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Sustainable plus energy neighbourhoods

Development and demonstration of plus energy multistorey apartment buildings in four climatic zones

D2.2 DETAILED DYNAMIC MODELS FOR THE PLUS ENERGY BUILDINGS OF SYN.IKIA NEIGHBOURHOODS IN FOUR CLIMATIC ZONES

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Executive Summary

The main goal of this technical report is to present a comprehensive description of the software, modelling methods, approaches, limitations, and final design inputs and outputs used to develop dynamic performance models of the syn.ikia demonstration projects. Additionally, the report presents and discusses updated results related to the simulated energy and indoor air quality performance indicators, which are based on the syn.ikia methodology for evaluating sustainable plus energy buildings and neighbourhoods.

This report (D2.2 on Detailed dynamic models for the plus energy buildings of syn.ikia neighbourhoods in four climatic types) corresponds to tasks 2.1.1- 2.4.1 and 2.2.1-2.4.2, lasting from the project months 1 to 47. These tasks address the evaluation of the building design and construction of seven demonstration projects in four different climate zones using dynamic building performance models based on dynamic computer simulations and syn.ikia's evaluation framework.

The table below summarises the simulation tools, the level of detail, and simulated outputs used to develop the dynamic performance models of the syn.ikia demonstration buildings located in four different climate zones. The dynamic building models were based on detailed multi-zone modelling methods. The well-established and validated building performance tools TRNSYS, IDA-ICE, and DesignBuilder were used to develop the dynamic building performance (thermal load) models. Energy demand and renewable energy generation were simulated in each demonstration case. In the framework of syn.ikia assessed energy includes HVAC, domestic hot water (DHW), Photovoltaic panels (PV) and lighting needs, excluding plug loads, appliances and electrical vehicle consumption.

The simulation results indicated that for all five new-build residential demonstration projects, the negative value of the annual non-renewable primary energy balance is achieved, meaning that the positive energy balance is fulfilled. However, the positive energy balance was not achieved for the two additional continental climate demonstration projects in Austria, that were retrofit projects of the residential buildings.

The developed dynamic building performance models and related results from the syn.ikia demonstration projects offer valuable recommendations for optimizing building performance. These include strategies to enhance energy efficiency by optimizing HVAC systems, improving insulation, adopting energy-efficient appliances, and the effective utilization of renewable energy and flexibility.

The building models should be validated with the use of the on-site measured data, and the performance gap between the simulation and actual building performance should be assessed. This will be addressed in the upcoming report on the operation of plus energy neighbourhoods in the four climatic zones (D2.8).

Demonstration project	Level of detail	BPS software	Time step	Simulated outputs
Mediterranean climate demonstration project in Spain, Barcelona, Santa Coloma de Gramenet. New built multi-family residential building	Detailed multi-zone performance model with detailed HVAC system model	TRNSYS 18	3min	i) Energy demand and generation ii) syn.ikia energy key performance indicators iii) Indoor air temperature
Marine climate demonstration project in Netherlands, Uden. New built multi-family residential building	Detailed multi-zone model with simplified HVAC system model	TRNSYS 18	15min	i) Energy demand and generation ii) syn.ikia energy key performance indicators
Continental climate Demonstration Project GNICE in Austria, Salzburg. New built multi-residential neighbourhood	Detailed building multi-zone performance model with simplified HVAC system model	Designbuilder 7.0.2	15 min	i) Energy demand and generation ii) syn.ikia energy key performance indicators iii) Indoor level of CO2 iv) Thermal comfort – PMV v) Operative temperature vi)Daylight factor
Continental climate Demonstration Project WirInHouser in Austria, Salzburg. Retrofit of a multi-residential neighbourhood	Simplified building performance model with simplified HVAC system model	IDA ICE 4.8	1h	i) Energy demand and generation
Continental climate Demonstration Project, Berchtesgadner Straße 70-72 in Austria, Salzburg. Retrofit of an multi-family residential building	Detailed building multi-zone performance model with simplified HVAC system model	Designbuilder 7.0.2	15 min	i) Energy demand and generation ii)Operative temperature
Subarctic climate demonstration project, Verket Panorama in Fredrikstad, Norway. New built multi-family residential buildings	Simplified building performance model (apartment-based scale) with simplified HVAC system model	IDA ICE 4.8 + PVsyst	1h	i) Energy demand and generation ii) syn.ikia energy key performance indicators iii) Indoor level of CO2 iv) Thermal comfort – PMV v) Operative temperature
Subarctic climate demonstration project, OEN residential building in Oslo, Norway. Planning of new built multi-family residential building.	Detailed building multi-zone performance model with simplified HVAC system model	IDA ICE 4.8 + PVsyst	1h	i) Energy demand and generation

1. Roles and Responsibilities

Name	Role	Responsibility
NTNU	WP2 leader. Coordination of deliverable contents and edition; Contributor and chapter editor	Development of report structure, Data gathering and analysis; Content review; Edition of Deliverables; Coordination; Developer of dynamic building model for Norwegian demo (Panorama, Fredrikstad)
IREC	Contributor, Research Partner	Developer of the dynamic building model for Spanish Demo
TNO	Contributor, Research Partner	Developer of the dynamic building model for the Dutch Demo, Report technical review
ABUD	Contributor, Research Partner	Developer of the dynamic building model for Austrian Demos
SINTEF	Contributor, Research Partner	Developer of the dynamic building model for Norwegian Demo (OEN-Oslo)

2. Introduction

Building energy modelling is an essential design tool that enables the assessment of the implications of various building system choices, construction methods, and occupant behaviour patterns. By employing models, engineers and designers can explore a range of scenarios related to a building's energy usage and environmental impact, drawing from diverse sets of model inputs. In the collaborative design process, energy simulation serves as a crucial linking tool and method delivering forecasts on how the building will perform regarding energy consumption, indoor air quality, operational GHG emissions or costs.

It's important to emphasize that dynamic building models should not be seen as an "add-on" but rather as an essential component of high-quality architecture and design. A significant body of research emphasises the significance of energy modelling in architectural and engineering practices towards energy-efficient and sustainable building design.

Furthermore, the significance of energy modelling extends to the integrated design process, where it plays a central role in providing critical data for the design team. This approach aligns with the principles outlined in the ASHRAE Standard 209, which emphasizes a holistic approach to building performance analysis and design.

In the context of the syn.ikia's demo projects, energy simulation tools were instrumental in evaluating and analysing different design possibilities focusing on energy efficiency, energy generation, and energy flexibility. A broad spectrum of passive design features, including choices related to the building's structure, strategies for shading, and the size and placement of windows, were rigorously tested for their impact on both energy performance and indoor environment quality. Additionally, active design elements, such as selecting heating and ventilation systems, were subjected to simulation and evaluation based on the same set of criteria. This comprehensive approach allows for informed decision-making and paves the way for more sustainable and high-performing buildings.

3. Objectives and description of the report

This report (D2.2) on detailed dynamic models for the plus-energy buildings of the syn.ikia neighbourhoods aims to provide a comprehensive description of the software, modelling methods, limitations, and design inputs used for developing dynamic performance models of the syn.ikia demonstration projects. Additionally, it presents updated results related to the simulated energy performance and other key performance indicators (KPIs) of the demonstration projects, which were a base for evaluating the design performance of the plus energy buildings and neighbourhoods according to defined framework (D3.1 – Methodology Framework for Plus Energy Buildings and neighbourhoods [1])

In Chapter 4, we include a detailed description of the developed dynamic building models for the plus-energy buildings of syn.ikia neighbourhoods in six demonstration projects.

In Chapter 5, the results of key performance indicators (KPIs) related to energy and indoor environmental quality (IEQ) are described.

4. Detailed dynamic models for the plus energy buildings of syn.ikia neighbourhoods

The following sections present in detail developed dynamic performance models from six demonstration multi-family buildings in the syn.ikia project located in four different European climate zones:

- The Mediterranean climate demonstration project in Spain, Barcelona, Santa Coloma de Gramenet (Section 4.1)
- The marine climate demonstration project in the Netherlands, Uden (Section 4.2)
- Continental climate demonstration projects (three demos) in Austria, Salzburg (Section 4.3)
- The subarctic climate demonstration projects (two demos) in Norway (Section 4.4)

4.1 Mediterranean climate demonstration project – Barcelona, Santa Coloma de Gramenet

General description of the demonstration project

The Spanish demo case is a new development in Fondo, a neighbourhood in Santa Coloma de Gramenet, a city close to Barcelona (around 4km) representing a typical Mediterranean climate. The development is a typical infill project in a dense urban area with squares of multistorey apartment blocks. This context is common in many European cities.

The main stakeholder in the project is the owner and developer INCASOL (Dept. of the Catalonian Government/ Catalan Land Institute). This development comprises one apartment block containing 38 apartments with a total gross building area of 4905 m^2 (Figure 1). Construction started in 4Q 2021 and is planned to be finished in 1Q 2024.

Figure 1 Visualisation of the Mediterranean demonstration building in Santa Coloma de Gramenet (Barcelona), Spain

The main aim of developing a dynamic building performance model was to optimise main design features like thermal insulation, percentage of openings depending on facade orientation, shading for sunlight control, the absorptivity of materials, and the colour of façades, achieving the best possible energy performance, indoor environmental comfort, and architectural quality.

Plan view

The Mediterranean demo site-building is a residential complex which has 38 dwellings. The building has two blocks; the larger one has its external side-oriented northwest, and the smaller one has its exterior side-oriented southeast. There is an open courtyard between two blocks, and the households' entrance is also provided from the courtyard side. The building has seven floors organised, as shown in Figure 2. In the northwest block, the ground floor holds commercial areas, and the upper five floors are residential households. In the southeast-oriented block, the first floor contains a common bicycle parking area, and the upper four floors are residential households. The building has parking lots on two floors (ground floor and sub-ground floor). A typical building dwelling consists of two bedrooms, one bathroom, and one open kitchen/living room.

Figure 2 Floor plan of the Mediterranean demonstration building in Santa Coloma de Gramenet (Barcelona), Spain attic floor (left) and the elevation section (right)

3D building model

The 3D model of the demonstration building (Figure 3), which is a base of dynamic performance simulations, has 32 zones. In general, there is 1 zone per household, but for detailed comfort analysis, there are four dwellings with four zones – one for each room. Additionally, three of the total six building floors have been simplified in the 3D model. They are not entirely included in the simulation model to speed up the computation time. Also, the simulation has not included the subground parking floor for the same reason. The 3rd and 4th floors are added to serve shading objects in the simulation. For model simplification purposes, the terraces of the building are added as shading objects. The surrounding buildings are added as shading objects (purple) to the model, as presented in Figure 2.

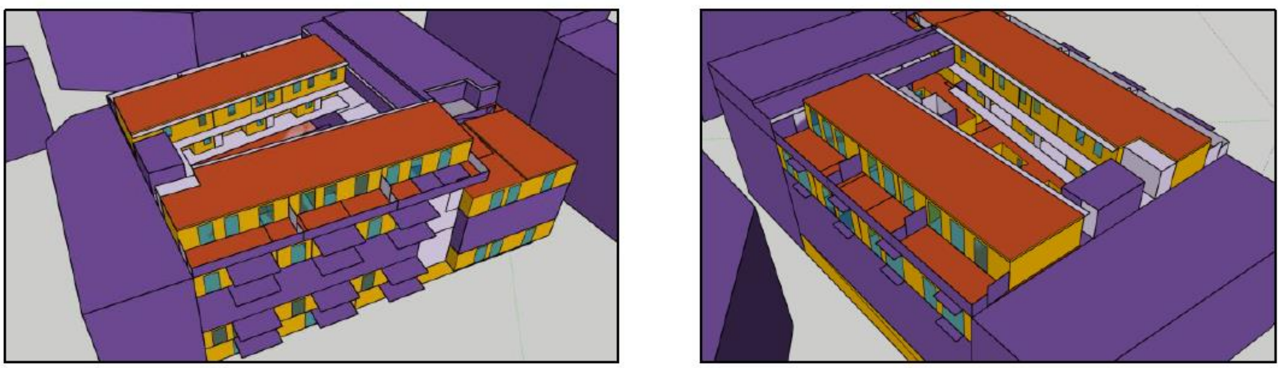


Figure 3 The 3D model of the Mediterranean demonstration building in Santa Coloma de Gramenet (Barcelona), Spain. View from the north (left) and east (right).

Dynamic building performance model - software and simulation timestep

The performance simulations of the Barcelona demo site building are carried out with the transient system simulation tool TRNSYS 18 [2], using SketchUp as a 3D interface. The simulation results timestep was set as 3 minutes. The building model has been performed to provide energy and thermal comfort performance predictions, including renewable energy potential. The development of the dynamic building performance model is based on the Simulation studio interface, which enables the use of individual components whose performance is based on mathematical models. Figure 4 below presents the general overview of the simulation model, whereas a detailed components description is presented in Table 1.

