive energy building or neighbourhood is to provide a positive energy balance (of the primary side), meaning that the yearly weighted export is greater than the yearly weighted import.

3.2. Overview of method approach

The method approach (Fig. 3) for this paper started with defining a base case design for each of the demonstration sites. Then, a set of passive and active strategies were developed and tested with building performance simulation software. The perceived best design was selected based on the key performance indicators annual primary energy balance, indoor comfort, flexibility potential, architectural quality, and costs. This was done in dialog between researcher and the different members of the local design teams. The perceived 'best design' was then simulated with different scenarios for climate change, user behaviour patterns to test the robustness against the key performance indicators. The design options, scenarios, and results with respect to key indicators for energy, thermal comfort, and flexibility are included in this article. The tools, models, design options, scenarios, and results are further described in Chapters 3.3–3.8.

3.3. Overview of performance prediction models

Detailed computer simulations of energy performance and indoor climate were carried out to inform the design process in the demo projects. Table 2 presents the simulation software used for the different demo projects. For each of the neighbourhoods, a base case building model was defined to represent the reference design (see descriptions in sections 3.4.2, 3.5.2, 3.6.2 and 3.7.2). From this model, different parameters were varied to study the effect on energy and indoor climate, that resulted in the final design choices (see section 3.8).

Table 3 shows the primary energy conversion factors that were used for estimating the weighted exported energy and therefore the total (TOT) and, renewable (REN) and non-renewable primary energy (N_REN).

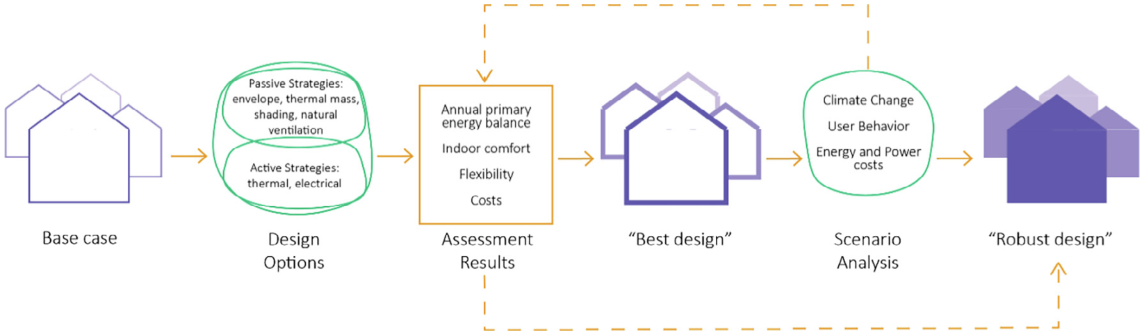

Fig. 3. Method approach for this study from base case design to final scenario analyses.

Fig. 4. Architectural drawings of the floor plan of the Barcelona demo site building's attic floor (left) and the elevation section (right). Apartments that were modelled in detail are circled with orange. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
Simulation software and characteristics for the demonstration projects.

Demo projects	Oen, Oslo, Norway	Loopkanstraat, Uden, The Netherlands	Santa Coloma de Gramenet, Barcelona, Spain	Gewin Gneis, Salzburg, Austria
Simulation software Energy use	IDA-ICE [35] (Energy Zone Model)	TRNSYS 18 [36]	TRNSYS 18 [36] w. SketchUP 2021 [37]	CEA (City Energy Analyst) [38] w. QGIS[39]
Simulation software Energy generation	Grasshopper [40] in Rhino[41] w. Energy Plus[42]	TRNSYS 18 [36]	Archelios [43] (PV generation)	CEA (City Energy Analyst) [38]

Table 3
Primary energy factors (PEF) for the demonstration projects in kWh_PE/kWh_FE.

Demo projects	Oslo, Norway			The Netherlands			Barcelona, Spain			Salzburg, Austria		
PEF [2], F_p	REN	N_REN	TOT	REN	N_REN	TOT	REN	N_REN	TOT	REN	N_REN	TOT
Electricity, Grid	0.94	0.60	1.54	–	1.45*	1.45	0.41	1.95	2.37	0.61	1.02	1.63
Electricity, PV	1	0	1	1.45	–	1.45	1	0	1	1	0	1
Environmental Heat**	1	0.07	1.07	1	–	1	1	0	1	0.72	0.28	1

*In the Netherlands, there is only one primary energy factor for the electricity from the grid. This is an average value for the mix of renewable and non-renewable energy sources.
**District heating in the case of Norway and the Netherlands.

3.4. Performance prediction model and design options for the Spanish demo

3.4.1. Simulation model

The TRNSYS 3D model of this building had 32 zones. In general, the model included 1 zone per household, but for detailed comfort analysis, there were in addition 4 dwellings that were modelled with 4 zones – one for each room. Two of the detailed dwelling zones were on the typical floor and two on the attic floor to model critically behaving zones. Also, apartments facing northwest and one facing southeast were modelled to evaluate the effects of orientation. The 3rd and 4th floors and the terraces were added as shading objects (and omitted the values of the typical floor (5th) in a later stage) to speed up the computation process.

3.4.2. Base case design

The properties of the base case building envelope are identical to the values of the Spanish regulation [44]. The heat generation system consists of three centralized air-to-water heat pumps that cover space heating and DHW energy demand of the whole building. The heat pumps support both systems, yet the DHW is prioritized over the heating system. The base case includes an average occupancy profile (2.46 occupants per household); energy-aware user behaviour that includes temperature based natural ventilation control, temperature- and radiation-based shading control with a shading factor 70 %, and occupancy-based heating set-point control. It is based on the current climate and current energy prices. The electric load of the building is supported by the photovoltaic system that is located on the roof.

3.4.3. Design options

The design options for the Spanish demo are presented in Table 4 and Table 5 and include envelope and infiltration, ventilation, solar shading, HVAC and DHW systems, and PV design. The results of the performance predictions are given in Chapter 4.1.1.

3.5. Performance prediction model and design options for the Austrian demo

3.5.1. Simulation model

The model was created with the CEA (City Energy Analyst) tool. A simplified geometry was built via QGIS and georeferenced. The baseline and the different scenarios were calculated with the CEA tool. The tool can evaluate designs at the city or neighbourhood level during early design phases with lower data availability by allowing iterations through different possible scenarios.

Table 4
Key components for testing of design strategies for the Spanish demo case.

Design option	Name	Description
Envelope & Infiltration	CTE	The minimum requirements of Spanish Technical Code (CTE)
	Improved CTE	CTE requirements with small improvements in insulation and airtightness
	High insulated	Insulation thickness is twice the minimum requirements of CTE
Ventilation	CTE	Night ventilation during summer months
	Optimized	Ventilation is based on operative and ambient temperature
Solar shading	CTE	Constant solar shading
	Optimized	Temperature- and radiation-based shading control
HVAC	2-pipes	2-pipes Heating and DHW system
	4-pipes	4-pipes Heating, (Cooling) and DHW system
PV design	SE	PV panels are oriented to southeast (SE)
	W	PV panels are oriented to the west (W)
	E/W	2-faced PV panels, that are oriented to east and west (E/W)
	SE-ZEB	PV panels are oriented to the southeast (SE), and the number of panels is reduced to meet the ZEB concept

Table 5
Key data for testing of design strategies for the Spanish demo case.

Design options	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 Heating DHW	2-pipes Heating DHW	2-pipes Heating DHW	4-pipes Heating DHW	4-pipes Heating Cooling DHW	4-pipes Heating DHW	4-pipes Heating DHW	4-pipes 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

3.5.2. Base case design

The base case envelope requirements were taken from the Austrian technical building guideline, the OIB Guideline 6 [45], which is also in line with the Energy Performance of Buildings Directive (EPBD). The maximum allowed infiltration rate of 1.5 ach is used for the base case scenario, and a window-to-wall ratio of 35 % is specified for all buildings. For heating and DHW, district heating is assumed, as it is the predominant heating type in the city. For cooling, individual AC units are used for every apartment. Occupancy schedules are estimated by the integrated model of the CEA, based on building use. Automatic user control based on room temperature was specified with a heating setpoint of 21/18 °C (day/night) and cooling setpoint of 26/28 °C (day/night). No internal shading was assumed, and for renewable electricity generation, south-facing PV panels were selected for the roof areas.

3.5.3. Design options

The design options for the Austrian demo are presented in Table 6 and include the design choices considered during performance predictions. The results of the performance predictions are given in Chapter 4.1.2.

3.6. Performance prediction model and design options for the Dutch demo

3.6.1. Simulation model

A model of the apartment building was made within TRNSYS18 to simulate the energy uses and indoor environment. The Uden apartment building consists of two wings (see Fig. 5). For each floor of a wing, all apartments were modelled as one (thermal) zone. In the TRNSYS model, electricity uses and gains for lighting, fans, equipment, and occupants were simulated. The electricity production of the PV panels was modelled using the radiation processor in TRNSYS18. A domestic hot water vessel of 150 L is to be installed in each apartment. The energy demand for DHW was calculated according to the Dutch EPB standard (NEN7120). It was assumed that the vessel was filled once a day for a period of 2 h. A fixed ventilation rate was used corresponding to the average ventilation rate

Table 6
Key data for testing of design strategies for the Austrian demo case.

Strategy	Base case	Option 1 (1)	Option 2 (2)
Passive options (PO) U-values are given in W/(m^{2}K)	Wall U values 0.35 Floor U values 0.40 Roof U values 0.20 Window U values 1.4 Infiltration rate 1.5 ach	Wall U values 0.14 Floor U values 0.18 Roof U values 0.13 Window U values 0.69 Infiltration rate 1.0 ach	Wall U values 0.13 Floor U values 0.14 Roof U values 0.10 Window U values 0.65 Infiltration rate 0.6 ach
Shading system (S)	No shading	Manually controlled shading	–
HVAC design and control (HV)	District heating, radiators	Heat pumps with floor heating and cooling, SCOP = 4.0	Heat pumps with floor heating and cooling combined with heat recovery ventilation and PI controller
On-site renewable electricity (R)	PV panels only on free rooftops	PV panels on both free rooftops and facades	–

Fig. 5. Floor plan of the apartment building in Uden.

that occurs with the installed CO_2-controlled mechanical exhaust system.

3.6.2. Base case design

The base case design consists of:

- U-values of walls: 0.16 W/(m^{2}K), U-value of floor: 0.20 W/(m^{2}K), U-value of roof: 0.12 W/(m^{2}K), U-values of windows: 1.0 W/(m^{2}K), glass-to-wall ratio of 0.37, and infiltration rate (n50) of 0.3 ACH. This was considered to be the most cost-effective and architecturally viable option for the envelope design.
- A ground source heat pump 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 50 for cooling)
- A domestic hot water vessel (150 L) 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 CO_2 sensor (air change rate depends on CO_2 level)
- PV panels on the roof (195 panels, 310 Wp/panel, orientation S and SWW)

3.6.3. Design options

The design options for the Dutch demo are presented in Table 7 and include DHW filling strategy, air-source heat pump, solar shading, radiators for heating, and heat recovery. The results of the performance predictions are given in Chapter 4.13.