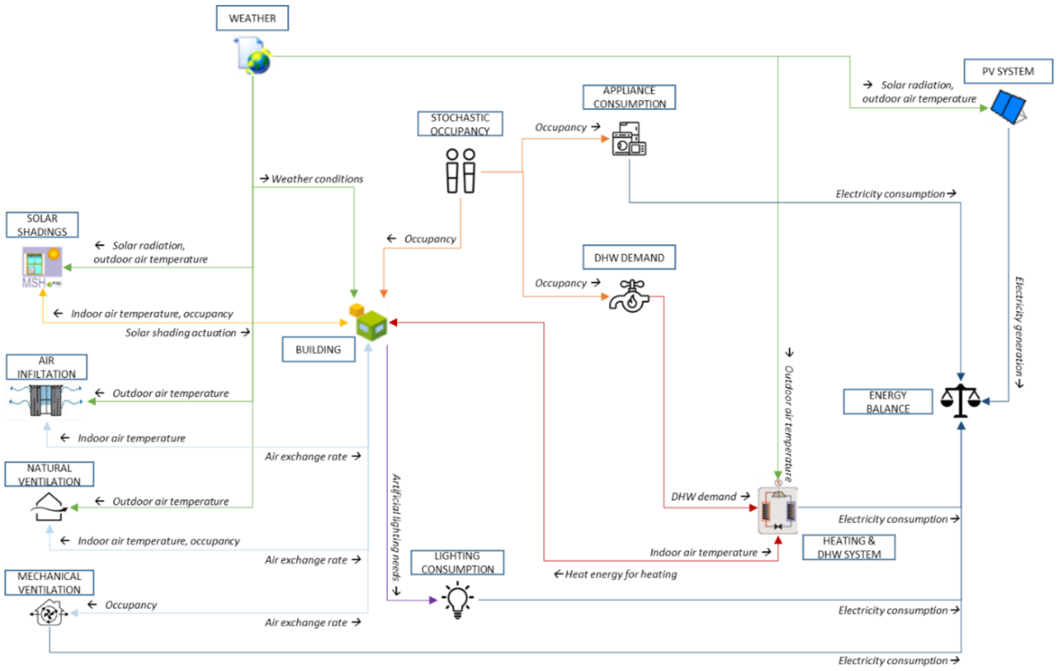


Figure 4 Overview of the building simulation model of the Mediterranean demo developed in TRNSYS 18 software

Table 1 Description of the main components implemented in the building performance model of the Mediterranean demo

Component	Modelling method	Description	Reference
Building zones	Standard library component - Type 56	Multizone building component. This component models the thermal behaviour of a building divided into different thermal zones. A "temperature level" approach is implemented; separate components are used to model the heating equipment. The outputs from the Type 56 zones are used as inputs to the heating system components, producing heating inputs to the Type 56 zones.	TRNSYS 18 Documentation [3]
Weather data	Standard library component - Type 15	Component for reading weather files/data based on typical meteorological years (TM2) format.	TRNSYS 18 Documentation [2]
Stochastic occupancy	Own type	Self-developed component for generating stochastic occupancy profiles.	Tejero, Ortiz and Salome, 2018 [4]
Appliance consumption	Own type	Self-developed component for generating appliance consumption linked to occupancy stochastic profiles.	Tejero, Ortiz and Salome, 2018 [4]
DHW demand	Own type	Self-developed component for generating DHW demand profiles linked to occupancy stochastic profiles.	Cleries, et all, 2022 [5]

Lighting consumption	Own calculation formula	The calculation formula uses the results of the daylight control type of Type 56 and the occupancy profile.	TRNSYS 18 Documentation [3]
Solar shadings	Own calculation formula	Calculation formula of the solar shading actuation based on the solar radiation, the indoor temperature and the occupancy.	-
Air infiltration	Based on EN 15242:2007 standard	Calculation of the infiltration flow rate, considering wind effect and chimney effect.	EN 15242:2007 [6]
Natural ventilation	Based on EN 15242:2007 standard	Calculation of the natural ventilation flow rate for cross-side ventilation. The operation of natural ventilation depends on the occupancy of indoor and outdoor temperatures.	EN 15242:2007 [6]
Mechanical ventilation	Own calculation formula	Calculation of the mechanical ventilation is implemented following a daily schedule.	-
Heating & DHW system	Detailed modelling macro	Details are presented in Table 2-3 and Figures 5-6	
PV system	Type 190 & Type 551	Type 190 determines the electrical performance of a photovoltaic array. The model is based on the calculation method presented by DeSoto et al. (2005). This component is configured with an inverter coupled with the PV array itself. Inverter efficiency effects are thereby considered. Type 551 determines the shaded area of a photovoltaic array.	TRNSYS 18 Documentation [3]
Energy balance	Own calculation	The energy balance has been calculated following the D3.1 Evaluation framework of syn.ikia project	Evaluation Framework for Plus Energy Buildings and Neighbourhoods [1]

In the developed performance model, particular attention was given to developing a detailed model of the HVAC system, whose general framework, scheme, and component descriptions are presented in Figures 5-6 and Tables 2-3. The HVAC system model is based on interconnected macro models (Figure 5), each consisting of multiple components representing the mathematic model of building systems elements (see Figure 6 for example).

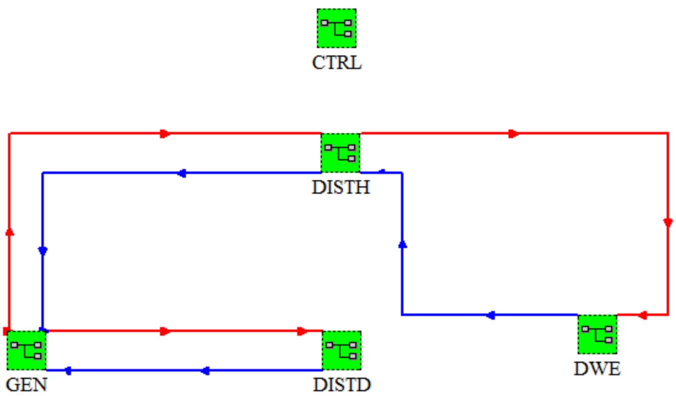


Figure 5 Overview of the Heating and DHW system models: macros configuration - Mediterranean demo

Table 2 Overview of the Heating and DHW system models: macros description

Macro name	Description
GEN	Generation macro, including the heat pump model
DISTH	Distribution of the heating system macro, including the heating storage tank model
DISTD	Distribution of DHW system macro, including the DHW storage tank and the consumption model
DWE	Dwelling macro, which includes an equivalent heat exchanger and the household macros
CTRL	Control macro that centralises the control of the system.

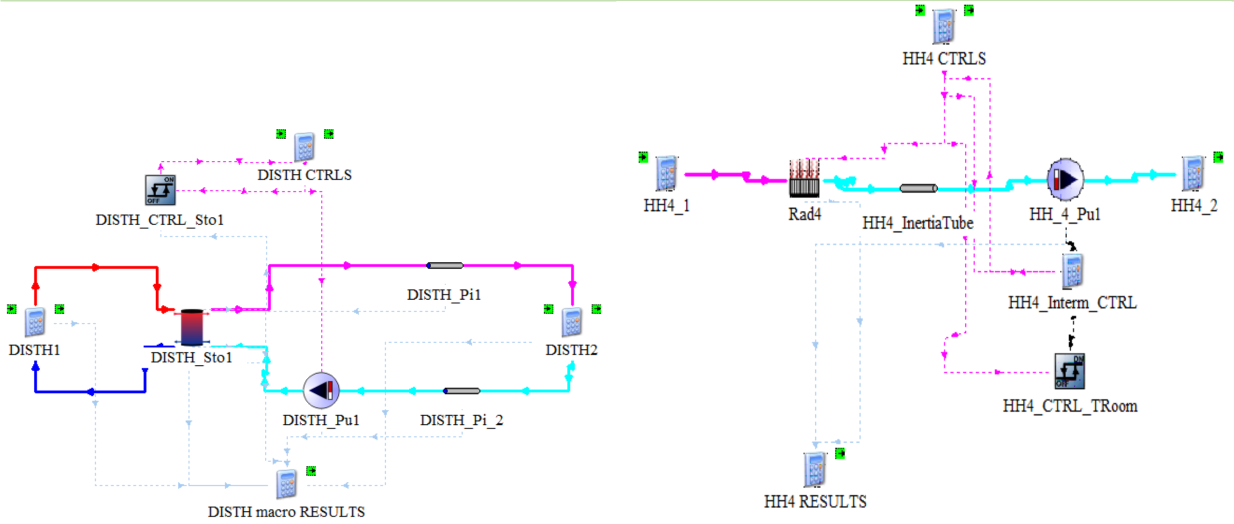


Figure 6 Example of distribution heating system macro (left) and household macro (right) - Mediterranean demo

Table 3 Main components used in the heating and DHW system models - Mediterranean demo

Component	Modelling method	Description	Reference
Heat pumps	Own calculation formula	Self-development component based on the heat pump performance obtained from the datasheet of the manufacturer	LG Hidrokit ARNH08GK3A4
Water tank	Type 534	This component models a cylindrical tank with a vertical configuration. This component has been used to simulate the heating water tank and the DHW tank.	TESS library [7]
Heat exchanger	Type 652	This component models a constant effectiveness/Cmin heat exchanger that can automatically bypass hot-side fluid around the heat exchanger to maintain the cold-side outlet temperature above a user-specified set point. This component has been implemented as an equivalent heat exchanger for the DHW and the heating distribution. It is equivalent to all the household's heat exchangers.	TESS library [7]
Radiator	Type 1231	This component models a heating radiator based on the ASHRAE method outlined in the 2004 ASHRAE Handbook - HVAC Systems and Equipment.	TESS library [7]
Controllers	Type 911	The on/off differential controller generates a control function with a value of 1 or 0.	TESS library [7]

Design inputs and outputs

The detailed presentation of building design inputs and assumptions implemented in the dynamic building model of the Mediterranean demonstration is presented in Table 4, whereas simulated outputs are listed in Table 5.

Table 4 Description of the main simulation design inputs and assumptions of the simulation model – Mediterranean demonstration project

Simulation input	Input description
Weather data	Meteonorm v7 - Weather station: Barcelona city
Building Geometry	In line with the information described above – 3D building model
Building envelope and shading	Building envelope: Façade walls (U=0.26W/m^2K), material layers (from exterior to interior): • External thermal insulation system (ETIS) with plaster and 7cm of XPS insulation material • 14 cm ceramic brick, • plasterboard with 4cm of Rockwool Windows: Aluminium frame (80 % recycled) with thermal bridge break and double glass. U=1.1 W/(m^2K), SHGC=0.67, class 3 air tightness < 9 m^3/m^2h at 100 Pa. Roof (U=0.15 W/m^2K) material layers (from exterior to interior): • Gravel finish, geotextile felt, • 12 cm XPS insulation material, • waterproof layer over a concrete structural floor Infiltration rate of envelope < 0.4 1/h Shading system: In all windows, manually regulated blinds are designed.
HVAC system specifications	The heating and DHW systems include three air-to-water heat pumps. The technical information of each heat pump is: COP (rated): 4.98 Capacity (rated): 50.40 kW Power (rated): 11.94 kW There are three air-to-water heat pumps; each outdoor unit is connected to two indoor units. After the indoor units, there is a collector to distribute the mass flow to the heating and DHW tank. After the heating and DHW tanks, the flow is delivered to the households. Control strategy: The heat pumps should meet the setpoint of the heating and DHW tanks. In case of simultaneity of DHW and heating needs, DHW is prioritised. The heat pumps are configured to operate in a cascade. The setpoints are: HOUSEHOLD T_HEAT= Heating curve T_DHW= 45ºC TANK T_tank_HEAT= Heating curve + 5ºC T_tank_DHW= 45 + 15ºC HEAT PUMP Supply T_HP_HEAT= Heating curve + 10ºC T_HP_DHW= 45 + 20ºC
Renewable energy specification	The Mediterranean demo has local energy production from photovoltaic panels placed on the northwest and southeast block roofs. Number of PV panels: 119 Orientation: South-Est Slope: 30º Total power: 39.1 kWp
Internal loads	Occupancy: Sensible heat - Convective load: 87.7 kJ/h person Sensible heat - Radiative load: 131.5 kJ/h person

	Latent heat: 0.06 kg/h person Lighting: Sensible heat - Convective load: 1.5 kJ/hm^2 Sensible heat - Radiative load: 6.2 kJ/hm^2 Equipment: Sensible heat - Convective load: 4.7 kJ/hm^2 Sensible heat- Radiative load: 11.1 kJ/hm^2
Occupancy schedule	The occupancy has been introduced using a set of stochastic profiles. The average occupancy of the household is 2.46, based on statistical data from Catalonia. Different levels of occupancy have been assigned to each household. The occupancy has an impact on the following elements of the dynamic simulation: - Activation of the different elements that depend on the occupancy: natural ventilation, solar shadings, lighting, and heating system. - DHW demand - Appliances energy consumption - Energy consumption - Thermal comfort, the passive and active strategies are implemented depending on the occupancy of the household and not following an ideal operation (e.g. the natural ventilation is applied only when there is occupancy, although it could be more convenient at other times of the day
Lighting and equipment schedule	The lighting and equipment are related to the stochastic occupancy profile The lighting is activated when there are occupants in the household, and there is not enough daylight. The equipment use follows a stochastic profile related to the occupancy profile.
Occupant behaviour	Activation of the different elements that depend on the occupancy: natural ventilation, solar shadings, lighting, and heating system.
Validation	The energy results of the model have been compared with the design project and the energy certificates to have representative results.

Table 5 Description of the main simulation design outputs of the simulation model – Mediterranean demonstration project

Simulation outputs	Description
Energy and Environmental performance indicators	Calculation of simulation outputs related to energy performance is based on the Methodology Framework for Plus Energy Buildings and Neighbourhoods (D3.1) and includes: a) Non-renewable primary energy balance (kWh/m^{2}a) b) Renewable energy ratio c) Grid purchase factor d) Load cover ratio e) Supply cover ratio f) Net energy/Net power (kW) g) Peak delivered and peak exported power (kW) h) Connection capacity credit i) Energy produced on site (kWh)
Indoor environmental quality indicators	Calculation of simulation outputs related to indoor environmental quality is based on the Methodology Framework for Plus energy Buildings Neighbourhoods (D3.1) and includes: a) thermal comfort with the use of the adaptive comfort model b) indoor temperature

4.2 Marine climate demonstration project – Apartment building in Uden, Netherlands

General description of the demonstration project

The Dutch Demonstration project is a new residential development in a mid–sized town named Uden, located in the North Brabant province (Figure 7). It is located near sports locations and an industrial park. The 'Loopkantstraat' is between Uden's residential and business areas. The development comprises an apartment complex with 39 apartments spread over three floors. The total plot area for this development is 3860 m^2, with a usable floor area of 2394 m^2. The building shell is well insulated, better than according to the Dutch standard required. Insulated cavity walls are used with bricks on the outside and sand-lime bricks on the inside. Concrete floors and roofs are used. The window-to-wall ratio is about 37%.

Figure 7 Visualisation of the Marine climate demonstration building in Uden, Netherlands

Plan view

The building is L-shaped and consists of 3 floors. A drawing of the plan of the ground floor is given in Figure 8. In total, 39 apartments are available, namely 18 two-room apartments and 21 three-room apartments (Figure 8). Nearby the connection of both wings of the building, a central entry is located from which the galleries on the outside can be reached. One wing of the building is orientated on North-Northwest and one on east. The total length of the North-West facade is roughly 60 m, and the East facade is roughly 67 m. Behind the building, a parking lot is present.

Figure 8 Ground floor of the apartment building in Uden – marine climate demonstration project

3D building model

In the simulation model, each floor of each building wing is modelled as one zone. The amount of shading due to adjacent buildings and trees is limited, while these are at some distance and relatively not very tall. A visualization of a 3D layout of the building model is not available; the geometrical information of the building was directly inserted into the simulation software being plain text-files (see description in the section below).

Dynamic building performance model - software and simulation timestep

The dynamic building model was developed with the use of the TRNSYS 18 software [2], with a simulation timestep of 15 minutes. Using TRNBuild (=building interface in TRNSYS) the building model is made. This concerns the layout and dimensions of the building, the properties of the building construction, the orientation of the building, the floor heating system and so on. The simulation model (the so-called deck file in TRNSYS) calls during the simulation the building model and provides for each timestep, based upon self-developed formulas and equations given in the deck file, the input concerning occupancy, ventilation, infiltration, and internal loads such as appliances, lighting, and persons. The inputs for occupancy are shown in figure 9 and in general the inputs are described in table 6. How the building model is called from the deck file is illustrated in the figures 10-12. In these figures the parameters supplied to and from the building model are given.

Furthermore, the simulation of the HVAC system was based on a simplified model, where the heating and cooling system performance model was based on the fixed efficiency of the designed ground source heat pump, whose performance was based on on-site measurements from similar research and development projects.

```
*** number of appartments**************************************************
equation 6
napp_bgA=9
napp_1verdA=9
napp_2verdA=7
napp_bgB=5
napp_1verdB=5
napp_2verdB=4

*** occupants *************************************************************
equation 8
!       napp (2kmr,3kmr) * (npers_niet_werkend + npers_werkend * (1-working_period))
npers_bgA=6*(1+1*(1-work_period))+3*(1+2*(1-work_period))
npers_1verdA=6*(1+1*(1-work_period))+3*(1+2*(1-work_period))
npers_2verdA=6*(1+1*(1-work_period))+1*(1+2*(1-work_period))
npers_bgB=5*(1+2*(1-work_period))
npers_1verdB=5*(1+2*(1-work_period))
npers_2verdB=4*(1+2*(1-work_period))

Ppers = 100*3.6*(day_period+evening_period)+70*3.6*(1-(day_period+evening_period))  !kJ/h heat per persoon, 100W overdag en avond, 70W nacht
Ppers_tot=(npers_bgA+npers_1verdA+npers_2verdA+npers_bgB+npers_1verdB+npers_2verdB)*Ppers  !kJ/h heat for all persons
```

```
*** floorsurface ********
equation 6
opp_bgA= 476       !m2
opp_1verdA= 476    !m2
opp_2verdA= 338    !m2
opp_bgB= 332       !m2
opp_1verdB= 332    !m2
opp_2verdB= 266    !m2
```

Figure 9 Example of modelling design input related to the number of occupants, number of apartments and floor surface in the TRNSYS deck file - marine climate demonstration project.

```
***BUIfile*********************************************************************************************
!UNIT 56 TYPE 56 MULTI ZONE BUILDING
!PARAMETERS 3
!31 0 0.5               !LU bui-file / don't recalc starnetw / Aop (Top = AopxTair + (1-Aop)xTsurf)

UNIT 56 TYPE 56   Type56a-TRNFlow

PARAMETERS 14
31              ! 1 LU bui-file
0               ! 2 Don't recalc starnetw
0.50            ! 3 Aop (Top = AopxTair + (1-Aop)xTsurf)
-1              ! 4 NOt used - LU for monthly summary
-1              ! 5 NOt used - LU for hourly temperatures
-1              ! 6 Not-used - Lu for hourly loads
1               ! 7 Comis output / Tstep   <0--> output per timestep, 0> --> output per iterationstep
10              ! 8 Altitude of building
10              ! 9 Height of meteo pylon
10              ! 10 Altitude of weather station
0.3             ! 11 Velocity profile at weather station
!0.000001     ! 12 Tolerance for internal iterations
0.001       ! 12 Temperature?? Tolerance for internal iterations
500             ! 13 Maximum number of internal iterations
0.1             ! 14 Minimum relaxation factor
```

Figure 10 Multizone building component Type 56 modelled in the TRNSYS deckfile - marine climate demonstration project.

```
************* REQUIRED INPUTS *************
*:InpNR   | Label                    | Unit        | INPUT DESCRIPTION

*  |    1 | TAMB                     | C           | ambient temperature
*  |    2 | RELHUMAMB                | %           | relative ambient humidity
*  |    3 | TSKY                     | C           | effective sky temperature for longwave radiation exchange (FSKY)
*  |    4 | TSGRD                    | C           | effective ground temperature for longwave radiation exchange (1-FSKY)
*  |    5 | AZEN                     | degrees     | solar zenith angle
*  |    6 | AAZM                     | degrees     | solar azimuth angle (0=facing equator, 90=facing west, -90=270=facing e
*  |    7 | IT_DAK                   | kJ/hr.m^2   | Incident radiaiton for Orientation DAK
*  |    8 | IT_SSE_330               | kJ/hr.m^2   | Incident radiaiton for Orientation SSE_330
*  |    9 | IT_SWW_60                | kJ/hr.m^2   | Incident radiaiton for Orientation SWW_60
*  |   10 | IT_NNW_150               | kJ/hr.m^2   | Incident radiaiton for Orientation NNW_150
*  |   11 | IT_E_265                 | kJ/hr.m^2   | Incident radiaiton for Orientation E_265
*  |   12 | IT_S_355                 | kJ/hr.m^2   | Incident radiaiton for Orientation S_355
*  |   13 | IT_W_85                  | kJ/hr.m^2   | Incident radiaiton for Orientation W_85
*  |   14 | IB_DAK                   | kJ/hr.m^2   | Incident beam radiaiton for Orientation DAK
*  |   15 | IB_SSE_330               | kJ/hr.m^2   | Incident beam radiaiton for Orientation SSE_330
*  |   16 | IB_SWW_60                | kJ/hr.m^2   | Incident beam radiaiton for Orientation SWW_60
*  |   17 | IB_NNW_150               | kJ/hr.m^2   | Incident beam radiaiton for Orientation NNW_150
*  |   18 | IB_E_265                 | kJ/hr.m^2   | Incident beam radiaiton for Orientation E_265
*  |   19 | IB_S_355                 | kJ/hr.m^2   | Incident beam radiaiton for Orientation S_355
*  |   20 | IB_W_85                  | kJ/hr.m^2   | Incident beam radiaiton for Orientation W_85
*  |   21 | AI_DAK                   | degrees     | angle of incidence for radiation DAK                             |
*  |   22 | AI_SSE_330               | degrees     | angle of incidence for radiation SSE_330                         |
*  |   23 | AI_SWW_60                | degrees     | angle of incidence for radiation SWW_60                          |
*  |   24 | AI_NNW_150               | degrees     | angle of incidence for radiation NNW_150                         |
*  |   25 | AI_E_265                 | degrees     | angle of incidence for radiation E_265                           |
*  |   26 | AI_S_355                 | degrees     | angle of incidence for radiation S_355                           |
*  |   27 | AI_W_85                  | degrees     | angle of incidence for radiation W_85                            |
*  |   28 | GRDREF                   | any         | ground reflectance (range 0...1)                    | GRDREF
*  |   29 | WINDVEL                  | m/s         | Wind speed at meteo station reference height (TRNFlow Input)
*  |   30 | WINDDIR                  | degrees     | Wind direction (TRNFlow Input - 0° wind from north, 90° wind from east
*  |   31 | PAMB_ABS                 | Pa          | Absolute ambient barometric pressure (TRNFlow Input)
*  |   32 | CONAMB_1                 | kg/kg       | Ambient concentration of pollutant no. 1 (TRNFlow Input)
*  |   33 | CONAMB_2                 | kg/kg       | Ambient concentration of pollutant no. 2 (TRNFlow Input)
*  |   34 | CONAMB_3                 | kg/kg       | Ambient concentration of pollutant no. 3 (TRNFlow Input)
*  |   35 | CONAMB_4                 | kg/kg       | Ambient concentration of pollutant no. 4 (TRNFlow Input)
*  |   36 | CONAMB_5                 | kg/kg       | Ambient concentration of pollutant no. 5 (TRNFlow Input)
*  |   37 | TRNFLOW                  | any         | Switch to turn off TRNFLOW (TRNFlow Input - 0... TRNFLOW off, >0...TRN
*  |   38 | Tground                  | any         | grondtemperatuur
*  |   39 | npers_bgA                | any         | aantal personen
*  |   40 | npers_1verdA             | any         | aantal personen
*  |   41 | npers_2verdA             | any         | aantal personen
*  |   42 | npers_bgB                | any         | aantal personen
*  |   43 | npers_1verdB             | any         | aantal personen
*  |   44 | npers_2verdB             | any         | aantal personen
*  |   45 | Ppers                    | kJ/hr       | warmteafgifte per persoon
*  |   46 | inf_bgA                  | 1/hr        | infiltratievoud
*  |   47 | inf_1verdA               | 1/hr        | infiltratievoud
*  |   48 | inf_2verdA               | 1/hr        | infiltratievoud
*  |   49 | inf_bgB                  | 1/hr        | infiltratievoud
*  |   50 | inf_1verdB               | 1/hr        | infiltratievoud
*  |   51 | inf_2verdB               | 1/hr        | infiltratievoud
*  |   52 | Pelec                    | kJ/hr.m^2   | warmteafgifte elektrische apparatuur
*  |   53 | Pvent                    | kJ/hr       | warmteafgifte ventilatieunit
*  |   54 | Pverl                    | kJ/hr.m^2   | warmteafgifte verlichting
*  |   55 | opp_bgA                  | m^2         | vloeroppervlak
*  |   56 | opp_1verdA               | m^2         | vloeroppervlak
*  |   57 | opp_2verdA               | m^2         | vloeroppervlak
*  |   58 | opp_bgB                  | m^2         | vloeroppervlak
*  |   59 | opp_1verdB               | m^2         | vloeroppervlak
*  |   60 | opp_2verdB               | m^2         | vloeroppervlak
*  |   61 | Tvent_sup                | °C          | toevoertemperatuur ventilatie
*  |   62 | vent_bgA                 | m^3/hr      | ventilatie
*  |   63 | vent_1verdA              | m^3/hr      | ventilatie
*  |   64 | vent_2verdA              | m^3/hr      | ventilatie
*  |   65 | vent_bgB                 | m^3/hr      | ventilatie
*  |   66 | vent_1verdB              | m^3/hr      | ventilatie
*  |   67 | vent_2verdB              | m^3/hr      | ventilatie
*  |   68 | Theat                    | °C          | setpoint heating
*  |   69 | Tcool                    | °C          | setpoint koeling
*  |   70 | clo                      | any         | clothing value
*  |   71 | metabolism               | any         | metabolisme in met
*  |   72 | napp_bgA                 | any         | aantal appartementen
*  |   73 | napp_1verdA              | any         | aantal appartementen
*  |   74 | napp_2verdA              | any         | aantal appartementen
*  |   75 | napp_bgB                 | any         | aantal appartementen
*  |   76 | napp_1verdB              | any         | aantal appartementen
*  |   77 | napp_2verdB              | any         | aantal appartementen
*  |   78 | Wflow_1verdA             | any         | aan/uit massastroom door vloerverwarming
*  |   79 | WTsup_1verdA             | °C          | aanvoerwatertemperatuur vloerverwarming
*  |   80 | Wflow_bgA                | any         | aan/uit massaflow vloerverwarming
*  |   81 | WTsup_bgA                | °C          | aanvoertemperatuur vloerverwarming
*  |   82 | Wflow_2verdA             | any         | aan/uit massastroom vloerverwarming
*  |   83 | WTsup_2verdA             | °C          | aanvoertemperatuur vloerverwarming
*  |   84 | Wflow_bgB                | any         | aan/uit massastroom door vloerverwarming
*  |   85 | WTsup_bgB                | °C          | aanvoertemperatuur vloerverwarming
*  |   86 | Wflow_1verdB             | any         | aan/uit massastroom door vloerverwarming
*  |   87 | WTsup_1verdB             | °C          | aanvoertemperatuur vloerverwarming
*  |   88 | Wflow_2verdB             | any         | aan/uit massastroom door vloerverwarming
*  |   89 | WTsup_2verdB             | °C          | aanvoertemperatuur vloerverwarming
```

Figure 11 The list of simulation inputs to the building model represented in the TRNSYS deckfile - Marine climate demonstration project.

************* DESIRED OUTPUTS

*	:OutNr	Label	Unit	ZNr	Airnode	OUTPUT DESCRIPTION
*	1	TAIR_bgA	C	1	bgA	air temperature of airnode
*	2	TAIR_1verdA	C	2	1verdA	air temperature of airnode
*	3	TAIR_trappenhuis	C	3	trappenhuis	air temperature of airnode
*	4	TAIR_2verdA	C	4	2verdA	air temperature of airnode
*	5	TAIR_bgB	C	5	bgB	air temperature of airnode
*	6	TAIR_1verdB	C	6	1verdB	air temperature of airnode
*	7	TAIR_2verdB	C	7	2verdB	air temperature of airnode
*	8	QHEAT_bgA	kJ/hr	1	bgA	heating demand
*	9	QHEAT_1verdA	kJ/hr	2	1verdA	heating demand
*	10	QHEAT_trappenhuis	kJ/hr	3	trappenhuis	heating demand
*	11	QHEAT_2verdA	kJ/hr	4	2verdA	heating demand
*	12	QHEAT_bgB	kJ/hr	5	bgB	heating demand
*	13	QHEAT_1verdB	kJ/hr	6	1verdB	heating demand
*	14	QHEAT_2verdB	kJ/hr	7	2verdB	heating demand
*	15	QCOOL_bgA	kJ/hr	1	bgA	cooling demand
*	16	QCOOL_1verdA	kJ/hr	2	1verdA	cooling demand
*	17	QCOOL_trappenhuis	kJ/hr	3	trappenhuis	cooling demand
*	18	QCOOL_2verdA	kJ/hr	4	2verdA	cooling demand
*	19	QCOOL_bgB	kJ/hr	5	bgB	cooling demand
*	20	QCOOL_1verdB	kJ/hr	6	1verdB	cooling demand
*	21	QCOOL_2verdB	kJ/hr	7	2verdB	cooling demand
*	22	PMV_bgA	-	1	bgA	predicted mean vote (PMV)
*	23	PPD_bgA	%	1	bgA	predicted percentage of dissatisfied persons (PPD)
*	24	TOP_bgA	C	1	bgA	operative room temperature
*	25	QGLIGHT_bgA	kJ/hr	1	bgA	Sensible energy gain from "lights" gains of airnode
*	26	QGLIGHT_1verdA	kJ/hr	2	1verdA	Sensible energy gain from "lights" gains of airnode
*	27	QGLIGHT_2verdA	kJ/hr	4	2verdA	Sensible energy gain from "lights" gains of airnode
*	28	QGLIGHT_bgB	kJ/hr	5	bgB	Sensible energy gain from "lights" gains of airnode
*	29	QGLIGHT_1verdB	kJ/hr	6	1verdB	Sensible energy gain from "lights" gains of airnode
*	30	QGLIGHT_2verdB	kJ/hr	7	2verdB	Sensible energy gain from "lights" gains of airnode
*	31	QGEQUIP_bgA	kJ/hr	1	bgA	Sensible energy gain from "equipment" gains of airnode
*	32	QGEQUIP_1verdA	kJ/hr	2	1verdA	Sensible energy gain from "equipment" gains of airnode
*	33	QGEQUIP_2verdA	kJ/hr	4	2verdA	Sensible energy gain from "equipment" gains of airnode
*	34	QGEQUIP_bgB	kJ/hr	5	bgB	Sensible energy gain from "equipment" gains of airnode
*	35	QGEQUIP_1verdB	kJ/hr	6	1verdB	Sensible energy gain from "equipment" gains of airnode
*	36	QGEQUIP_2verdB	kJ/hr	7	2verdB	Sensible energy gain from "equipment" gains of airnode
*	37	QGPEOPLE_bgA	kJ/hr	1	bgA	Sensible energy gain from "people" gains of airnode
*	38	QGPEOPLE_1verdA	kJ/hr	2	1verdA	Sensible energy gain from "people" gains of airnode
*	39	QGPEOPLE_2verdA	kJ/hr	4	2verdA	Sensible energy gain from "people" gains of airnode
*	40	QGPEOPLE_bgB	kJ/hr	5	bgB	Sensible energy gain from "people" gains of airnode
*	41	QGPEOPLE_1verdB	kJ/hr	6	1verdB	Sensible energy gain from "people" gains of airnode
*	42	QGPEOPLE_2verdB	kJ/hr	7	2verdB	Sensible energy gain from "people" gains of airnode
*	43	TOP_1verdA	C	2	1verdA	operative room temperature
*	44	TOP_bgA_#2	C	1	bgA	operative room temperature
*	45	TOP_2verdA	C	4	2verdA	operative room temperature
*	46	TOP_bgB	C	5	bgB	operative room temperature
*	47	TOP_1verdB	C	6	1verdB	operative room temperature
*	48	TOP_2verdB	C	7	2verdB	operative room temperature
*	49	TOFL_S8	C	1	bgA	fluid outlet temperature of active layer ->FLOOR=bgvloer_vv_W1:KNOWN BOUNDARY
*	50	QALFL_S8	kJ/hr	1	bgA	energy input by fluid of active layer ->FLOOR=bgvloer_vv_W1:KNOWN BOUNDARY
*	51	TIFL_S8	C	1	bgA	inlet temperature of active layer ->FLOOR=bgvloer_vv_W1:KNOWN BOUNDARY
*	52	MFLAL_S8	kg/hr	1	bgA	inlet mass flow rate of active layer ->FLOOR=bgvloer_vv_W1:KNOWN BOUNDARY
*	53	QALFL_S12	kJ/hr	2	1verdA	energy input by fluid of active layer ->FLOOR=tussenvloer_vv_W1:ADJ=bgA
*	54	QALFL_S26	kJ/hr	4	2verdA	energy input by fluid of active layer ->CEILING=tussenvloer_vv_W1:ADJ=1verdA
*	55	QALFL_S50	kJ/hr	5	bgB	energy input by fluid of active layer ->FLOOR=bgvloer_vv_W1:KNOWN BOUNDARY
*	56	QALFL_S52	kJ/hr	6	1verdB	energy input by fluid of active layer ->FLOOR=tussenvloer_vv_W1:ADJ=bgB
*	57	QALFL_S65	kJ/hr	7	2verdB	energy input by fluid of active layer ->CEILING=tussenvloer_vv_W1:ADJ=1verdB
*	58	PMV_1verdA	-	2	1verdA	predicted mean vote (PMV)
*	59	PPD_1verdA	%	2	1verdA	predicted percentage of dissatisfied persons (PPD)
*	60	PMV_2verdA	-	4	2verdA	predicted mean vote (PMV)
*	61	PPD_2verdA	%	4	2verdA	predicted percentage of dissatisfied persons (PPD)
*	62	PMV_bgB	-	5	bgB	predicted mean vote (PMV)
*	63	PPD_bgB	%	5	bgB	predicted percentage of dissatisfied persons (PPD)
*	64	PMV_1verdB	-	6	1verdB	predicted mean vote (PMV)
*	65	PPD_1verdB	%	6	1verdB	predicted percentage of dissatisfied persons (PPD)
*	66	PMV_2verdB	-	7	2verdB	predicted mean vote (PMV)
*	67	PPD_2verdB	%	7	2verdB	predicted percentage of dissatisfied persons (PPD)