3.7. Performance prediction model and design options for the Norwegian demo

3.7.1. Simulation model

To model the energy and indoor environment performance, a section facing south of the building was extracted from the circular form and modelled in the simulation program IDA-ICE [20]. Curved exposed surfaces towards the north and south of the section were straightened in the model (Fig. 6), while east and west facades

Table 7
Key data for testing of design strategies for the Dutch demo case.

Strategy	Differences with the base case as described in paragraph 3.5.2
Design option1	Hot water vessel DHW filled during the day from 12:00 to 14:00
Design option2	Air source heat pump in each apartment, capacity 3.3 kW, SCOP 3.5 for heating, SCOP 2.1 for DHW, SCOP 7.5 for cooling (COP calculated based upon occurring ambient temperatures). Hot water vessel DHW filled during the day from 12:00 to 14:00
Design option3	Air source heat pump (same as design option2) in combination with solar shading: External solar shading on each orientation of the building. 90 % shading when the total solar load on window $\geq$ 250 W/m^2 DHW boiler filled during the day from 12:00 to 14:00
Design option4	Radiators instead of floor heating. Water temperatures radiators 40-45°C (5°higher compared to floor heating as a result of the assumed dimensions for the radiators). 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
Design option5	Heat recovery ventilation system. Heat recovery of 80 % during heating season, otherwise bypass. Ventilation level average 18,5 dm^3/s per apartment. Less than mechanical exhaust system in base case (25 dm^3/s), due to the better ventilation efficiency. Effective fan power 60 W per apartment instead of 20 W in case of the mechanical exhaust system. DHW boiler filled during the day from 12:00 to 14:00

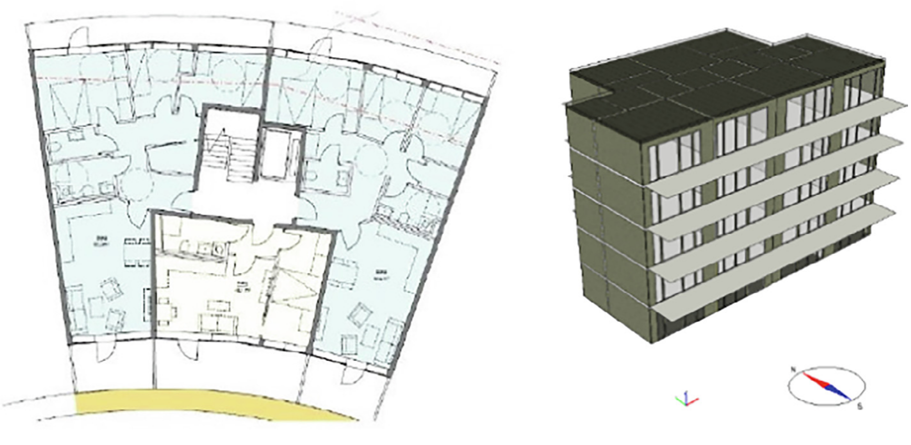

Fig. 6. The digital model that was developed in IDA ICE for environmental and energy performance analyses.

Table 8
Key data for testing of design strategies for the Norwegian demo case.

Strategy	Design options		
Thermal mass	**TM1**: Floor slab increased thickness of 0.05 m with insulation and gypsum panels (0.025 m)	**TM2**: Floor slab thickness increased 0.05 m of exposed concrete	
Shading system and natural ventilation	**SS1:** No solar shading and no natural ventilation	**SS2**: Solar screen automatically activated based on the operative temperature in the room. No natural ventilation. Hypothetical cooling system to estimate overheating.	**SS3**: Solar screen deactivated. Natural ventilation activated. Hypothetical cooling system to estimate overheating.
HVAC design and control	**HV1**: Floor heating w. district heating. Ventilative heating excluded. Natural ventilation under 26 °C excluded.	**HV2**: Radiators w. district heating. Ventilative heating excluded. Natural ventilation under 26 °C excluded.	
Energy supply	**HP1**: Ground source heat pump for space heating, SCOP = 3.5		

were assumed as adiabatic, considering they are adjacent to other dwellings. The extracted cluster included four residential units per floor; living areas facing south and sleeping areas facing north. A sensitivity analysis of the model showed that the effect of orientation on the overall energy performance of the building cluster was limited to 5 %. Simulations were carried out using the Energy Zone Model in IDA-ICE v.4.8. 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.

3.7.2. Base case design

The base case design of the building envelope is set to comply with the Norwegian passive house standard [46]. It includes U-values of walls at 0.10 W/(m^{2}K), U-value of floor at 0.08 W/(m^{2}K), U-value of roof: 0.11 W/(m^{2}K), U-values of windows: 0.8 W/(m^{2}K), glass-to-wall ratio of 0.50, and infiltration rate (n50) of 0.6 ACH. This was considered to be the most cost-effective and architecturally viable option for the envelope design. All space heating energy was considered coming from district heating, as the building is in a concession area. Fresh air is provided by an AHU that preheats the external air to 19 °C and recovers heat from collected exhausted air with a yearly average temperature efficiency of 80 %. The rest of the heating is provided by radiators connected to the district heating system with a supply temperature of 55 °C. The domestic hot water (DHW) needs are fulfilled using an ideal electric boiler common for the whole domain.

3.7.3. Design options

The design options for the Norwegian demo are presented in Table 8 and include thermal mass, shading system, floor heating and ground source heat pump. The results of the performance predictions are given in Chapter 4.1.4.

3.8. Scenario analyses

Scenario planning aims to identify possible pathways towards a vision of the future through a detailed analysis. In syn.ikia, different future scenarios were developed and analysed to ensure robustness in terms of the energy performance of the demo projects. The overall intention was to check if the energy balance would still be favourable given a series of different boundary conditions. The scenarios included variations of the following three parameters: Climate change (Cl), User behaviour (Ub), and Energy and power cost in relation to flexibility (EpC). Detailed description of the different scenarios can be found in Appendix A.

3.8.1. Climate change

The IPCC panel describes four different storylines related to climate change [47] (ref. Appendix A.1). In the analysis of the environmental and energy performance of the demonstration projects, scenarios A2 and B1 were considered to represent the maximum and minimum impact in terms of global warming. Therefore, the climate scenario analyses are based upon these (Table 9).

3.8.2. 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 profiles based on "passive" and "active" users have been created based on local climate conditions, national regulatory frameworks, and different buildings' use cultures.

3.8.3. Energy flexibility and power cost

Future energy and power costs depend on national policies, local 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.

3.8.4. Optimistic and pessimistic scenarios

Future scenarios for climate change, user behaviour, and energy/power costs were first modelled separately. However, future conditions, will be characterized by a combination of these factors. For this reason, two combined scenarios were also modelled, i.e., the combination of the most favourable (optimistic scenario) and the least favourable conditions (pessimistic scenario). The pessimistic scenario was used to check the robustness of the project under what could be foreseen as being the least favourable conditions with respect to fulfilling the SPEN targets.

Table 9
Scenarios for climate change used in the energy performance predictions of the demo projects in syn.ikia.

Scenario	IPCC	Year	Description
Cl1	A2	2050	This can be seen as a worst-case climate change scenario. Emissions continue to rise throughout the 21st century. This scenario is useful for predicting mid-century (and earlier) conditions based on current and stated policies [48].
Cl2	B1	2050	This can be seen as an optimistic climate change scenario. The expected global temperature rise in 2100 is limited to 2C. The CO$_2$ emissions from 2010 to 2100 need to be reduced by 70 % [49].

3.8.5. Description of scenarios for the Spanish demo

The Spanish demo included a climate scenario for the current climate, Cl0, in addition to the future prediction based on IPCC B1 and A2, named Cl1 and Cl2 respectively. Four different user behaviour profiles were created based on active and passive users and occupancy size. The active user applies natural ventilation based on temperature, and solar shading is optimally controlled based on temperature and radiation. Further, the heating system is only on when the space is occupied. The passive user does not use natural ventilation, and only uses solar shading when the space is occupied depending on temperature and radiation. The flexibility scenarios include increasing heating and DHW setpoints. Fl0 assume that when there is an excess of PV generation, no changes will be made to the setpoints, and energy is exported to the grid. Fl1 assumes that the DHW and heating setpoints are increased with 5°C and 1°C respectively.

The pessimistic scenario combines a climate scenario based on IPCC A2 (Cl1), passive user behaviour with increased occupancy (Ub3), and an increase of heating and DHW setpoints (Fl1). The optimistic scenario combines the current climate (Cl0) with an active user and standard occupancy (Ub0) and assumes standard operation (Fl0).

3.8.6. Description of scenarios for the Austrian demo

A pandemic user behaviour strategy was created for the Austrian demo, Ub1, where occupants are present all day at home. The second user behaviour scenario assumes conscious lighting use, where lights are switched off during work hours. The flexibility scenario considers the effect of increased setback points for heating and cooling to evaluate the effect of the building's thermal capacity on energy use. For the pessimistic scenario, the IPCC B1 climate (Cl1) was used together with a pandemic situation with a home office. The pessimistic scenario includes climate pattern A2 (Cl2) combined with the use of energy-efficient lighting and higher setpoints for heating.

3.8.7. Description of scenarios for the Dutch demo

Three different user behaviour profiles were created. The first, Ub1, assumed active window use with a result of doubling the ventilation rate. The second, Ub2, is based on occupants always being present at home. The third, Ub3, was based on the use of energy-efficient lighting. For flexibility, two strategies were developed. EpC2 considered an increase of heating setpoint during the day to utilize thermal mass in the floor. Epc3 applied a shift in the use of appliances from the evening to the daytime. Each scenario was simulated using the final design as a starting point, in which the domestic hot water vessel is filled during the day. The pessimistic scenario in the Dutch demo assumed active window use (Ub1) and that the DHW was filled during the night (base case). The optimistic scenario assumed that the DHW was filled during the day (EpC1), the use of energy-efficient lighting (Ub3) and the use of appliances during the day instead of the evening (EpC3).

3.8.8. Description of scenarios for the Norwegian demo

Two user behaviour typologies were created; an 'active' and a 'passive' user. The active user has an understanding of the technical systems and takes action to reduce the energy consumption of the household and chooses to invest in more efficient appliances. The passive user does not take these measures, increases the heating set-point, and opens windows without considering the outdoor weather conditions. The flexibility scenarios defined include the smart use of thermal energy storage and electric vehicle (EV) charging. In the first scenario, Epc1, we increase the heating and DHW setpoint to utilize excess renewable energy generation. In the second scenario, Epc2, we consider daily charging of EVs to increase the self-consumption of the electricity from the building integrated PV system. The pessimistic scenario combines the worst considered climate (Cl2) with a passive user (Ub2) and increased heating setpoint (Epc1). The optimistic scenario includes the perceived best climate scenario (Cl1), an active user, and the presence of EV charging.

4. Results and discussion

4.1. Results and discussion of design options

4.1.1. Spanish demo

Results for the different design options are included in Fig. 7 and in Table B1 in Appendix B. The simulation results of the base case (Case 0) give a total annual primary energy consumption of 43.0 kWh/m^2 with a non-renewable primary energy of −4.8 kWh/m^2, indicating energy export. The average supply cover factor is between 0.1 and 0.2, indicating that relatively small fraction of the on-site generated electricity is used directly in the building for EPB uses.