Figure 12 The list of simulation outputs form the building model represented in the TRNSYS deck file - Marine climate demonstration project.

Design inputs and outputs

The detailed presentation of design inputs and assumptions implemented in the dynamic building model of the Marine demonstration building is presented in Table 6, whereas simulated outputs are presented in Table 7.

Table 6 Description of the main simulation design inputs and assumptions of the simulation model – Marine demonstration project.

Simulation input	Input description
Weather data	Weather data, according the NEN5060 standard, is used. This concerns representative weather data for determining the energy use of buildings in the Netherlands. The weather data, according to NEN5060, is obtained via statistical processing of weather data from weather station "the Bilt" over a period of 20 years.
Building Geometry	Heated floor area: 2235 m^2 Number of floors: 3 Height: 9 m Wall thickness: 0.44 m (including 0.13 m insulation)
Building envelope and shading	Rc facade: 6.1 m^2K/W Rc roof: 8.1 m^2K/W Rc floor: 4.8 m^2K/W U window: 1 W/m^2K No external shading devices were used
HVAC system specifications	**Heating:** The apartments are heated via an underfloor heating system modelled in TRNSYS using the active layer method available in TRNBuild. The heating is provided via a ground source heat pump. Each apartment has its own heat pump. **setpoint heating**: 19/20/21C (night/day/evening) **COP heating: 5.7** A fixed efficiency of 5.7 is used in the simulations, while measurements have shown this is the case for a ground source heat pump. **Domestic hot water preparation (DHW):** DHW system is also provided with the ground source heat pump and a 150-litre storage vessel. COP DHW: 3.6 (fixed value used in simulations average for the season) **Cooling:** Passive cooling via ground source. Efficiency cooling: 50 (fixed value used in simulations) setpoint cooling: 23C **Ventilation:** Each apartment has a mechanical exhaust system that extracts air from the kitchen, bathroom, and toilet. This system is controlled via a CO2 sensor in the living room. Besides that, the occupants can manually control the system. The air supply is obtained via ventilation grids in the facades. So-called 1Pa self-regulation grids are used, which maintain the design airflow in case the pressure over the grid is >= 1Pa. Based upon detailed simulations for the used ventilation system, the following averaged values are determined and used: - ventilation: 22,5 dm^3/s for 2 room apartment and 27,5 dm^3/s for 3 room apartment - infiltration: 13 dm^3/s per apartment.
Renewable energy specification	Photovoltaic panels are placed on the roof. For each apartment, 5 panels with 310 Wp/panel are available. The panels are orientated to the south.

Internal loads and schedule	**Occupancy** It is assumed that 1 person is present during working hours in each apartment. Outside of working hours, it is assumed that two persons are present in the 2-room apartments and three persons are present in the 3-room apartments. Working hours are from 8h-18h from Monday to Friday. The heat production per person is 100W and 70W while sleeping (from 23h-8h) **Appliances:** For appliances, heat production of 6 W/m^2 during the day (8h-18h) and 15W/m^2 during the evening (18h-23h) is assumed. This is based upon 2500 kWh of electric energy used for appliances. **Mechanical ventilation:** For the mechanical fan, 20W heat production per apartment is assumed. **Lighting:** For lighting during the heating period (1st of October until 1st of May), due to less solar, heat production is assumed to be 0.5W/m2 during the day (8h-18h) and 3W/m^2 during the evening (18h-23h). Outside the heating period, only heat production of 1.3W/m^2 is assumed in the evening. This is based upon a yearly energy consumption for lighting of 5 kWh/m^2.
Validation	The results of the simulation model are compared to the energy performance calculation. The figures showed a reasonable agreement.

Table 7 Description of the main simulation design outputs of the simulation model – Marine demonstration project

Simulation outputs	Description
Energy and Environmental performance indicators	Time series with the following items are outputted: - energy demand for heating - energy demand for cooling - energy production internal gains (persons, electric equipment, lighting) - energy production of solar panels
Indoor environmental quality indicators	The following IEQ indicators are outputted: - Indoor air temperatures - Operative indoor temperatures - PMV and PPD figures

4.3 Continental Climate Demonstration Projects in Austria

Continental climate demonstration projects consist of three residential development projects located in Salzburg, Austria. The dynamic performance model was developed and summarised for each demonstration case in the sections below.

4.3.1 GNICE in Salzburg, Austria

General description of the demonstration project

The Austrian demonstration project - GNICE is a new residential development in Salzburg (Fig.13). It is a greenfield development located on the city's outskirts in a quiet area with primarily multifamily houses. The 17 buildings on the plot consist of mostly multi–residential dwellings, from which half will be social housing units, and the other half will be sold at a certain fixed price. There will also be a Kindergarten and a base zone, managed by the social aid and service organisation "Caritas" on the spot.

Figure 13 Planned section and facades of the buildings in the GNICE Demonstration Project - Continental Climate Demonstration Project in Salzburg.

Plan view

The buildings featured in the GNICE demo primarily consist of 2 to 4 floors and are predominantly residential. The floor plan is typically standard, with a central core comprising a staircase, corridor, and shaft. Apartments are situated around this core, extending along the perimeter (Figure 14).

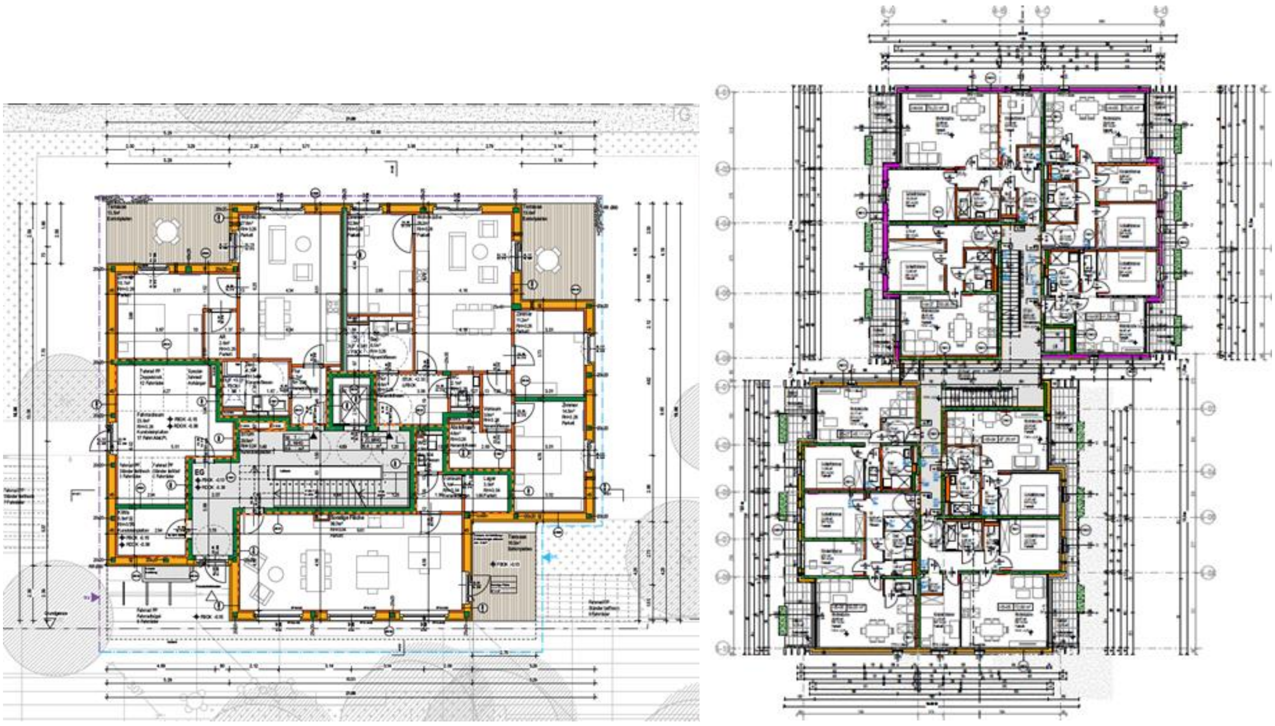


Figure 14 Representative floor plans, ground floor of building 1 on the left, and ground floor of buildings 4-5 on the right of the residential building in GNICE project

3D building model

In the 3D model created using DesignBuilder, all 17 buildings from the GNICE project, as well as the 2 buildings on Berchtesgadenerstrasse, are represented (Figure 16). Within the apartments, living rooms and bedrooms are designated as separate zones (Figure 15), whereas bathrooms and corridors are combined into a single zone. The model does not include the underground parking. Additionally, terraces are incorporated as shading elements for each building.

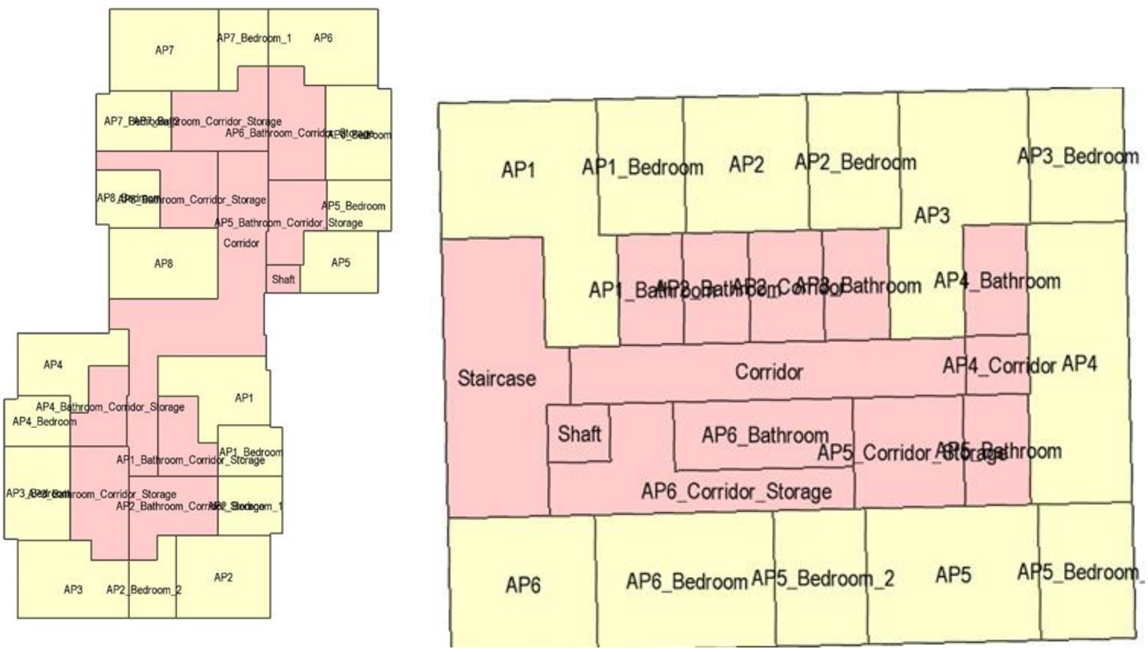


Figure 15 *Zoning of buildings - GNICE demonstration project*

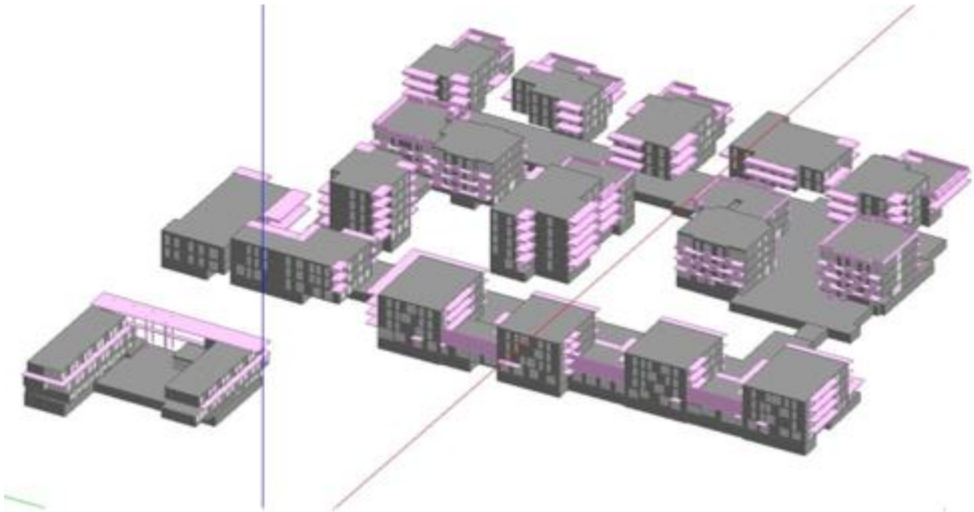


Figure 16 The 3D model – GNICE demonstration project - Continental Climate Demonstration Project in Salzburg

Dynamic building performance model - software and simulation timestep

The dynamic building performance model was developed in Designbuilder 7.0.2 software. DesignBuilder uses the EnergyPlus dynamic simulation engine to generate performance data. The simulation timestep was set as 15 minutes. The description of the modelling approach related to simulating building loads (heat transfer) and HVAC system performance designed in the GNICE demonstration project is presented in Tables 8 and 9, respectively.

Table 8 Heat transfer models implemented in the dynamic performance model of the Continental Climate Demonstration Project - Gnice in Salzburg

Heat transfer model	Modelling description
Conduction	In the dynamic simulation model - the two-dimensional conduction model was used to analyse heat transfer by conduction through a building envelope. This model solution was obtained using the Finite Difference Method. The thermal resistance of the envelope is represented by an R-value, which is calculated based on the thermal conductivity and thickness of each material layer. The thermal capacitance of the envelope is defined by a heat capacity, which is based on the density and specific heat of each material layer.
Convection	The convection model was simplified without using the detailed Airflow Network model. The infiltration method was used to provide additional outdoor ventilation loads to the indoor spaces to capture the natural ventilation benefits.
Radiation	The radiation model used in the dynamic building model is based on the FullExterior method for calculating the radiative heat transfer between surfaces in a building. In this case, shadow patterns on exterior surfaces caused by all zones' detached shading, wings, overhangs, and exterior surfaces are computed. All beam solar radiation entering the zone is assumed to fall on the floor, which is absorbed according to the floor's solar absorptance. Any reflected by the floor is added to the reflected diffuse radiation, which is assumed to be uniformly distributed on all interior surfaces.

HVAC system modelling approach

For the HVAC system, sequenced ground source heat pumps were modelled, as well as a stratified hot water tank, aiming to provide constant temperature water for the radiant ceiling heating of the apartments. Below a schematic representation showing the HVAC overview of the simulation (Figure 17).

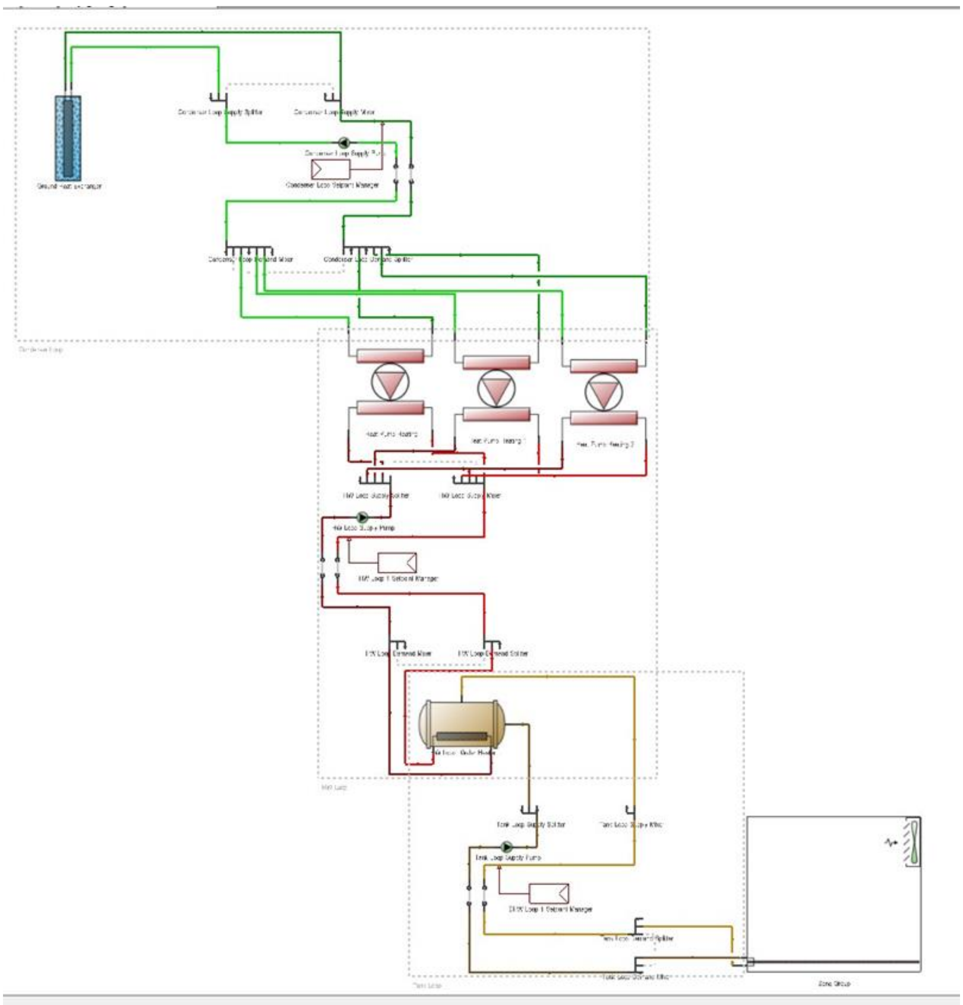


Figure 17 Overview of the schematic HVAC model from DesignBuilder – GNICE demo

Table 9 Summary of HVAC system modelling implemented in the dynamic performance model of the Continental Climate Demonstration Project - Gnice in Salzburg

Information	Modelling description
Model structure and algorithm	The EnergyPlus simulation Manager in EnergyPlus software coordinates the simulation of the building, system, and plant components to simulate the HVAC system performance comprehensively. The software uses an integrated approach to simulate the performance of the Loads, Systems, and Plants, which involves correctly predicting loads and associated energy consumption. The simulation algorithm used in the HVAC system modelling inside EnergyPlus is a time-stepping approach that combines a system-level simulation with a zone-level simulation. It calculates the performance of the HVAC system components and the thermal loads on each thermal zone of the building. The simulations are iterated at each time step until convergence is achieved. This approach provides a detailed and accurate simulation of the HVAC system performance.

System configuration and HVAC elements	The system configuration in HVAC modelling inside the BPS software is a network of interconnected components, including air handling units, chillers, boilers, pumps, fans, ducts, and terminals. It is organised into zones and includes the distribution network, designed to minimise pressure drop and energy losses while maintaining required airflow and water flow rates. The system configuration determines the system components' performance and the occupants' thermal comfort.
Zoning	The building was divided into thermal zones based on their thermal loads and usage patterns. Each thermal zone was then served by one air handling unit, designed to provide the required supply air temperature and flow rate based on the temperature and humidity setpoints for the zone. The zoning approach allowed us to optimise the HVAC system performance by providing more precise air supply control to each thermal zone, resulting in improved energy efficiency and occupant comfort.
Control strategies	The HVAC system control strategy implemented in the BPS model is mainly based on PID control, using a proportional-integral-derivative algorithm to adjust the supply air temperature and flow rate based on sensor feedback. This allowed for precise indoor climate control, minimising temperature and humidity fluctuations and improving occupant comfort.
Limitations	The modelling of the stratified Tank model was challenging to implement in the model. Still, with the help of some additional iterations, it was conservatively incorporated into the model for performance testing.

Design inputs and outputs

The detailed description of design inputs and assumptions implemented in the dynamic building model of the Continental demonstration project Gnice, Salzburg, Austria is presented in Table 10, whereas simulated outputs are presented in Table 11

Table 10 Description of the main simulation design inputs and assumptions of the simulation model – Continental demonstration project- GNICE building

Simulation input	Input description
Weather data	Energy Plus Data File (epw) from 2020, file name: Salzburg-hour_2020.epw
Building Geometry	There are new multiple residential building models in a single thermal model. Most buildings are G+3 floors consisting of apartments, living rooms, restrooms, and ancillary spaces. The as-designed floor plans were used to create a detailed energy model. The average height of the thermal blocks is 3 meters, with some variations based on false ceilings in some areas.
Building envelope and shading	The following thermal performance parameters (U value) were used in the thermal model: External Wall: 0.15 m^2K/W Roof: 0.13 m^2K/W Window: 0.69 m^2K/W SHGC: 0.6
HVAC system specifications	The HVAC system consists of a ground source heat pump that supplies hot water to a stratified buffer tank and serves each building from there. The apartments have a radiant heating system to maintain the heating setpoint. There is no cooling in the buildings, and it is expected to maintain summer comfort conditions by opening windows through natural ventilation.
Renewable energy specification	PV placed on the buildings, with an overall capacity of 620 kWp, ground-coupled heat-pump.
Internal loads and schedule	The internal loads are modelled with 2.5 W/m^2, an average equipment power density for all types of equipment such as refrigerators, etc. **Occupancy:** The occupancy schedule was used with maximum occupancy (80-90%) during night hours and fractional low diversity of 30-60% during the day and afternoon hours.

	Lighting: The lighting schedule was used with the maximum during the evening and before 10 PM. The fractional low diversity of 10-20% during afternoon hours and ramp-up in the evening was used.
Occupant behaviour	The window openings to enhance fresh air intake were closely tied up with the occupancy schedule and when the outdoor air temperature was lower than the zone temperature. The effect of occupant behaviour was not explicitly studied in the current scope.
Validation	The simulation output results were extensively quality checked, such as space temperatures, CO_2 concentration, operative temperatures, hot water flow, temperatures in the radiant system, etc. Due to the lack of operational performance results, the building model was not validated in the current scope of the work.

Table 11 Description of the main simulation design outputs of the simulation model – Continental demonstration project - GNICE building

Simulation outputs	Output description
Energy and Environmental performance indicators	Time series with the following items are outputted: - Temperature of water at Heat Pump, stratified tank, - Flow of water at Heat Pump, stratified tank, -Radiant system at each apartment Inlet/Outlet node temperature nodes - Energy (electrical) consumed by the heat pump. - Energy (thermal) produced by the heat pump. - COP of Heat Pump - Range of Heat Pump power consumption - Heat Pump working on/off status.
Indoor environmental quality indicators	- Ambient temperature - Operative temperature- - Space Thermal Comfort (PPM/PPD) - Space CO2 ppm - Daylighting Factor

4.3.2 Wir inHAUSer in Salzburg

General description of the demonstration project

The building site is located in the Salzburg and Parsch district, constructed in the mid-1980s and urgently needed renovation. In terms of sustainability, climate, and environmental protection, Heimat Österreich (HÖ) has dared to take the visionary step of developing a renovation concept with experts and planners, with which not only the Paris climate goals of 2030 can be met but also considers the social needs of the residents – and all this within the tight budget of subsidised housing. The existing buildings of the settlement were renovated and revitalised (Figure 18). In addition, the former 75 apartments have now become 99 residential units through increased floor height. The project's primary goal was to reduce the operational CO_2 emissions of the housing complex to a minimum.

Figure 18 Wir inHAUSer demonstration project in Salzburg, Austria. Continental Climate Demonstration Project in Salzburg

Plan view

The Wir inHAUSer demo features buildings composed of residential apartments. Each floor comprises 2 or 3 individual apartments, along with a corridor and staircase providing access to these units. Additionally, several apartments include balconies, which also serve as shading elements for the windows below.

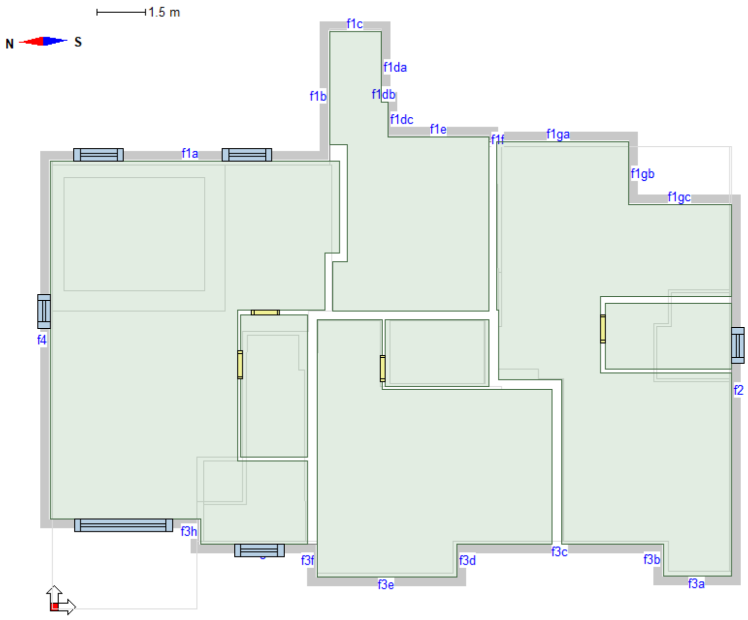


Figure 19 Overview of the schematic HVAC model from DesignBuilder – GNICE demo

3D building model

The building model depicted below illustrates that most of the buildings consist of 3 to 4 floors. The balconies are designed as shading features, and the detailed model includes an underground parking facility (Figure 20)

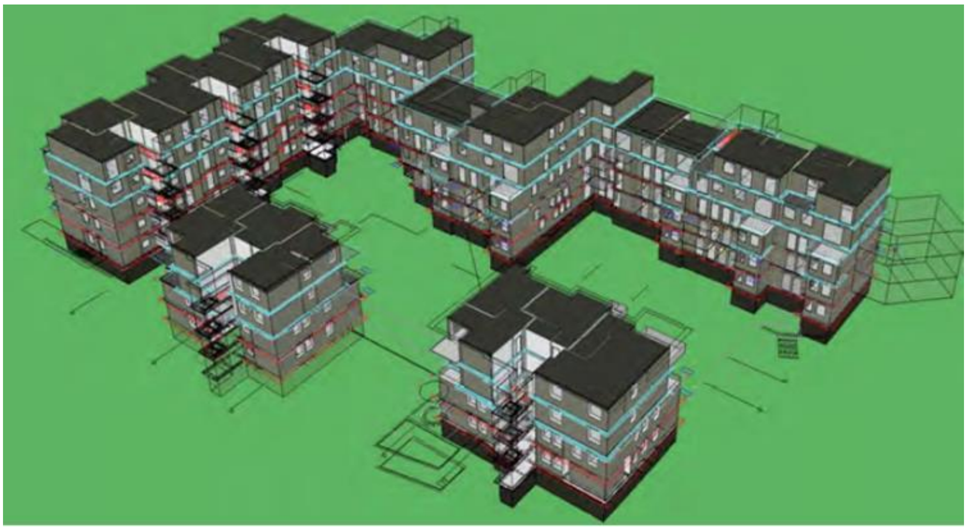


Figure 20 3D representation of the residential blocks in Wir InHAUSer demonstration project in Salzburg

Building model software and simulation timestep

The simplified simulations were performed using the IDA-ICE 4.8 software [8] with the hourly timestep. The description of the modelling approach related to simulating building loads (heat transfer) and HVAC system performance designed in the GNICE demonstration project is presented in Tables 12 and 13, respectively.