Case 0, 1 and 2 are simulated to determine the optimal level of insulation, together with user awareness changes (ref. Table 5). Comparing Case 0 and Case 1, the overheating hours are reduced from 5.6 % to 1.3 % and the annual heating demand is reduced from 15.9 to 9.9 $kWh/(m^2yr)$. Case 2 has a bit lower heating demand (9.6 $kWh/(m^2yr)$), but a bit higher annual overheating (1.4 %), which makes Case 1 the best performing of those options. Case 3 introduces a 4-pipe system (that would allow installing cooling in the future if needed) instead of 2-pipe ones (Case 2), which leads to significantly improved COPs of the systems and a reduction in total primary energy consumption by 34 % compared to Case 0. Case 4 includes the addition of a cooling system, and therefore the overheating that is present in Case 3 is replaced by a high cooling load of 9.5 $kWh/(m^2\ yr)$. The high cooling load indicates the strong need to engage the users to use the passive systems of the building. Cases 5, 6 and 7 introduce different PV designs applied to the previous best scenario (Case 3). When changing the orientation or reducing the number of panels, the PV production drops. Therefore, the total primary energy consumption increases, leaving Case 3 as the highest performing option (Fig. 7).

4.1.2. Austrian demo

A hierarchical workflow was used to select design options for simulation. First, to lower the energy demand, passive design options were evaluated with multiple sets of U-values, infiltration rates, and shading elements. Then, two different HVAC options were assessed for each passive design option. Finally, alternative renewable options were assessed. Results are presented in Fig. 8, with detailed results in Appendix B.2.

The results show that changes in envelope construction and infiltration rates have the largest impact on the energy demand. Realistic envelope solutions (POS1 scenario) reduce the heating demand by >70 % and the cooling demand by 48 %. Stricter envelope solutions reduce the heating demand by another 35 % but increases the cooling demand by 20 %. Since the simulations were done in an early phase of design, the PMV at room level were not evaluated at this stage. However, the cooling load gives an indication of the needed energy to keep the indoor temperatures at a comfortable level.

Another option considered includes the use of a common ground source heat pump system for the development. In this option, the radiators are replaced by floor heating and cooling to reach a better system efficiency (HV1). In another step, a PI controller and a heat recovery ventilation system are added (HV2) which results in a 24 % reduction in cooling demand and a 6 % reduction in heating demand.

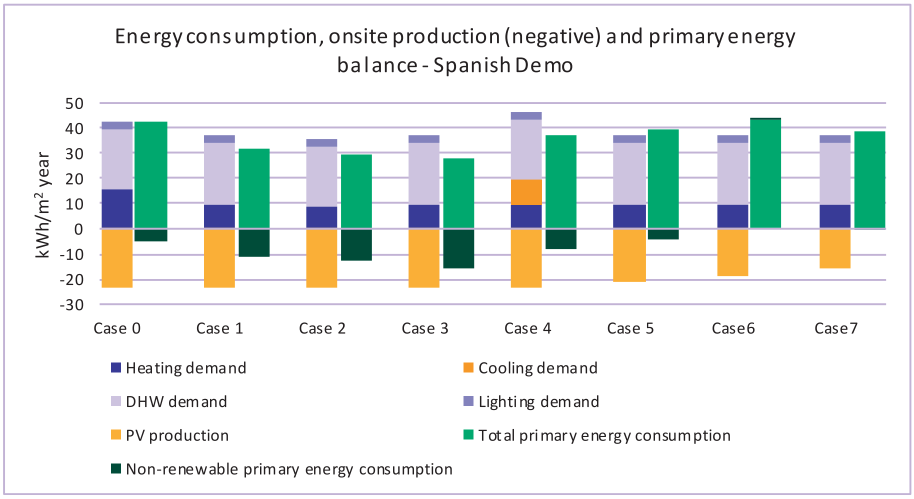

Fig. 7. Results from simulation of design strategies for the Spanish demo project. Negative non-renewable primary energy consumption means that there is a surplus of renewable energy onsite compared to EPB uses.

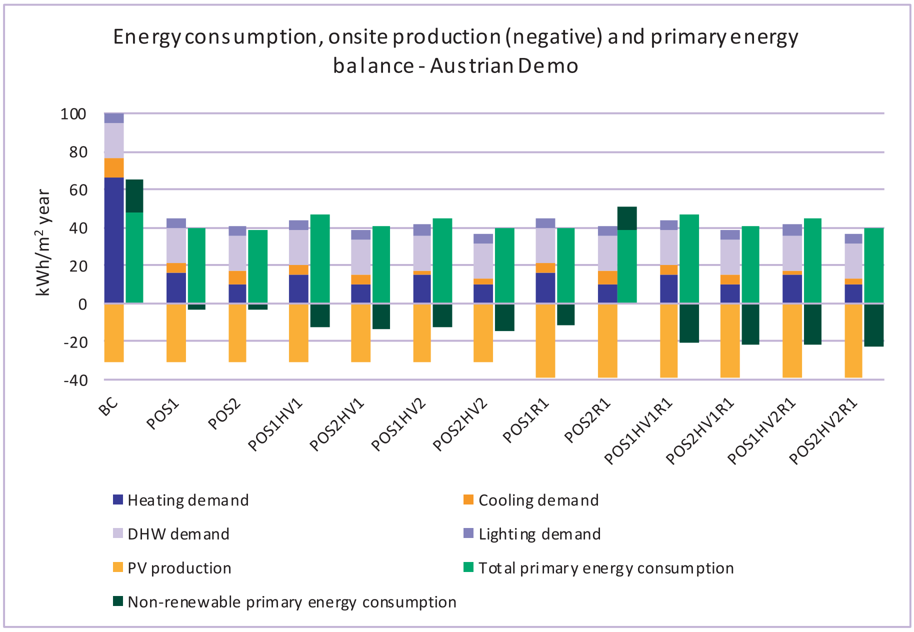

Fig. 8. Results from simulation of design strategies for the Austrian demo project. Negative non-renewable primary energy consumption means that there is a surplus of renewable energy onsite compared to EPB uses.

Lastly, when considering façade integrated PV (scenarios ending with R1), the supply cover factor does not increase significantly compared to the options with PV only on the roofs.

For the final design, the POS2HV2R1 scenario was chosen (the middle option in Table 6), which has a quite well insulated and air tight envelope, a heat pump system, and no ventilation heat recovery. This was regarded to be the most cost-effective solution, considering a trade-off between constructions costs and energy costs. The final design thus resulted in a decrease in the non-renewable energy consumtiopn by 40 kWh/(m^{2}yr) compared to the base case.

4.1.3. Dutch demo

Fig. 9 shows the simulation results for the base case and the five design options. Detailed results are included in Table B.3.1 in Appendix B.3. The simulations show that the plus energy level cannot be achieved with design options 2 and 3 (design options with an air source heat pump). For these options, the efficiency of the air-source heat pump is not high enough to significantly reduce the cooling energy. In design option 3, this is tried solved by the application of solar shading, but the shading leads to increased energy use for heating.

Another goal is to use the on-site PV production internally as much as possible, which influences the amount of imported electricity. The results show that filling the hot water vessel during the day (design option 1) compared to filing during the night (base case) leads to a significant drop in the imported electricity for EPB uses i.e., from 20.1 to 15.6 kWh/(m^{2}yr). This is due to improved matching in time between on-site PV production and electricity consumption. The supply cover factor increases from 0.13 (base case) to 0.33 (design option 1). Design option 4 has a slightly higher supply cover factor (0.36), but using radiators for cooling was considered less desirable due to the risk of condensation. For design option 5, the energy savings due to ventilation heat

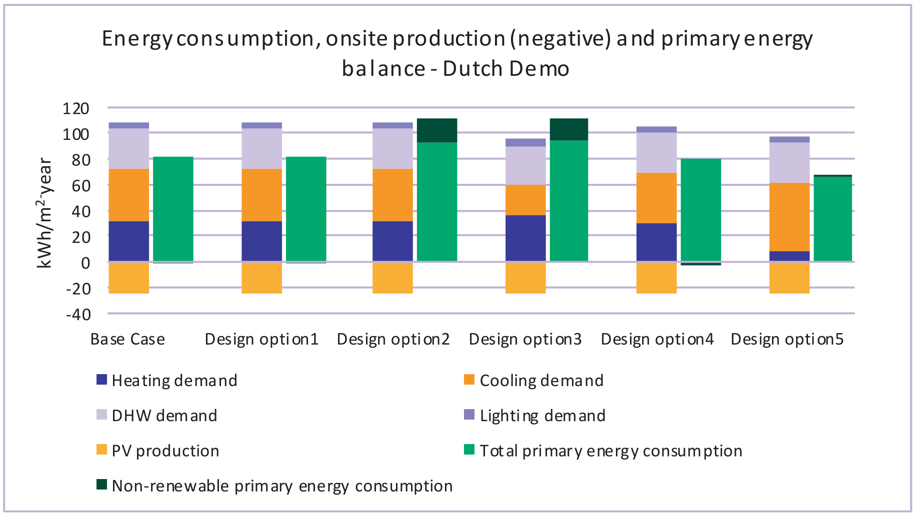

Fig. 9. Results from simulation of design strategies for the Dutch demo project. Negative non-renewable primary energy consumption means that there is a surplus of renewable energy onsite compared to EPB uses.

recovery are exceeded by the extra energy needed for the fans, resulting in a non-renewable energy consumption of 1.36 kWh/(m^{2}yr) compared to -1.99 kWh/(m^{2}yr) in the option with exchaust ventilation.

Design option 1 was chosen as the final design because the annual imported electricity for EPB uses is low (15.6 kWh/m^2), the supply cover factor is relatively high (0.33), the ground source heat pump is in balance (the same amount of energy is subtracted and added to the ground during a year), and the indoor comfort is acceptable.

4.1.4. Norwegian demo

Fig. 10 shows the simulation results for the base case and the 8 design options. Detailed results are included in Table B.4.1 in Appendix B.4. Comparing the options TM1 and TM2, it shows that the exposed thermal mass of the concrete slab (in TM2) decreases the heating demand by about 30 %, but has no effect on the cooling demand because there is no cooling system installed. But also, the thermal comfort value for overheating, represented by the percentage of hours with PMV > 0.5, shows no difference between TM1 and TM2, which is somewhat surprising. However, it may be attributed to the fact that there is no active night cooling strategy, and also to the presence of automated exterior shading, but it needs further investigation. The design option SS1 does not involve any use of a shading system or natural ventilation. This leads to a higher thermal load that in this case was estimated by calculating how much energy a hypothetical cooling system would require. The resulting hypothetical annual cooling load was as high as 42.7 kWh/m^2, which indicates that the lack of solar shading and natural ventilation may cause considerable overheating problems. The design options SS2 (solar screens activated by operative room temperature, no natural ventilation) and SS3 (no solar screens, natural ventilation activated) are calculated in a similar way. These designs reduce the annual cooling demand from 42.7 kWh/m^2 (in SS1) to 12.7 kWh/m^2 (SS2) and 14.7 kWh/m^2 (SS3). However, they have an increase in the EPB uses because of lost solar gains and SS2 gives an increase in lighting consumption due to excessive blocking of daylight.