Table 12 Heat transfer models implemented in the dynamic performance model of the Continental Climate Demonstration Project - Wir inHAUSer in Salzburg.

Heat transfer model	Modelling description
Conduction	The 2D conduction model was employed to evaluate heat conduction across the building envelope, utilising the Finite Difference Method for numerical solutions. The envelope's thermal resistance is quantified by an R-value derived from each material layer's thermal conductivity and thickness. Similarly, the thermal capacitance is expressed through heat capacity, calculated based on each layer's density and specific heat.
Convection	The Airflow Network model, integrated with convective heat transfer coefficients, was employed to assess convective heat transfer across the building envelope. The model accounts for natural ventilation effects like wind, stack-driven flows, and mechanical ventilation systems. The Airflow Network analysis includes both convective and infiltration/exfiltration heat transfer modes.
Radiation	The radiation model in the dynamic building simulation employs the view factor method to compute radiative heat exchange between building surfaces. Besides surface-to-surface radiation, IDA ICE's model also accounts for solar gains through windows and openings. It incorporates a sky model to simulate diffuse sky radiation, factoring in location, time of year, cloud cover, and atmospheric conditions.

HVAC system modelling approach

Various configurations of the HVAC system were tested through simulations. The basic simulated setup includes a heat pump for drain water heat recovery, another for exhaust air heat recovery, a biomass boiler, an electric heating rod, and photovoltaic panels. The heat energy recovered from the exhaust air and drain water is channelled into the buffer tank. When this recovered heat is insufficient for maintaining the buffer tank's temperature, a pellet boiler supplements the necessary heat. Additionally, the buildings' roofs are equipped with photovoltaic panels (Figure 21).

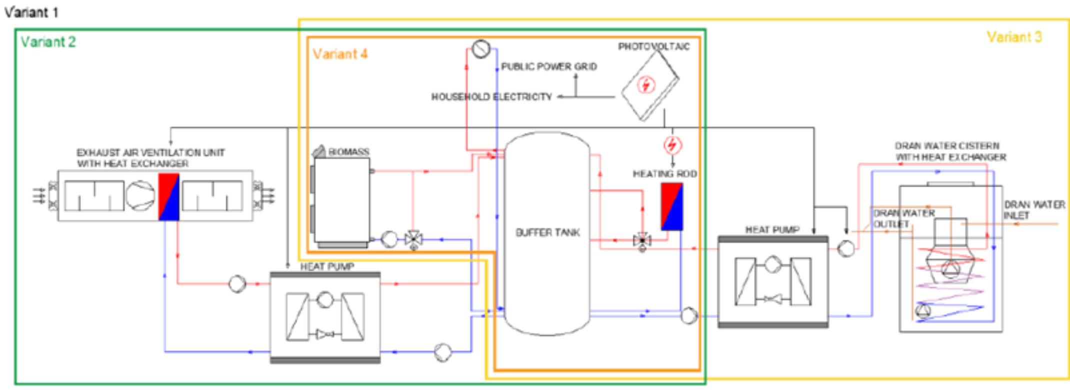


Figure 21 HVAC system model variants - Wir inHAUSer demonstration proect in Salzburg

Table 13 Summary of HVAC system modelling implemented in the dynamic performance model of the Continental Climate Demonstration Project - Wir inHAUSer in Salzburg

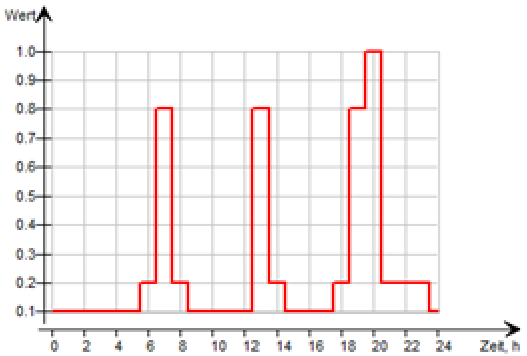
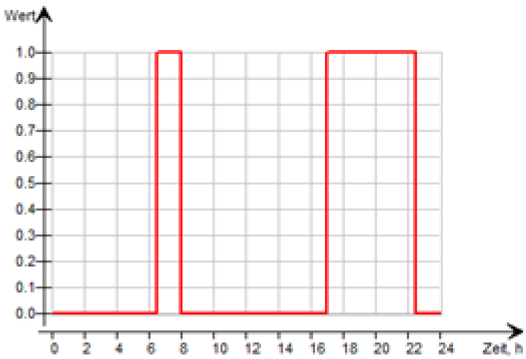
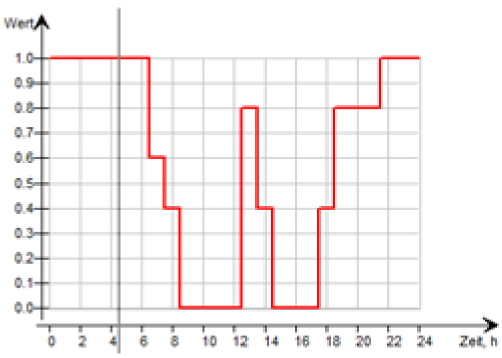
Information	Modelling description
Model structure and algorithm	Simulations were conducted using IDA ICE Version 4.8. The simulation involved various building technology concepts and evaluated their performance in terms of primary energy demand and carbon emissions. The systems included heat pumps for drain water heat recovery, a biomass boiler, an electric heating rod, and photovoltaics.
System configuration and HVAC elements	The system configuration includes a heat pump for drain water heat recovery, a heat pump for exhaust air heat recovery, a biomass boiler, an electric heating rod, and photovoltaics. The heat recovered from exhaust air and drain water is fed into a buffer tank, and a pellet boiler provides additional heat energy as required. The electricity generated by photovoltaics is used for household electricity needs and for building services, with surplus electricity feeding an electric heating rod or the public grid.
Zoning	Multiple zones in each apartment, splitting perimeter and core zones
Control strategies	The control strategies focus on maximizing self-consumption of the electricity generated by photovoltaics and efficiently managing the heat pumps for exhaust air and drain water heat recovery. The system prioritizes different electricity consumption areas for the use of PV electricity.
Limitations	Limitations in optimization and synchronization of heat pumps and PV system.

Design inputs and outputs

The detailed description of design inputs and assumptions implemented in the dynamic building model of the Continental demonstration project Wir inHauser, Salzburg, Austria, is presented in Table 14, whereas simulated outputs are presented in Table 15.

Table 14 Description of the main simulation design inputs and assumptions of the simulation model – Continental demonstration project- Wir inHAUSer demonstration project in Salzburg, Austria.

Simulation input	Input description
Weather data	Energy Plus Data File (epw) from 2020 name: Salzburg-hour_2020.epw
Building Geometry	All the buildings contain residential and shared areas, with apartments consisting of bedrooms, living rooms, bathrooms, and other ancillary areas. There is an underground parking garage under the building. Buildings are G+ 3 or G+4 floor high. Average building height is around 3 meters.
Building envelope and shading	Designed thermal properties of the building envelope: U – values [W/m^{2}K]: • exterior wall = 0.09

	• roof = 0.09 • external floor: 0.20 • windows = 0.71 • doors = 1.7 Infiltration (n50): 0.6 ACH
HVAC system specifications	The heating system consists of two heat pumps (heat source: sewage and exhaust air), a biomass plant, and there is also a photovoltaic system. The photovoltaic system will be implemented as a common energy production system.
Renewable energy specification	PV was placed on the buildings, with an overall area of 1100 m^2 and a capacity of 158 kW.
Internal loads and schedule	**Internal loads**: Internal loads were calculated with 8 W/m^2 average with the following schedule:  **Lighting**: Lighting was calculated with a load of 2,7 W/m^2 with the following schedule: 
Occupant behaviour	**Occupancy**: For occupancy, the following schedule was used based on national standards and experience: 
Validation	The results of the simulations were compared with metered data.

	Simulation was validated with actual metered data. The simulation results of energy production deviate acceptably within -4% to +11% from actual metered data. A precise thermal building simulation is challenging due to uncontrollable factors, like weather prediction limitations. However, achieving a 4% approximation to practical operation is considered excellent. The major difference is attributed to the downtime of the exhaust air heat pump.

Table 15 Description of the main simulation design inputs and assumptions of the simulation model – Continental demonstration project- Wir inHAUSer demonstration project in Salzburg, Austria.

Simulation outputs	Description
Energy and Environmental performance indicators	Time series with the following items are outputted: Energy demand for heating Energy production solar panels Energy consumption heating Energy consumption electricity (connected to HVAC systems)
Indoor environmental quality indicators	No indoor environmental quality indicators were simulated.

4.3.3 Berchtesgadner Straße 70-72

General description of the demonstration project

The Austrian demonstration project – Berchtesgadner Straße 70-72 is based on retrofitting the two residential buildings constructed in 2002 (Figure 18). The project's gross floor area is 1844m2, while the heating floor area is 1474m2. The building comprises 24 apartments with 50 inhabitants.

Figure 22 Demonstration project - Berchtesgadner Straße 70-72 in Salzburg, Austria. Continental Climate Demonstration Project.

Plan view

The two buildings on Berchtesgadner Strasse are each composed of a ground floor plus two additional floors. The building at Berchtesgadner Strasse 70, situated to the north, exclusively houses apartments. In contrast, the southern building at Berchtesgadner Strasse 72 features retail functions on the ground floor and residential apartments on the upper floors. Nestled between these buildings is a private garden with a playground. The staircases for both buildings are located on their eastern sides, and there are open corridors along the buildings that provide access to the individual apartments. Additionally, on the second floor, a corridor links the two buildings (Figure 23).

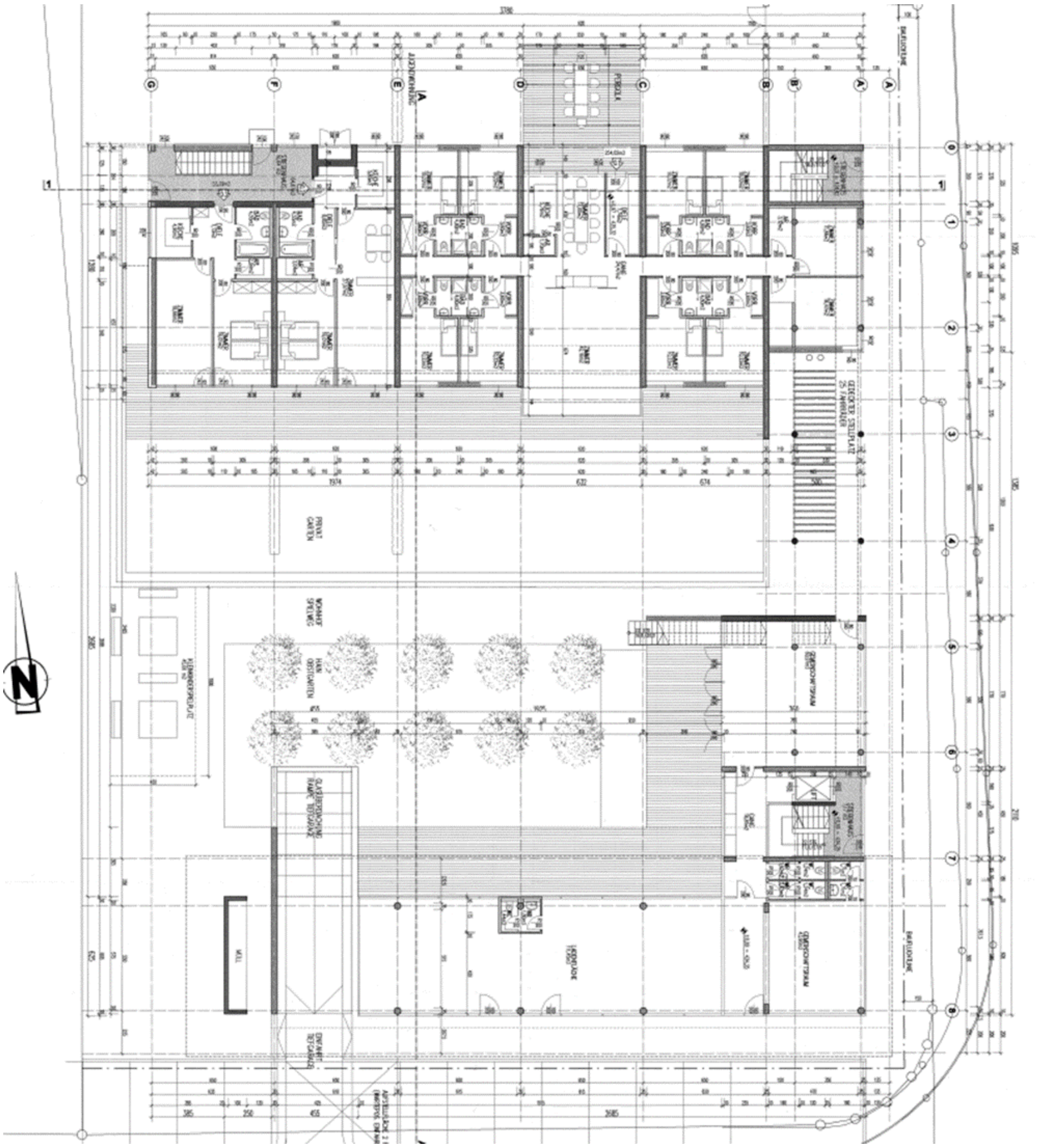


Figure 23 Representative floor plans of the Berchtesgaden Straße 70-72 residential building demonstration project in Salzburg, Austria. Continental Climate Demonstration Project.

3D building model

A 3D model (Figure 25) of Berchtesgadnerstrasse 70-72 was developed using DesignBuilder, similar to the approach taken for the GNICE project. The zoning approach (Figure 24) was also consistent, differentiating the rooms along the perimeter from those adjacent to the corridor. The external corridors were designed as shading elements, as was the corridor connecting the two buildings.

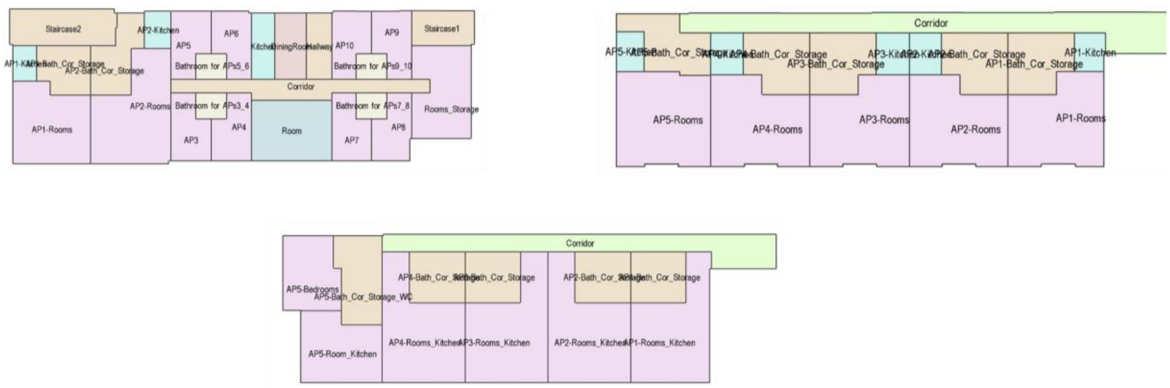


Figure 24 Representative zoning plan of the residential building in Berchtesgadner Straße 70-72, demonstration project in Salzburg, Austria.

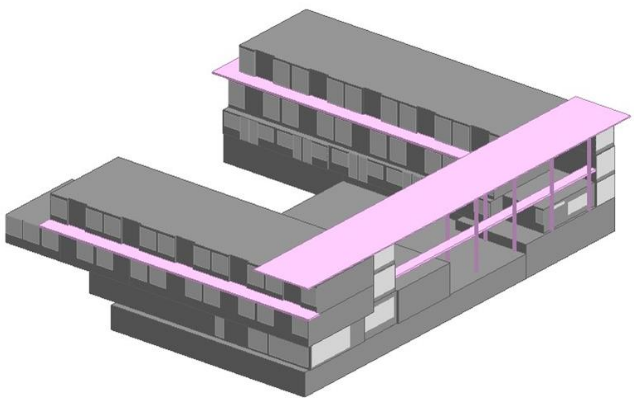


Figure 25 The 3D model of the Berchtesgaden Straße 70-72 residential building demonstration project in Salzburg, Austria. Continental Climate Demonstration Project.

Dynamic building performance model - software and simulation timestep

The dynamic building performance model was developed in Designbuilder 7.0.2 software. DesignBuilder uses the EnergyPlus dynamic simulation engine to generate performance data. The simulation timestep was set as 15 minutes. The description of the modelling approach related to simulating building loads (heat transfer) and HVAC system performance designed in the Berchtesgaden Straße 70-72 demonstration project is presented in Tables 16 and 17, respectively.

Table 16 Heat transfer models implemented in the dynamic performance model of the Continental Climate Demonstration Project - Berchtesgaden Straße 70-72.

Heat transfer model	Modelling description
Conduction	The two-dimensional conduction model was used to analyse heat transfer by conduction through a building envelope. This model solution was obtained using the Finite Difference Method. The thermal resistance of the envelope is represented by an R-value, which is calculated based on the thermal conductivity and thickness of each material layer. The thermal capacitance of the envelope is characterised by a heat capacity, which is based on the density and specific heat of each material layer.
Convection	There was no Airflow Network design element that was part of the study. However, EnergyPlus can use the Airflow Network Model if needed. The infiltration method was used to provide additional outdoor airflow to the spaces to capture the natural ventilation benefits

Radiation	The radiation model used in the dynamic building model is based on the FullExterior method for calculating the radiative heat transfer between surfaces in a building. In this case, shadow patterns on exterior surfaces caused by all zones' detached shading, wings, overhangs, and exterior surfaces are computed. All beam solar radiation entering the zone is assumed to fall on the floor, which is absorbed according to the floor's solar absorptance. Any reflected by the floor is added to the reflected diffuse radiation, which is assumed to be uniformly distributed on all interior surfaces.

HVAC system modeling approach

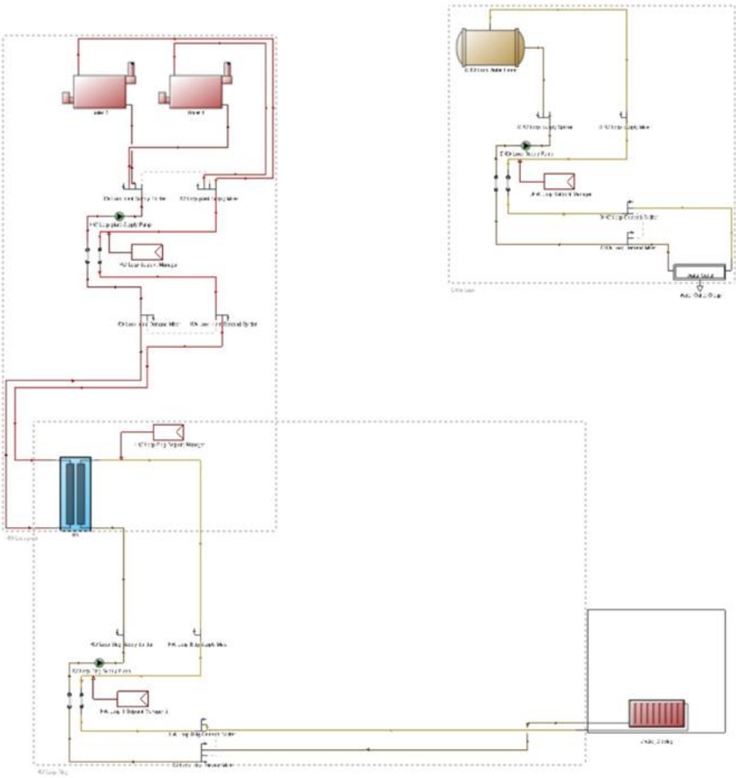


Figure 26 Overview of the schematic HVAC model from DesignBuilder- Berchtesgadnerstrasse demo

Table 17 Summary of HVAC system modelling implemented in the dynamic performance model of the Continental Climate Demonstration Project - Berchtesgaden Straße 70-72

Information	Modelling description
Model structure and algorithm	The EnergyPlus simulation Manager in EnergyPlus software coordinates the simulation of the building, system, and plant components to simulate the HVAC system performance comprehensively. The software uses an integrated approach to simulate the performance of the Loads, Systems, and Plants, which involves correctly predicting loads and associated energy consumption. The simulation algorithm used in the HVAC system modelling inside EnergyPlus is a time-stepping approach that combines a system-level simulation with a zone-level simulation. It calculates the performance of the HVAC system components and the thermal loads on each thermal zone of the building. The simulations are iterated at each time step until convergence is achieved. This approach provides a detailed and accurate simulation of the HVAC system performance.
System configuration and HVAC elements	The system configuration in HVAC modelling inside the BPS software is a network of interconnected components, including air handling units, chillers, boilers, pumps, fans, ducts, and terminals. It is organised into zones and includes the distribution network, designed to

	minimise pressure drop and energy losses while maintaining required airflow and water flow rates. The system configuration determines the system components' performance and the occupants' thermal comfort.
Zoning	The building was divided into thermal zones based on their thermal loads and usage patterns. Each thermal zone was then served by one air handling unit, designed to provide the required supply air temperature and flow rate based on the temperature and humidity setpoints for the zone. The zoning approach allowed us to optimise the HVAC system performance by providing more precise air supply control to each thermal zone, resulting in improved energy efficiency and occupant comfort.
Control strategies	The HVAC system control strategy implemented in the BPS model is mainly based on PID control, using a proportional-integral-derivative algorithm to adjust the supply air temperature and flow rate based on sensor feedback. This allowed for precise indoor climate control, minimising temperature and humidity fluctuations and improving occupant comfort.
Limitations	The existing Boiler is a biofuel-based boiler where pellets are being fed to generate the heat. Since EnergyPlus does not have the flexibility to model Biopellet fuel, a conservative approach was used to model the Boiler with "Natural Gas", and the rest of the calculations, such as heat generation CO2 emissions, were done based on the biofuel fuel input.

Design inputs and outputs

The detailed description of design inputs and assumptions implemented in the dynamic building model of the Continental demonstration project Berchtesgadner Straße 70-72, Salzburg, Austria, is presented in Table 18. In contrast, simulated outputs are presented in Table 19.

Table 18 Description of the main simulation design inputs and assumptions of the simulation model – Continental demonstration project- Berchtesgadner Straße 70-72 demonstration project in Salzburg, Austria.

Simulation input	Input description
Weather data	Energy Plus Data File (epw) from 2020 name: Salzburg-hour_2020.epw
Building Geometry	There are two existing residential building models in a single thermal model. Both buildings are G+2 floors consisting of apartments, living rooms, restrooms and ancillary spaces. An existing floor plan was used to create a detailed energy model. Each thermal block was modelled with an average height of 3 meters.
Building envelope and shading	Designed thermal properties of the building envelope: U – values [W/m^{2}K]: • exterior wall = 0.14 • roof = 0.19 • external floor: 0.20 • windows = 1.6 • doors = 1.7
HVAC system specifications	The HVAC system consists of a Biofuel boiler that serves both buildings. The apartments have a radiant heating system to maintain the heating setpoint. There is no cooling in the buildings, and expected to maintain summer comfort conditions by opening windows through natural ventilation.
Renewable energy specification	Existing solar PV of 65 kW capacity serves the building with an annual simulated solar PV production of 61 MWh. The roof is also equipped with a 77 m^2 solar thermal collector with an annual useful heat production of 18 MWh thermal.
Internal loads and schedule	The internal loads are modelled with 5 W/m^2, an average equipment power density for all types of equipment such as refrigerators, etc. **Occupancy:** The occupancy schedule was used with maximum occupancy (80-90%) during night hours and fractional low diversity of 30-60% during the day and afternoon hours.

	Lighting: The lighting schedule was used with the maximum during the evening and before 10 PM. The fractional low diversity of 10-20% during afternoon hours and ramp-up in the evening was used.
Occupant behaviour	The window openings to enhance fresh air intake were closely tied up with the occupancy schedule and when the outdoor air temperature was lower than the zone temperature. The current simulation framework did not explicitly study the effect of occupant behaviour.
Validation	The simulation output results were quality checked, such as space temperatures, CO2 concentration, operative temperatures, hot water flow, temperatures in the radiant system, etc., which were not validated in the current scope of the work.

Table 19 Description of the main simulation design inputs and assumptions of the simulation model – Continental demonstration project- Berchtesgadner Straße 70-72 demonstration project in Salzburg, Austria.

Simulation outputs	Output Description
Energy and Environmental performance indicators	Time series with the following items are outputted: Temperature of water at Boiler Radiant system at each apartment Inlet/Outlet node Temperature Radiant system at each apartment Inlet/Outlet Flow Baseboard Heating capacity (W) Lighting Electric Power Misc Equipment Power
Indoor environmental quality indicators	Ambient Temperature Space Temperature

4.4 Subarctic climate demonstration projects in Norway

This section presents the description of the developed building performance models for the two subarctic demonstration projects in Norway: the final demonstration case – Verket Panorama in Fredrikstad (section 4.4.1), and the initial planned demonstration case, OEN building in Oslo (section 4.4.2)

4.4.1 Verket Panorama in Fredrikstad

General description of the demonstration project

The case study is located in Fredrikstad, Norway (Latitude: 59° 13' 5.16" N, Longitude: 10° 55' 47.28" E). It is a multistorey apartment building with six floors, a parking basement, and nine apartment typologies (Figure 27). The demo project is part of a broader neighbourhood regeneration scheme of about 2,000 new housing units during the next ten years. It involves the transformation of a former industrial into a contemporary, modern, and sustainable residential area.

Figure 27 Verket Panorama demonstration project – block K and L (from left to right). Subarctic climate demonstration project.

Plan view

Each floor of the case building has four apartments (Figure 28), except for the 5th and 6th floors, which have two apartments extending over two floors (Figure 29). The building has a compact body, shaped like a box, to ensure minimal heat loss through the envelope. The windows oriented towards the south, east, and west have integrated exterior screens with manual operation. Each apartment has a balcony with an open and enclosed glazed part. All apartments have an open floor plan for the kitchen and living room. The roof is tilted 8 degrees towards the Southeast and is covered in photovoltaic panels.

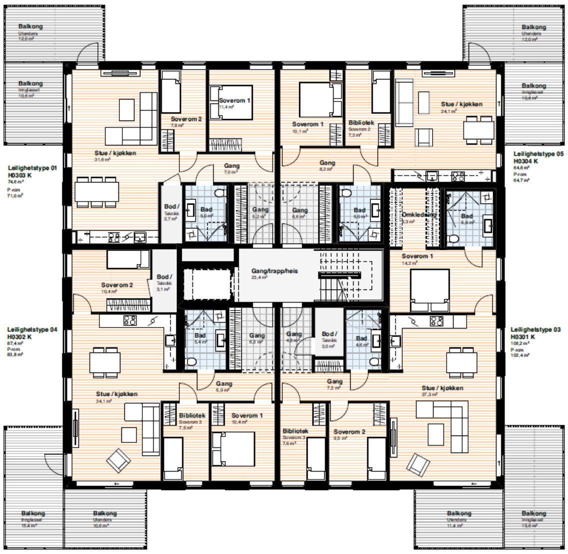


Figure 28 1-4 floor plan, Verket Panorama demonstration project

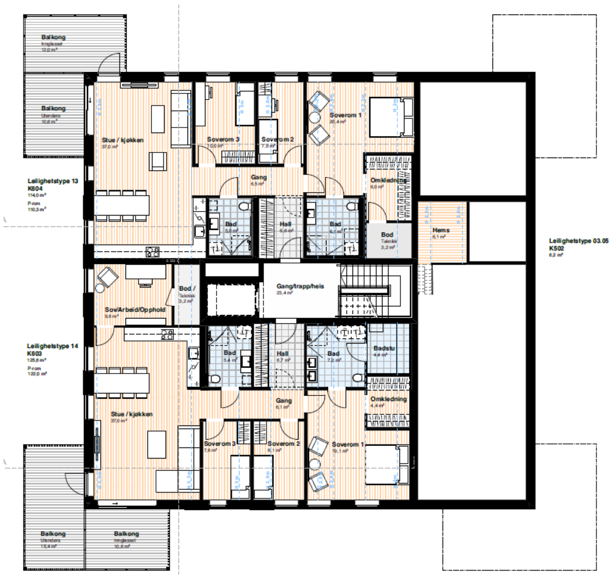


Figure 29 5-6 floor plan, Verket Panorama demonstration project

3D building model

Two apartments were selected as representative apartments for the building performance model development based on orientation and size. One apartment faces Northwest (Apartment 01), and one apartment faces Southeast (Apartment 03, Figure 30). The apartments were simulated individually with adiabatic surfaces for walls, ceilings, and floors towards neighbouring apartments. The balconies were simulated without railing as the railing will be of glass, and the simulation software did not include glazed railing.