The option HV1 (floor heating, natural ventilation, and no ventilative heating) presents the best value with respect to non-

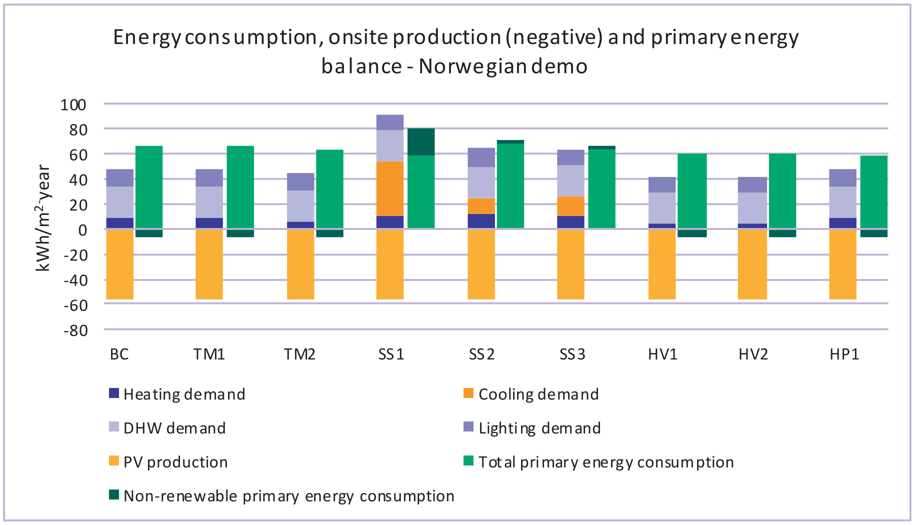

Fig. 10. Results from simulation of design strategies for the Norwegian demo project. Negative non-renewable primary energy consumption means that there is a surplus of renewable energy onsite compared to EPB uses.

renewable primary energy consumption, supply cover factor, and thermal comfort.

4.2. Results and discussion of scenario analyses

4.2.1. Spanish demo

The perceived best design option, Case 3, was selected as a base case for analyzing the impact of future scenarios related to climate change, user behaviour, and energy flexibility. Fig. 12 presents the results of the different scenarios. Detailed results are given in Appendix B.1.

The changes from the current climate (Cl0) to the year 2050 (Cl1 and Cl2) cause a decrease in EPB used electricity, due to higher ambient temperatures and thus lower heating needs. As predicted, the overheating is increased, leaving the current climate scenario the best performing one.

Scenario Ub1 results in larger heating demand and the overheating is increased significantly, due to the poor use of passive and active systems by the users. Compared to the base case, the heating demand in the Ub2 scenario is slightly decreased, due to the higher internal gains of the larger occupancy load. At the same time, the DHW demand and overheating are slightly increased. The scenario with increased occupancy (Ub3) (Fig. 11) has slightly lower heating demand, but increased overheating and DHW demand. In general, user engagement is the key element in thermal comfort and reduction of the thermal demands, leaving the Ub0 scenario as the best performing one.

The Fl1 scenario that introduces higher heating set-points in case of excess PV electricity, result in slightly higher energy demands than for the base case, but the supply cover factor increases from 0.2 to 0.3, while the thermal comfort remains unchanged.

The optimistic and pessimistic scenarios are determined by user comfort in terms of overheating and the primary energy balance of the building, from which the user comfort was prioritized. The heating demand of the optimistic (OPT) scenario is higher than the pessimistic (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 have lower demand than the PES scenario. The optimistic case has lower total primary energy consumption and higher export of energy.

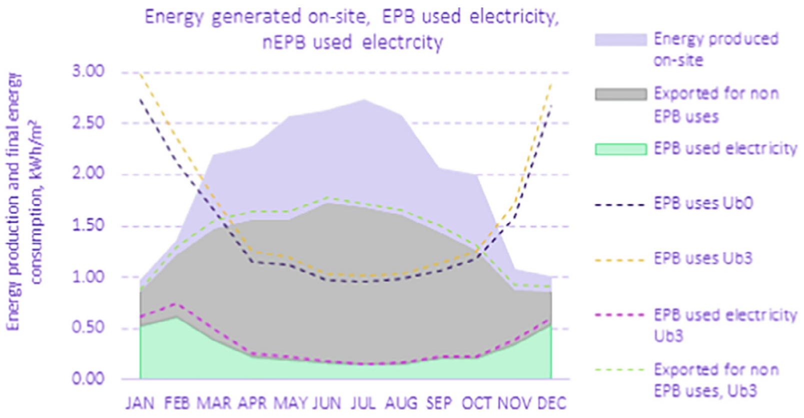

Fig. 11. Annual energy performance for user behaviour scenarios; Ub0 (base case) and Ub3 for Spanish demo.

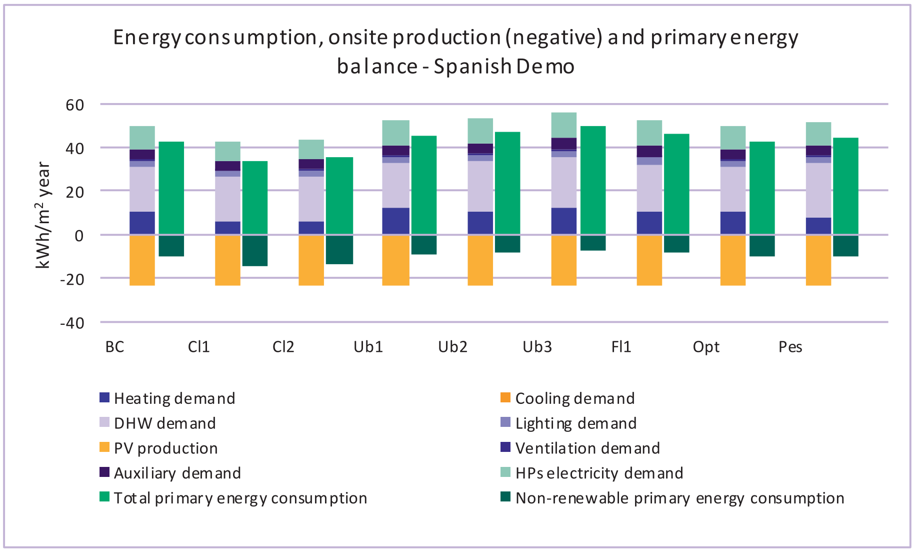

Fig. 12. Annual results for scenarios of the Spanish demo project. Negative non-renewable primary energy consumption means that there is a surplus of renewable energy onsite compared to EPB uses.

4.2.2. Austrian demo

The design option POS2HV1 was selected as a base case for analyzing the impact of future scenarios related to climate change, user behaviour, and energy flexibility. Fig. 14 presents the results of the different scenarios. Detailed results are given in Appendix B.2.

Regarding the two climate scenarios, the largest difference is the cooling load and the final energy consumption, which can be attributed to the higher solar radiation in scenario CL2. When it comes to the two scenarios focused on user behaviour, the pandemic scenario (UB1) (Fig. 13) yields significantly higher heating loads and cooling demands. The supply cover factor is the highest in this scenario. In the scenario where energy conscious lighting is considered, non-renewable primary energy consumption is the lowest.

Finally, since the primary energy balance is positive in both the optimistic and pessimistic scenarios, the development will likely be able to stay plus energy even in the worst conditions in the future.

4.2.3. Dutch demo

The design option 1 (called EpC1 in Fig. 13) was selected as a base case for analyzing the impact of future scenarios related to climate change, user behaviour, and energy flexibility. Fig. 15 presents the results of the different scenarios, and detailed results are given in Appendix B.3.

The main effects of the future climate change scenarios (Cl1 and Cl2) are higher cooling demands and more frequent overheating (PMV > 0.5) since higher outside air temperatures occur more often. Active window ventilation (Ub1) plays a major role in energy consumption (increased heating demand from 32.3 kWh/m^2 in EpC1 to 60.8 kWh/m^2 in Ub1), especially because the dwellings are well insulated. The Ub1 scenario shows the best thermal comfort, but it has the highest energy use and costs, and the plus energy level is not achieved. The scenario with energy-efficient lighting (Ub3) shows the lowest annual primary energy consumption (79.5 kWh/m^2). Shifting the use of the household appliances to the day (EpC3) leads to increased use of the energy produced by the PV panels. This is however not shown in the results, as the given supply cover factor does not consider non-EPB uses.

The pessimistic scenario assumed active window use (UB1) and that the DHW tank was filled during the night (design option 0). This scenario shows an annual non-renewable primary energy consumption of 5.1 kWh/m^2, thus not achieving the plus energy balance. The optimistic scenario assumed that the DWH tank was filled during the day (EpC1), the use of energy-efficient lighting (Ub3), and the use of appliances during the day instead of the evening (EPC3). This scenario gave an annual non-renewable energy

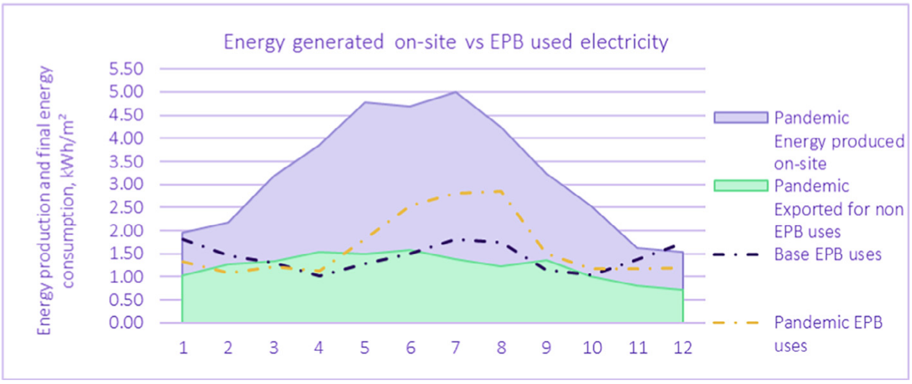

Fig. 13. Annual energy performance for user behaviour scenario Ub1 with energy generated on-site for the base case compared EPB uses for the user behaviour scenario for the Austrian demo.

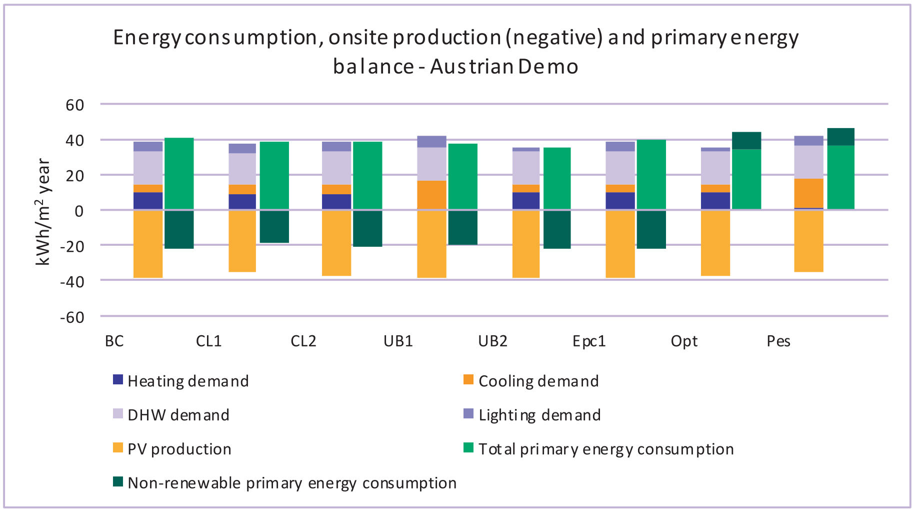

Fig. 14. Annual scenarios results for the Austrian demo project. Negative non-renewable primary energy consumption means that there is a surplus of renewable energy onsite compared to EPB uses.

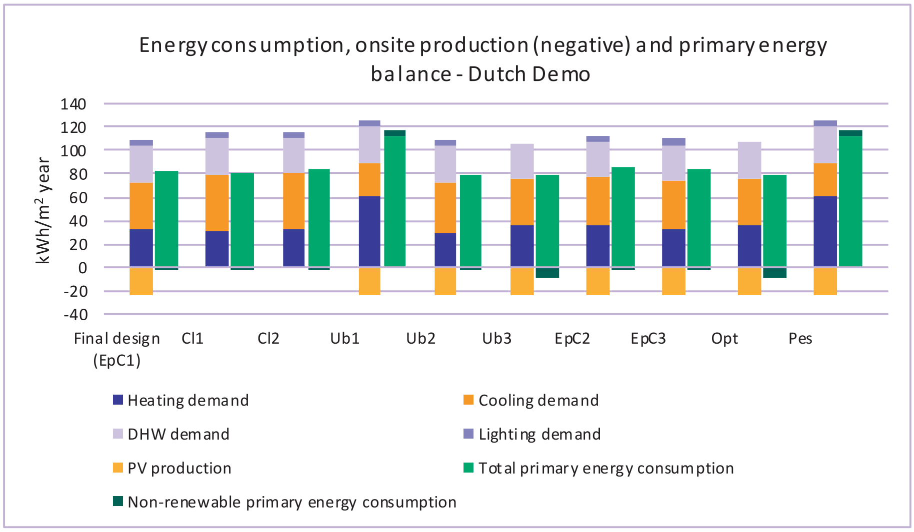

Fig. 15. Scenario results for the Dutch demo project. Negative non-renewable primary energy consumption means that there is a surplus of renewable energy onsite compared to EPB uses.

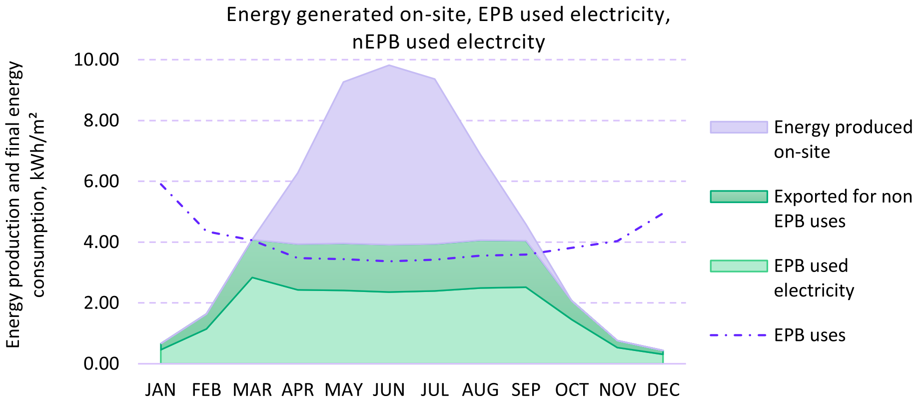

Fig. 16. Annual energy performance for the HV1 energy budget, used as a base case for scenario planning, with energy generated onsite compared to EPB uses.

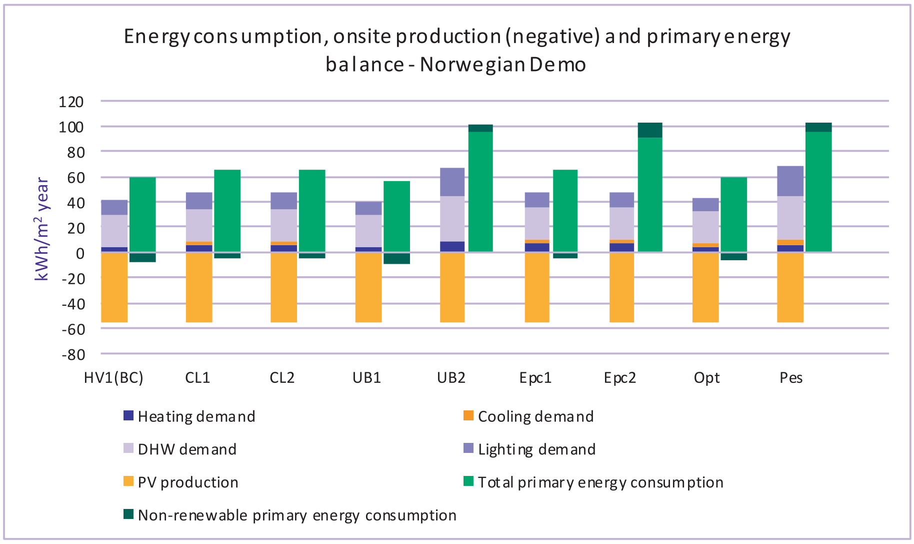

Fig. 17. Scenario results for the Norwegian demo project. Negative non-renewable primary energy consumption means that there is a surplus of renewable energy onsite compared to EPB uses.

consumption of -8.3 kWh/m^2, thus achieving a plus energy balance.

4.2.4. Norwegian demo

The design option HV1 with district heating was selected as the base case (Fig. 16) for analysing the impact of future scenarios related to climate change, user behaviour, and energy and power cost. The simulation results for the different scenarios are presented in Fig. 17, with detailed results in Appendix B.4.

The results show an increase in primary energy consumption for the future climate scenarios, Cl1 and Cl2, which is due to increase in both heating and cooling energy demands. Also, there is an increased risk of overheating in both future climate scenarios. The decrease in the primary energy consumption in scenario Ub1 compared to the base case (from 60 kWh/m^2 to 56 kWh/m^2) is due to the assumption that an active user would be energy conscious. However, the building is already quite energy efficient, so the increase is not very high. On the other hand, the increase in energy demand associated with the passive user scenario (Ub2) is significant (from 60 kWh/m^2 to 95 kWh/m^2). The results for Epc1 shows an increase in heating and cooling consumption due to increased heating set-points. In the second scenario, Epc2, concerning energy flexibility and costs, a part of the on-site produced energy is used for charging the EVs. The results show an increase in the primary energy consumption from 60 kWh/m^2 in the base case to 91 kWh/m^2 for Epc2. The supply cover factor increases from 0.38 in the base case to 0.74 in the Epc2. The final energy balance in the pessimistic scenario is 8.6 kWh/(m^{2}yr), which shows that there is a chance the demo project will not reach the balance, especially if the building occupants are behaving in a way of wasting energy.

5. Conclusions and Further work

The first research question addressed in this article was: *What are the perceived 'best designs' of the buildings in the four climates and contexts with respect to achieving the plus energy balance, while ensuring indoor comfort, minimizing costs, and sustaining high architectural qualities?*

The four design teams in the four different demo sites, have chosen somewhat different designs as their 'best option', but there are still some similarities.

The Spanish demo has chosen a design relying on natural ventilation for occupant comfort, combined with an air-to-water heat pump to supply low temperature radiators and DHW. The building envelope is relatively well insulated and airtight in comparison to the current Spanish building code. Glazing area is moderate with effective movable solar shading, and in combination with a natural ventilation system, the concept can provide thermal comfort without the use of an active cooling system. Roof-mounted PV panels contribute to an energy production of 23.4 kWh/(m^{2}yr). This results in an annual primary energy consumption as low as 28.2 kWh/(m^{2}yr) and a positive energy balance of -15.6 kWh/(m^{2}yr).

The Austrian team has specified a quite well-insulated and airtight building envelope, with a moderate amount of glazing, mechanical exhaust ventilation, along with an effective common ground source heat pump system for heating and cooling. The choice was based on a trade-off between construction costs and energy costs for operation. Building integrated PV provides an energy output of 38.9 kWh/(m^{2}yr). The annual primary energy consumption of this design was calculated to 39.5 kWh/(m^{2}yr), with a primary energy balance of –22.7 kWh/(m^{2}yr).

The Dutch demo has chosen a design with a well-insulated and airtight building envelope in accordance with the Dutch building code. The apartments have mechanical exhaust ventilation with CO_2-sensors and air intake in the façade. For thermal energy supply, the team specified individual ground source heat pumps for space heating and cooling, and DHW. This was considered to be a cost-efficient solution based on the Dutch market situation. The design has a primary energy consumption of 82.4 kWh/(m^{2}yr). Photovoltaic panels on the roof give an energy production of 24.5 kWh/(m^{2}yr), which give a non-renewable energy balance of -1.8 kWh/(m^{2}yr).

The Norwegian team chose to go for a well-insulated and airtight envelope along with a balance mechanical ventilation system with high heat-recovery. The thermal supply was based on district heating, since the building was located in a concession area, and the district heat had a high percentage of renewable energy sources. The design concept has a relatively high glazing ratio compared to the other demo projects (glass to wall ratio of 50 % compared to 35–38 % for the other demos). This was considered necessary to get enough daylight into the relatively deep apartments. To avoid overheating, an effective automated exterior solar shading system was prescribed. The primary energy consumption was calculated to 60.2 kWh/(m^{2}yr). The rooftop PV system was predicted to generate 55.9 kWh/(m^{2}yr), which gave a non-renewable primary energy balances of -7.1 kWh/(m^{2}yr) for this design.

The findings in our case studies are in line with studies reported in the literature. Recent research on the design of plus energy buildings and neighbourhoods shows that cost-effective design solutions should focus on compact, well-insulated and airtight envelopes, effective shading and ventilation systems, ground source heat pump systems or district heating, and roof mounted photovoltaics [50–58]. In warmer climates, free cooling with natural ventilation is often recommended along with the activation of thermal mass [59–63]. Studies in colder climates recommend a higher degree of thermal insulation and airtightness along with mechanical ventilation with heat recovery [64–66].

Conversion factors for primary energy and CO_2 emissions are commonly used to assess the environmental building performance in Europe, and the EPBD requires the use of primary energy factors (PEFs) [9]. However, a study found that there is no consensus on how to calculate or use conversion factors in Europe [67]. The final primary energy use of projects is highly affected by the primary energy factors (PEF) for the energy supply options [68]. Without a standardized method for the calculation of conversion factors, performance assessments can lead to different results and conclusions depending on the selected conversion factors. In addition, the use of PEF is not mandated in Norway and thus available sources for primary energy factors are limited [69]. Hamels et al. [67] suggests to create a common European database for conversion factors, arguing that such a database would also support the development of new building performance assessment methods and smart grid algorithms.

The second research question was: *How robust are the designs with respect to changes in climate conditions and user behaviour?*

This question was addressed in the scenario analyses reported in chapter 4.2. For the Spanish demo case, the future climate scenarios resulted in lower heating needs (about 50 %) but also higher indoor temperatures. For the most pessimistic scenario, the simulations showed that the overheating risks was significant. However, the non-renewable energy balance was negative in all simulated scenarios, showing a high robustness of the positive energy balance. Nevertheless, for optimal performance, the concept relies on active system control and rational energy behaviour of the occupants.

In the case of the Austrian demo, a similar trend for future climate scenarios as for the Spanish demo was observed, though not as profound. In the future climate scenarios, the heating demand decreased by around 15 % while the cooling demand increased by around 30 %. However, due to the effective heat pump system, the effect on the non-renewable energy demand was moderate. The non-renewable energy balances remained safely on the negative side for all scenarios including PV systems, showing a very robust concept.

For the Dutch demo case, the future climate had only a small impact on the heating demand, but a higher impact on the cooling demand (15 % increase). The highest deviations were found in the user behaviour scenarios, that showed that the non-renewable primary energy could vary between −8.6 to 5.1 kWh/(m^2yr). This clearly shows the importance of concious user behaviour in achieving the plus energy goal.

For the Norwegian demo case, the primary energy demand increased only slightly for the future climate scenarios. However, the simulations indicated an increased risk of overheating, Aslo, in case of non-consious user behvaur, the simulations showed that the primary energy consumption by up to 30 %, and lead to increased risk of overheating. This shows that the performance is quite dependant on energy conscious user behaviour, and it could result in the positive energy balance not being achived.

Overall, our findings are in quite in line with other research that has studied the effects of future climate change. A recent article focusing on future climate impact of nearly zero energy buildings in 8 locations around Europe found that heating demands may decrease between 38 and 57 % while cooling demands will increase by 99–380 % depending on location and type of buildings [70].

Also, other studies show that the influence of user behaviour on the energy performance of buildings is significant. A review of the energy-saving potential from occupant behaviour for residential buildings from 2018 estimated energy savings in the range of 10–25 % [71]. The so called energy performance gap, i.e. the discrepancy between the energy consumption predicted during design and the energy use in actual operation, is a well-known concept. A review article investigating the role of occupant behaviour on building's energy performance gap found a performance gap of 55 % in average, with deviations of ± 90 % [72]. However, a recent review of 160 scientific articles concluded that the energy performance gap is complex and not sufficiently understood, and recommends in-depth monitoring and analysis of sufficiently large samples of buildings [73].

The third research question was: *How to utilize energy flexibility measures to increase the self-consumption of on-site renewable energy?* This question was addressed by studying the effect of different user behaviours as well as different setpoints schedules for space and DHW heating. For the Norwegian case, also the introduction of electric vehicle charging was studied.

In the Spanish demo case, a scenario was introduced where the setpoints for space and DHW heating were increased when there was an excess of PV electricity on-site. The results showed that the supply cover factor could be increased by almost 20 % (to 0.29) by this scenario.

The Austrian demo team tested a scenario where the diurnal space heating and cooling setpoint range were slightly increased (by 1 °C) to take advantage of the buildings' thermal mass. This resulted only in a small change in supply cover factor.

In the case of the Dutch demo, the simulations showed that heating the DHW vessel in the apartments during the day instead of during the night, led to a drop in imported electric for EPB uses from 20.1 to 15.6 kWh/(m^2yr), due to better matching with the on-site produced PV electricity. By doing this, the supply cover factor increased from 0.13 to 0.33.

In the Norwegian demo case, it was shown that in a scenario with smart charging of electric cars, the supply cover factor could be increased from 0.38 to 0.74.

Although only a selection of strategies for increased self-consumption was tested in our study, it shows that there is a significant potential for improving the on-site utilization of solar electricity in the dwellings. This is also confirmed by other studies, showing a range of different energy flexibility measures and related effects [74–80]. Our further investigations within the syn. ikia project will include developing flexibility functions taking into account forecasting of weather and energy prices [81] to be tested in the demonstration neighbourhoods. We will also investigate other benefits and challenges of energy flexibility such as peak shaving and user's satisfaction.

Data availability

The authors do not have permission to share data.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

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Appendix

Appendix A. - Design and scenario options

A.1 IPPC Scenarios for climate change.
Table A.1.
A.2 Spanish Demo Scenarios.
Table A.2.1. Table A.2.2.
A.3 Austrian Demo Scenarios.
Table A.3.1. Table A.3.2.
A.4 Dutch Demo Scenarios.
Table A.4.1. Table A.4.2.
A.5 Norwegian Demo Scenarios.
Table A.5.1. Table A.5.2.

Table A.1
Summary of IPCC scenarios for climate change based on [47].

IPCC Storyline	Description
A1	A future world of very rapid economic growth, a global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies.
A2	A highly heterogeneous world where local identities are preserved, the economy is locally oriented, and the global population still increases according to today's patterns.
B1	A 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. T
B2	The emphasis is on local solutions to economic, social, and environmental sustainability. 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.

Table A.2.1
Description of scenarios for Spanish Demo.

Scenario		Parameters describing input in the simulation model	
Cl0		Current climate	
Cl1		Pessimistic future climate scenario	Climate scenario based on IPCC B1 for 2050
Cl2		Optimistic future climate scenario	Climate scenario based on IPCC A2 for 2050
Ub0	Active User + standard occupancy	Natural ventilation	Natural ventilation is used depending on: Temperature; Occupancy > 0
		Solar protection	Optimal use: preventive use of the solar shadings. The solar shading activation depending on: Temperature; Radiation; Shading factor: 70 %
		Heating use	The heating system is used only when: Occupancy > 0
		Occupancy	Average occupancy: 2.46 occupants per apartment
Ub1	Passive User + standard occupancy	Natural ventilation	No use of natural ventilation
		Solar protection	Standard use: the solar shadings are used depending on: Temperature; Radiation; Occupancy > 0; Shading factor: 50 %
		Heating use	The operation of the heating system follows a constant schedule, independent of the household's occupancy
		Occupancy	Average occupancy: 2.46 occupants per apartment
Ub2	Active User + increased occupancy	Natural ventilation	Natural ventilation is used depending on: Temperature; Occupancy > 0
		Solar protection	Optimal use: preventive use of the solar shadings. The solar shading activation depending on: Temperature; Radiation; Shading factor: 70 %
		Heating use	The heating system is used only when: Occupancy > 0
		Occupancy	Increased occupancy: 2.93 occupants per apartment
Ub3	Passive User + increased occupancy	Natural ventilation	No use of natural ventilation
		Solar protection	Standard use: the solar shadings are used depending on: Temperature; Radiation; Occupancy > 0; Shading factor: 50 %
		Heating use	The operation of the heating system follows a constant schedule, independent of the household's occupancy
		Occupancy	Increased occupancy: 2.93 occupants per apartment
Fl0	Energy use	Heating	If there is excess of PV generation: The energy will be exported to the grid
		DHW	If there is excess of PV generation: The energy will be exported to the grid
Fl1	Energy use	Heating	If there is excess of PV generation: Increasing the household setpoint (+1°C)
		DHW	If there is excess of PV generation: Increasing the DHW tank setpoint (+5°C)

Table A.2.2
Description of pessimistic and optimistic scenarios for the Spanish demo.

Scenario		Parameters describing scenario
Pessimistic:	Climate change	Future climate scenario based on IPCC A2 for 2050: Cl1
	User behaviour	Passive user and increased occupancy: Ub3
	Energy flexibility	Flexible operation: Fl1
Optimistic:	Climate change	Current climate: Cl0
	User behaviour	Active user and standard occupancy: Ub0
	Energy flexibility	Standard operation: Fl0

Table A.3.1
Description of scenarios for Austrian Demo.

Scenario		Parameters describing input in the simulation model
Cl1	Optimistic climate change	Optimistic climate scenario based on IPCC B1 for 2050
Cl2	Pessimistic climate change	Pessimistic climate scenario based on IPCC A2 for 2050
Ub1	Pandemic scenario	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	Energy conscious user	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.
Epc1	Energy flexibility	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

Table A.3.2
Description of pessimistic and optimistic scenarios.

Scenario	Parameters describing scenario
Pessimistic:	−2050B1 weather file - Pandemic or home office situation (everybody always at home)
Optimistic:	– 2050A2 weather file - Use of energy-efficient lighting - Use of higher setpoints

Table A.4.1
Description of scenarios for Dutch Demo.

Scenario*		Parameters describing input in the simulation model
Cl1		Climate scenario based on IPCC B1 for 2050
Cl2		Climate scenario based on IPCC A2 for 2050
Ub1	Active window use	Two times higher ventilation rate due to the opening of windows. 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 to 18 h.
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.
EpC2	Heating setpoint during the day increased with 1 K	In scenario EpC2 the space heating setpoint during the day is increased with 1 K. The heating setpoint for the night (23–8 h), day (8–18 h) and evening (18–23 h) 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. 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, from 10 to 12 h and 14–16 h. Additional electricity use takes place in periods when high loads by PV-panels might occur. 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.

*Each scenario is simulated using the final design, in which the domestic hot water vessel is filled during the day, as starting point.

Table A.4.2
Description of pessimistic and optimistic scenarios for the Dutch demo.

Scenario	Parameters describing scenario
Pessimistic:	Hot water vessel for DHW filled during the night (base case) Active window use (scenario Ub1)
Optimistic:	Hot water vessel for DHW filled during the day (scenario EpC1 (final design)) Use of energy efficient lighting (scenario Ub3) Use of household appliances shifted to the day period (scenario EpC3)

Table A.5.1
Description of scenarios for Norwegian Demo.

Scenario		Parameters describing input in the simulation model	
Cl1		Climate scenario based on IPCC B1 for 2050	
Cl2		Climate scenario based on IPCC A2 for 2050	
Ub1	Active User	DHW	DHW is heated in the night when energy price is lower
		Ventilation rate	0.6 ACH (as base case)
		Temperature setpoint	19 °C
		Lighting	Efficient LED. Adjusted schedule, Lux target: 200 lx (as base case)
		Appliances use	Weekend and weekdays have same schedule Power > 10 % less (efficient appliances)
Ub2	Passive User	DHW	35 $kWh/(m^2yr)$
		Ventilation rate	0.8 ACH (as base case) Windows: opened 1 hr/day independently of 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
Epc1	Increase of heating setpoint		Heating setpoint of the building is increased by 1 °C during the whole day and the DHW setpoint increased by 5 °C during the whole day when there is excess of renewable energy generation.
Epc2	Epc1 + Electric car use		EV charging, the average charging session is set to 20 kWh 5 EVs in the model (1 per floor, 1 every 4 apartments) EV's charged 30 times per month = 2.38 kWh/m^2 per month. Surplus energy used for EV charging up to the limit of 2.38 kWh/m^2 per month.

Table A.5.2
Description of pessimistic and optimistic scenarios.

Scenario	Parameters describing scenario
Pessimistic: Cl2 + Ub2 + Epc1	Climate: Oslo-A2Non-responsible use behaviour (passive user) Higher setpoints for heating
Optimistic: Cl1 + Ub1 + Epc2	Climate: Oslo-B1Responsible use behaviour (active user) Electric car use

Appendix B. - Results

B.1 Spanish Demo Results.
Fig. B.1. Table B.1.1. Table B.1.2.
B.2 Austrian Demo Results.
Fig. B.2. Fig. B.2.1. Fig. B.2.2. Fig. B.2.3. Fig. B.2.4. Fig. B.2.5. Table B.2.1. Table B.2.2.
B.3 Dutch Demo Results.
Table B.3.1. Table B.3.2.
B.4 Norwegian Demo Results.
Fig. B.4.1. Fig. B.4.2. Table B.4.1. Table B.4.2.

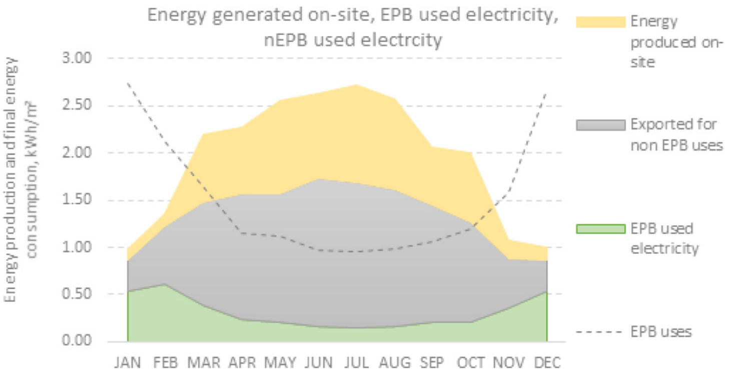

Fig. B.1. Energy generation on-site compared to EBP uses for the base case design of the Spanish demo.

Table B.1.1
Results from simulation of design options for the Spanish demo case (yearly totals).

Main KPIs	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5	Case6	Case7
Heating demand [kWh/m^2]	15.9	9.9	8.6	9.9	9.9	9.9	9.9	9.9
Cooling demand [kWh/m^2]	–	–	–	–	9.5	–	–	
DHW demand [kWh/m^2]	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0
Lighting [kWh/m^2]	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
COP – Heating	2.6	2.4	2.4	4.4	4.4	4.4	4.4	4.4
COP – Cooling	–	–	–	–	3.5	–	–	–
COP – DHW	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
PV production [kWh/m^2]	23.4	23.4	23.4	23.4	23.4	21.4	18.8	15.7
Total primary energy consumption [kWh/m^2]	42.9	31.7	29.3	28.2	36.9	39.6	43.3	38.8
Non-renewable primary energy consumption [kWh/m^2]	−4.8	−11.0	−12.3	−15.6	−8.4	−4.5	0.7	−0.5
Supply cover factor	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1
Annual overheating [%]*	5.6	1.3	1.4	1.3	0.2	1.3	1.3	1.3
Total investment cost [M€]	4.6	4.7	4.7	4.7	4.7	4.7	4.7	4.7
Envelope	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
HVAC system	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
PV system	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

*The annual overheating has been calculated based on the adaptive comfort model [82] which establishes that the comfortable temperature depends on the outdoor conditions and varies accordingly.

Table B.1.2
Summary of results from simulations of scenarios for the Spanish demo case (yearly totals).

Main KPIs	BC	Cl1	Cl2	Ub1	Ub2	Ub3	Fl1	OPT	PES
Heating demand [kWh/m^2]	10.5	5.8	6.4	12.4	10.4	12.2	11.0	10.5	8.2
DHW demand [kWh/m^2]	20.5	20.5	20.5	20.5	23.4	23.4	21.4	20.5	24.4
HPs electricity consumption [kWh/m^2]	10.8	9.1	9.3	11.0	11.6	11.8	11.6	10.8	10.9
Lighting consumption [kWh/m^2]	2.9	2.8	2.9	2.9	3.0	3.0	2.9	2.9	3.0
Appliances consumption [kWh/m^2]	39.9	39.9	39.9	39.9	42.1	42.1	39.9	39.9	42.1
Ventilation consumption [kWh/m^2]	0.5	0.5	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	4.7	4.7
COP of HPs (heating/DHW)	4.2	4.3	4.3	4.2	4.1	4.2	4.1	4.2	4.2
PV production [kWh/m^2]	23.4	23.4	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	43.0	44.8
Non-renewable primary energy consumption [kWh/m^2]	−10.2	−14.5	−13.9	−9.2	−8.2	−7.4	−8.4	−10.2	−9.7
Supply cover factor. [-]	0.24	0.22	0.22	0.25	0.24	0.26	0.29	0.2	0.3
Overheating, yearly average [%]*	1.1	2.0	1.6	42.6	1.0	42.9	1.1	1.1	46.4
Overheating, worst zone [%]	5.5	7.0	7.1	62.0	5.8	62.2	5.5	5.5	63.8

*The annual overheating has been calculated based on the adaptive comfort model [82] which establishes that the comfortable temperature depends on the outdoor conditions and varies accordingly.

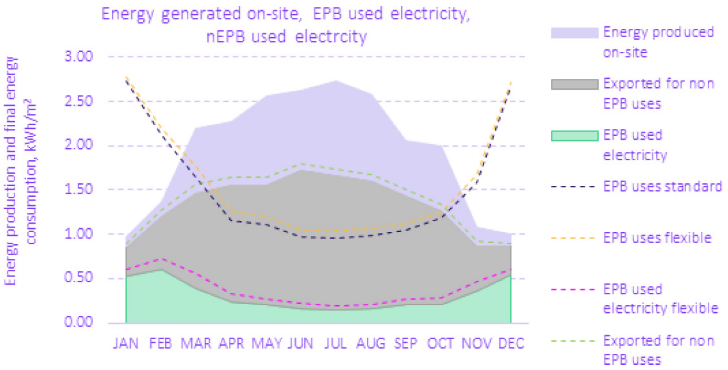

Fig. B.2. Spanish: Annual energy performance for energy flexibility scenario Fl1 (flexible).

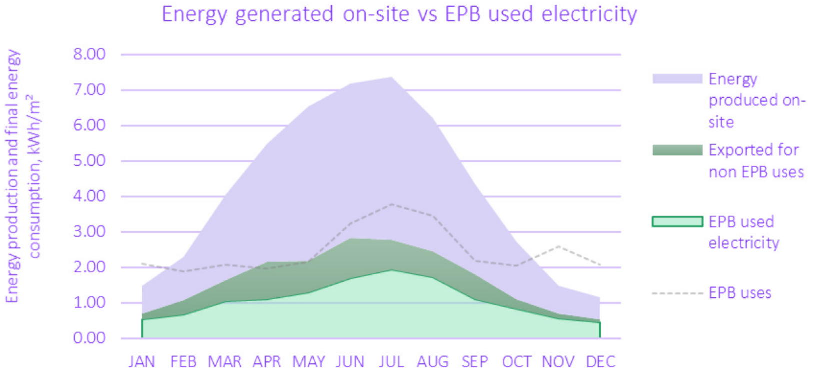

Fig. B.2.1. Energy generation on-site compared to EBP uses for the base case design of the Austrian demo.

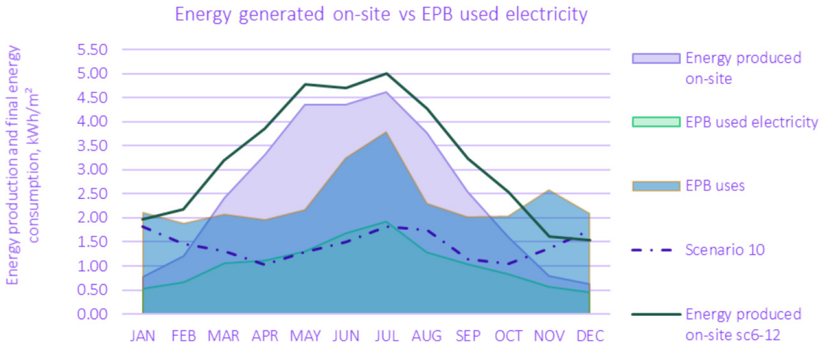

Fig. B.2.2. Energy generation on-site for final design compared to EBP uses for the base case design of the Austrian demo. Negative non-renewable primary energy consumption means that there is a surplus of renewable energy onsite compared to EPB uses.

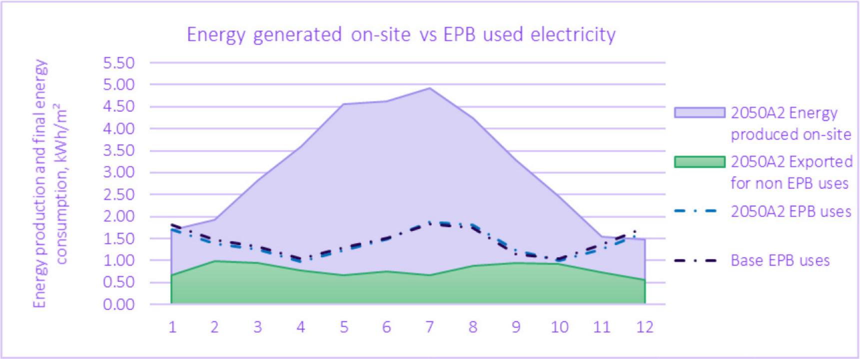

Fig. B.2.3. Energy generation on-site compared to EBP uses CL2 scenario of the Austrian demo.

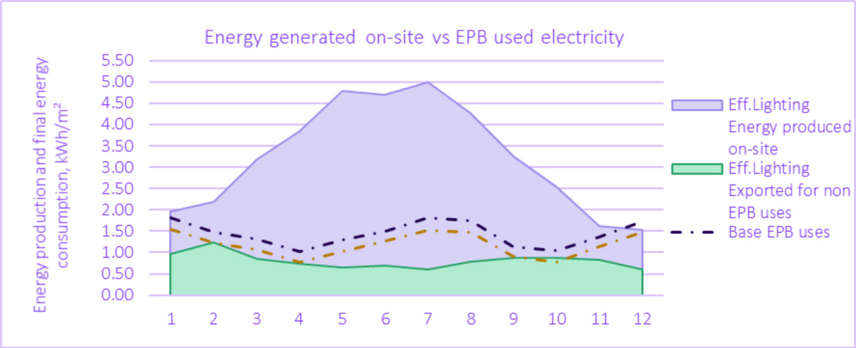

Fig. B.2.4. Annual energy performance for user behaviour scenario Ub2 with energy generated on-site for the base case compared EPB uses for the user behaviour scenario for the Austrian demo.

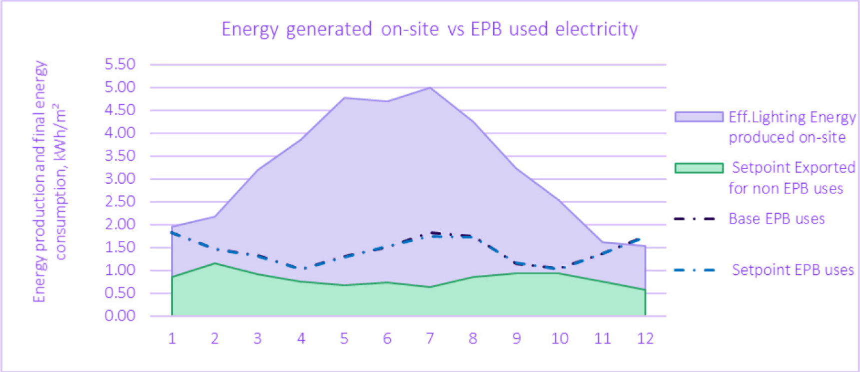

Fig. B.2.5. Annual energy performance for energy flexibility scenario Epc21 considers the tighter setpoints for heating and cooling for the Austrian demo.

Table B.2.1
Results from simulation of design options for the Austrian demo case (yearly totals).

Main KPI	BC	POS1	POS2	POS1HV1	POS2HV1	POS1HV2	POS2HV2	POS1R1	POS2R1	POS1HV1R1	POS2HV1R1	POS1HV2R1	POS2HV2R1
Heating Demand [kWh/m^2]	66.3	16.2	10.5	15.3	10.2	14.7	9.6	16.2	10.5	15.3	10.2	14.7	9.6
Cooling Demand [kWh/m^2]	9.9	5.2	6.2	4.8	4.6	3.0	3.5	5.2	6.2	4.8	4.6	3.0	3.5
DHW Demand [kWh/m^2]	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/m^2]	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3
PV production [kWh/m^2]	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/m^2]	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/m^2]	17.7	−2.9	−3.3	−12.0	−13.3	−12.8	−14.2	−11.5	12.0	−20.6	−22.0	−21.5	−22.7
Supply cover factor	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.3
PMV*>0.5 [%]	–					–	–	–	–	–	–	–	–

*[3].

Table B.2.2
Summary of results from simulations of scenarios for the Austrian demo case (yearly totals).

Main KPI	BC	CL1	CL2	UB1	UB2	Epc1	Opt.	Pes.
Heating Demand [kWh/m^2]	10.2	8.6	8.5	0.6	10.2	10.2	10.0	1.35
Cooling Demand [kWh/m^2]	4.6	5.5	6.35	16.3	4.6	4.6	4.6	16.7
DHW Demand [kWh/m^2]	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4
Lighting [kWh/m^2]	5.3	5.3	5.3	7.14	2.17	5.3	2.2	5.3
COP-Heating, Cooling, and DHW	4	4	4	4	4	4	4	4
PV production [kWh/m^2]	38.9	35.4	37.2	38.9	38.9	38.9	37.2	35.4
Total primary energy consumption [kWh/m^2]	41.0	38.6	38.1	37.5	35.3	39.8	34.6	36.2
Non-renewable primary energy consumption [kWh/m^2]	−22.0	−18.9	−20.8	−19.4	−21.7	−22.1	9.2	9.8
Supply cover factor	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
PMV > 0.5 [%]	–	–	–	–	–	–	–	–

*[3].

Table B.3.1
Results from simulation of design options for the Dutch demo case (yearly totals).

Main KPI	Base Case	Design option1	Design option2	Design option3	Design option4	Design option5
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
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	0.13	0.33	0.28	0.26	0.36	0.37
PMV > 0,5 [%]	11.0	11.0	11.0	1.7	3.4	18.5

Table B.3.2
Summary of results from simulations of scenarios for the Dutch demo case (yearly totals).

Main KPI	Final Design (EpC1)	Climate change		User behaviour			Energy flexibility		Opt.	Pes.
		Cl1	**Cl2**	**Ub1**	**Ub2**	**Ub3**	**EpC2**	**EpC3**		
Heating demand [kWh/m^2]	32.3	31.3	33.3	60.8	29.6	35.6	35.7	33.3	36.7	60.8
Cooling demand [kWh/m^2]	40.8	48.1	47.0	28.6	43.5	39.5	41.0	40.8	39.5	28.6
DHW demand [kWh/m^2]	30.6	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	0	5.2	5.2	0	5.2
PV production [kWh/m^2]	24.5	23.4	23.7	24.5	24.5	24.5	24.5	24.5	24.5	24.5
Total primary energy consumption [kWh/m^2]	82.4	81.4	83.6	112.7	79.5	78.3	86.0	83.5	79.6	112.7
Non-renewable primary energy consumption [kWh/m^2] (A)	33.6	33.6	34.0	40.5	33.0	26.9	34.5	33.9	27.2	40.5
Renewable primary energy delivered by PV [kWh/m^2](B)	35.5	33.9	34.3	35.5	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	–0.32	–0.27	5.05	–2.46	–8.55	–0.98	–1.58	–8.25	5.05
Imported EPB uses [kWhe/m^2]	15.6	15.3	15.7	20.2	15.2	11.5	15.6	15.8	11.8	24.6
Exported EPB uses [kWhe/m^2]	16.8	15.5	15.9	16.7	16.9	17.4	16.2	16.9	17.5	21.1
Environmental use [kWh/m^2]	48.7	47.9	49.6	72.2	46.5	51.4	51.5	49.6	52.4	72.2
Environmental return [kWh/m^2]	41.6	49.0	47.9	29.2	44.4	40.3	41.9	41.6	40.3	29.2
Supply cover factor	0.33	0.34	0.33	0.28	0.33	0.38	0.35	0.32	0.37	0.12
PMV > 0,5 [%]	11.0	15.0	16.2	6.5	13.4	10.5	11.1	12.4	12.0	6.5
Current energy cost [€/apartment per year]	–16.1	–2.8	–2.3	44	–21	–74	–8.6	–13.9	–72	44
Future energy cost [€/apartment per year]*	198	194	199	256	193	146	197	201	150	321

[3] Difference between yearly costs for imported electricity and yearly compensation for exported electricity for an average apartment (useful floor area of 57.7 m^2). Costs and compensation are 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). Costs identical as mentioned in note 3.

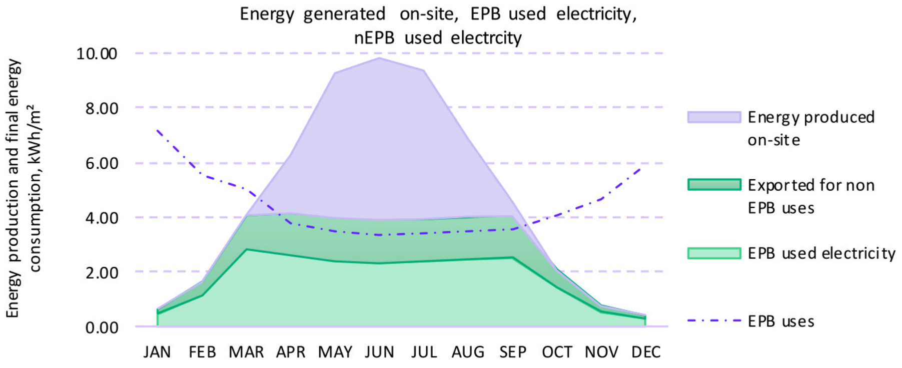

Fig. B.4.1. Energy generation on-site compared to EBP uses for the base case design of the Norwegian demo.

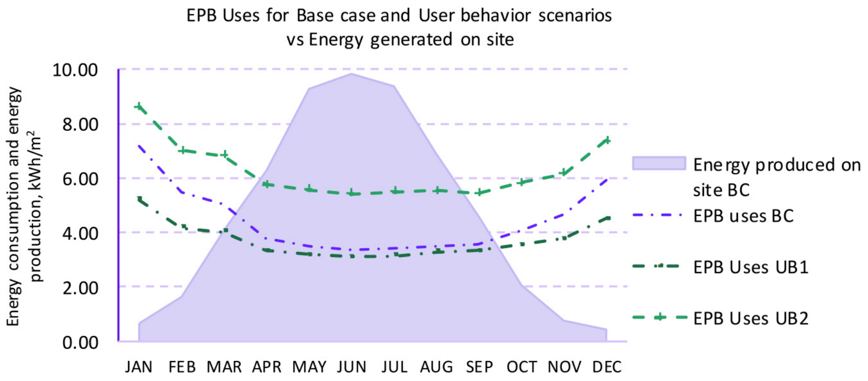

Fig. B.4.2. Annual energy performance for user behaviour scenarios; Ub1 and Ub2, with energy generated on-site for the base case compared EPB uses for the two user behaviour scenarios.

Table B.4.1
Results from simulation of design options for the Norwegian demo case (yearly totals).

Main KPI	BC	TM1	TM2	SS1	SS2	SS3	HV1	HV2	HP1
Heating Demand [kWh/m^2]	9.1	9.4	6.0	10.6	12.0	10.6	4.0	3.7	9.4
Cooling Demand [kWh/m^2]	0	0	0	42.7	12.7	14.7	0	0	0
DHW Demand [kWh/m^2]	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Lighting [kWh/m^2]	13.0	13.0	13.0	13.0	15.0	13.0	13.0	13.0	13.0
PV production [kWh/m^2]	55.9	55.9	55.9	55.9	55.9	55.9	55.9	55.9	55.9
Total primary energy consumption [kWh/m^2]	66.2	66.4	62.6	58.7	67.6	62.7	60.3	60.0	58.5
Non-renewable primary energy consumption [kWh/m^2]	−6.7	−6.8	−6.9	21.9	3.2	3.2	−7.1	−7.1	−6.3
Supply cover factor	0.39	0.39	0.38	0.69	0.55	0.56	0.38	0.38	0.38
PMV*>0.5 [%]	0.40	0.37	0.40	0.31	0.31	0.09	0.40	0.40	0.39

*[3].

Table B.4.2
Summary of results from simulations of scenarios for the Norwegian demo case (yearly totals).

Main KPI	HV1(BC)	CL1	CL2	UB1	UB2	Epc1	Epc2	Opt.	Pes.
Heating Demand [kWh/m^2]	4.0	5.4	5.4	4.3	9.1	7.6	7.6	4.3	6.0
Cooling Demand [kWh/m^2]	0	3.1	3.1	0	0	2.5	2.5	2.8	4.0
DHW Demand [kWh/m^2]	25.0	25.5	25.0	25.0	35.0	25.0	25.0	25.0	35.0
Lighting [kWh/m^2]	13.0	13.5	13.6	10.1	23.5	13.0	13.0	10.4	23.5
Efficiency of Heating / Cooling / DHW	1.1 / 1 / 1.1	1.1 / 1 / 1.1	1.1 / 1 / 1.1	1.1 / 1 / 1.1	1.1 / 1 / 1.1	1.1 / 1 / 1.1	1.1 / 1 / 1.1	1.1 / 1 / 1.1	1.1 / 1 / 1.1
PV production [kWh/m^2]	55.9	56.1	56.1	55.9	55.9	55.9	55.9	55.9	55.9
Total primary energy consumption [kWh/m^2]	60.2	64.8	65.0	55.8	95.0	66.0	91.0	58.8	94.6
Non-renewable primary energy consumption [kWh/m^2]	−7.1	−4.7	−4.7	−9.2	6.2	−5.1	11.4	−6.7	8.6
Supply cover factor	0.38	0.43	0.43	0.36	0.53	0.43	0.58	0.42	0.57
PMV > 0.5 [%]	0.40	0.83	1.35	0.39	0.31	0.47	0.47	0.6	0.5

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