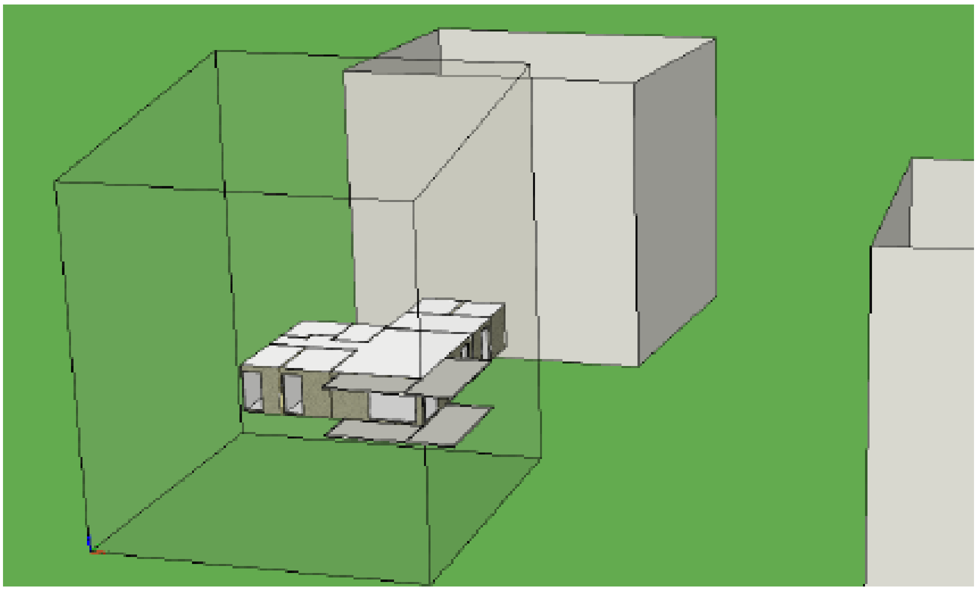


Figure 30 Thermal energy model of apartment 03 in Verket Panorama demonstration project modelled in the IDA-ICE software.

Dynamic building performance model - software and simulation timestep

The simulations were performed using the IDA-ICE version 4.8. The simulation timestep was set as one hour. PVsyst V7.2.12 was used to perform photovoltaic system simulation for panels on the roof, which were rough estimates due to limited project information, and the same for all design options and scenarios. The description of the modelling approach related to simulating building loads (heat transfer) and HVAC system performance designed in the Verket Panorama demonstration project is presented in Tables 20 and 21, respectively.

Table 20 Heat transfer models implemented in the dynamic performance model of the Subarctic Climate Demonstration Project – Verket Panorama.

Heat transfer model	Modelling description
Conduction	The two-dimensional conduction model was used to analyse heat transfer by conduction through a building envelope. This model solution was obtained using the Finite Difference Method. The thermal resistance of the envelope is represented by an R-value, which is calculated based on the thermal conductivity and thickness of each material layer. The thermal capacitance of the envelope is represented by a heat capacity, which is based on the density and specific heat of each material layer.
Convection	The Airflow Network model incorporated with the convective heat transfer coefficients was used to analyse heat transfer by convection through a building envelope. The model considers the effects of natural ventilation, such as wind-driven ventilation and stack-driven ventilation, and the effects of mechanical ventilation systems. The convective and infiltration/exfiltration heat transfer modes are considered to model heat transfer using the Airflow Network model.
Radiation	The radiation model used in the dynamic building model is based on the view factor method for calculating the radiative heat transfer between surfaces in a building. In addition to simulating the radiative heat transfer between surfaces, the radiation model in IDA ICE also considers the effects of solar radiation entering the building through windows and other openings. This considers the sky model that allows users to simulate diffuse sky radiation, which is the radiation that is scattered by the atmosphere and enters the building through windows and other openings. The sky model considers the location and time of year, as well as the cloud cover and atmospheric conditions.

Table 21 Summary of HVAC system modelling implemented in the dynamic performance model of Subarctic Climate Demonstration Project – Verket Panorama

Information	Modelling description
Model structure and algorithm	The integrated solution manager in IDA ICE software coordinates the simulation of the building, system, and plant components to comprehensively simulate the HVAC system performance. The software uses a predictor-corrector approach to simulate the performance of the HVAC system, which involves predicting the system response based on the current state and inputs and then correcting the prediction based on the actual response. The simulation algorithm used in the HVAC system modelling inside IDA ICE is a time-stepping approach that combines a system-level simulation with a zone-level simulation. It calculates the performance of the HVAC system components and the thermal loads on each thermal zone of the building. The simulations are iterated at each time step until convergence is achieved. This approach provides a detailed and accurate simulation of the HVAC system performance.

System configuration and HVAC elements	The system configuration in HVAC modelling inside the BPS software is a network of interconnected components, including air handling units, chillers, boilers, pumps, fans, ducts, and terminals (Figure 31). It is organised into zones and includes the distribution network, which is designed to minimise pressure drop and energy losses while maintaining required airflow and water flow rates. The system configuration determines the system components' performance and the occupants' thermal comfort.
Zoning	The building was divided into thermal zones based on their thermal loads and usage patterns. Each thermal zone corresponds to the apartment room in this simplified apartment model (Figure 32). The air-handling unit with heat recovery provides airflow to all thermal zones.
Control strategies	The HVAC system control strategy implemented in the BPS model is mainly based on PID control, using a proportional-integral-derivative algorithm to adjust the supply air temperature and flow rate based on sensor feedback. This allowed for precise indoor climate control, minimising temperature and humidity fluctuations and improving occupant comfort.
Limitations	The primary limitation lies in the simplicity of the building model, which is based only on two representative apartments; additionally, due to the limitation of the IDA-ICE 4.8 software, the renewable energy generation potential analysis was performed outside the simulation model in the PVsyst software.

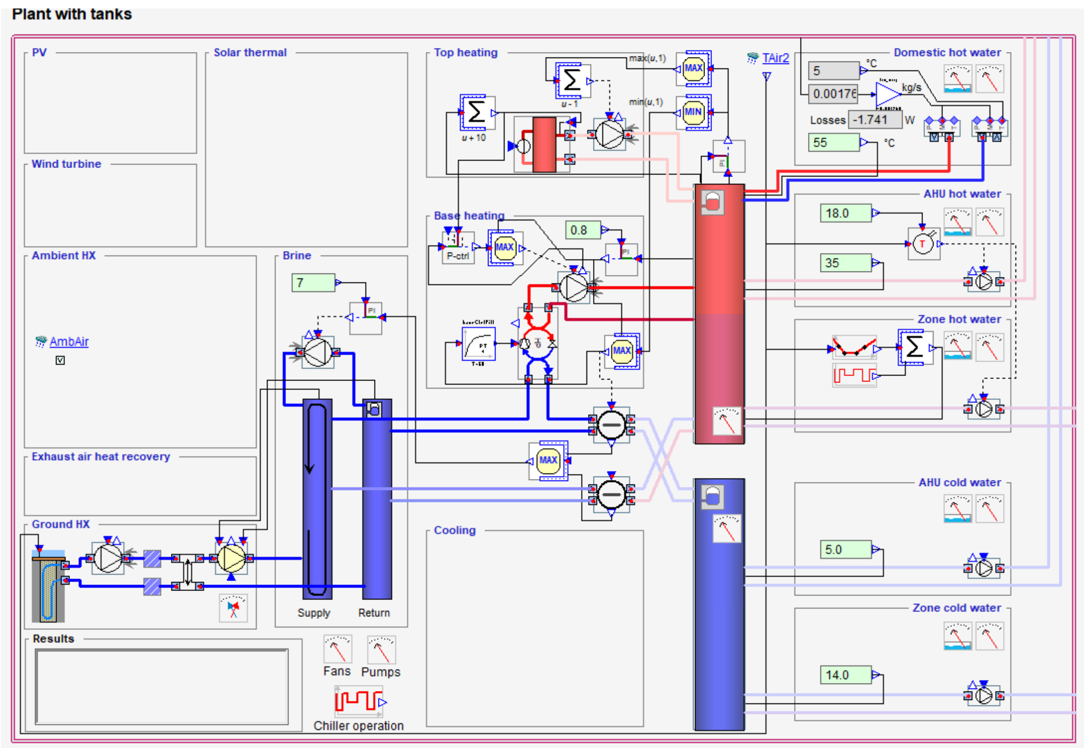
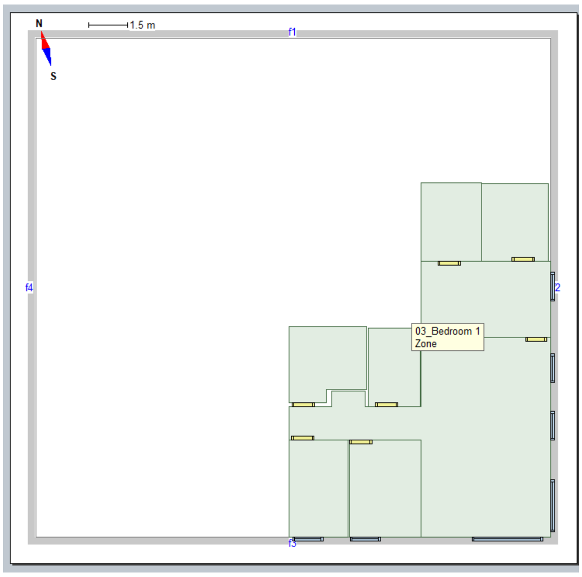


Figure 31 HVAC system plant based on ground heat pump modelled in IDA-ICE software. Subarctic Climate Demonstration Project – Verket Panorama



Details

Zones | Zone totals | Zone setpoints | Surfaces | Windows | Openings | Leaks | Internal gains | Wall constructions | Time schedules | Materials | Room units | Energy meters | Air

Name	Group	Floor height, m	Room height, m	Floor area, m2	Heat setp., °C	Cool setp., °C	AHU	System	Supply air, L/(s*m2)	Exhaust air, L/(s*m2)	Occup., no./m2	Lights, W/m2	Lights, kWh/m2	Equipment, W/m2	Equipment, kWh/m2	Ext win. area, m2	Occup. schedule	Light schedule	Equipm. schedule	Zone control
03_Kitchen/living		9.0	2.6	46.23	n.a.	26.0	Standa...	CAV	0.472	0.655	0.0099...	1.939	11.32	2.983	17.42	15.05	©Alwa...	Passiv...	Passiv...	<contr...
03_Bedroom 1		9.0	2.6	14.78	n.a.	26.0	Standa...	CAV	0.472	0.0	0.01	1.95	11.39	3.0	17.52	2.387	©Alwa...	Passiv...	Passiv...	<contr...
03_Bedroom 2		9.0	2.6	10.27	n.a.	26.0	Standa...	CAV	0.472	0.0	0.0094...	1.848	10.79	2.843	16.61	2.387	©Alwa...	Passiv...	Passiv...	<contr...
03_Bedroom 3		9.0	2.6	8.524	n.a.	26.0	Standa...	CAV	0.472	0.0	0.0090...	1.756	10.26	2.702	15.78	2.387	©Alwa...	Passiv...	Passiv...	<contr...
03_bathroom 1		9.0	2.6	6.132	n.a.	26.0	Standa...	CAV	0.0	0.655	0.0094...	1.841	10.75	2.832	16.54	0.0	©Alwa...	Passiv...	Passiv...	<contr...
03_hall		9.0	2.6	8.009	n.a.	26.0	Standa...	CAV	0.0	0.0	0.0099...	1.95	11.39	3.0	17.52	0.0	©Alwa...	Passiv...	Passiv...	<contr...
03_bathroom 2		9.0	2.6	7.7	n.a.	26.0	Standa...	CAV	0.0	0.655	0.0082...	1.603	9.362	2.466	14.4	0.0	©Alwa...	Passiv...	Passiv...	<contr...
03_Storage		9.0	2.6	7.138	21.0	25.0	Standa...	CAV	0.0	0.0	0.0089...	1.752	10.23	2.696	15.74	0.0	©Alwa...	Passiv...	Passiv...	<contr...
Total/m2									0.3463	0.3616	0.0096...	1.877	10.96	2.887	16.86	7.133				

Figure 32 – Thermal zoning in IDA-ICE software. Subarctic Climate Demonstration Project – Verket Panorama

Design inputs and outputs

The detailed description of design inputs and assumptions implemented in the dynamic building model of the Subarctic demonstration project Verket Panaroma, Norway, is presented in Table 22. In contrast, simulated outputs are presented in Table 23.

Table 22 Description of the main simulation design inputs and assumptions of the simulation model – Subarctic climate demonstration project- Verket Panaroma, Norway.

Simulation input	Input description
Weather data	ASHRAE 2013 weather file for Rygge (30km distance from the building location in Fredrikstad)
Building Geometry	Two apartments were selected as representative apartments for the building based on orientation and size. One apartment faces Northwest (Apartment 01), and one apartment faces Southeast (Apartment 03). The apartments were simulated individually with adiabatic surfaces for walls, ceilings, and floors towards neighbouring apartments. The balconies were simulated without railing as the railing will be of glass, and the simulation software did not include glazed railing.
Building envelope and shading	Designed thermal properties of the building envelope: U – values [W/m^{2}K]: • exterior wall = 0.10 • roof = 0.08 • external floor: 0.13 • windows and doors = 0.85 Normalised thermal bridge value = 0.03 W/m^{2}K Air tightness: 0.6 ACH at 50Pa

HVAC system specifications	The heating system is based on the ground source heat pump and the floor-based radiant heating. The domestic hot water system is based on combining the ground heat pump and district heating with heat storage accumulation. Each apartment is equipped with an air-handling unit with heat recovery rate higher than 85%
Renewable energy specification	PV panels will be installed on roofs and suitable east-south-west–facing facades of the Panorama building. The design power of the on–site PV is 107kW.
Internal loads and schedule	**Occupancy:** The occupancy schedule was based on the NS3700 standard **Lighting:** The lighting load was estimated as 1.95 W/m^2, and the operation time (schedule) was set as 06:00-22:00 **Equipment** The equipment load was estimated as 3 W/m^2, and the operation time (schedule) was set as 06:00-22:00
Occupant behaviour	The dynamic building model considers different user behaviour scenarios, including active and passive user profiles, where the active user is energy conscious and takes action to reduce energy consumption. In contrast, the inactive user does not consider energy consumption.
Validation	The simulation output results were quality checked, such as space temperatures, CO2 concentration, operative temperatures, hot water flow, temperatures in the radiant system, etc., which were not validated in the current scope of the work.

Table 23 Description of the main simulation design inputs and assumptions of the simulation model – Subarctic climate demonstration project- Verket Panaroma, Norway

Simulation outputs	Output Description
Energy and Environmental performance indicators	Time series with the following items are outputted: Delivered energy Renewable energy generation Non-renewable energy consumption
Indoor environmental quality indicators	Operative temperatures PMV indicators

4.4.2 OEN residential building in Oslo

General description of the demonstration project

The initial subarctic demonstration case was planned to be a new residential development in the outskirt of Oslo, approximately 10 km away from the Oslo Central Station. It is located at a short distance from green recreation areas, and it is close to public transportation nodes. The development consists of a neighbourhood of flats collected in a circular shape and includes approximately 150 apartments distributed on 4-5 floors, with a total floor area of around 14 450 m^2 (Figure 33).

Figure 33 Design visualisation of the OEN building – initial planned subarctic climate demonstration project

Plan view

To model the environmental and energy performance of the neighbourhood, a cluster of the OEN building was extracted from the circular form and modelled in the dynamic simulation program IDA-ICE (Figure 34). Curved exposed surfaces towards north and south were straightened in the model, because of the impossibility to adapt some calculation routines to curved surfaces, while East and West facades were assumed as adiabatic, considering they are adjacent to the rest of the neighbourhood. In the extracted cluster, four different residential units per floor are included; living areas are facing south, sleeping areas are facing north. A sensitivity analysis of the model showed that incidence of the orientation in the overall energy performance of the building cluster was limited to 5%.

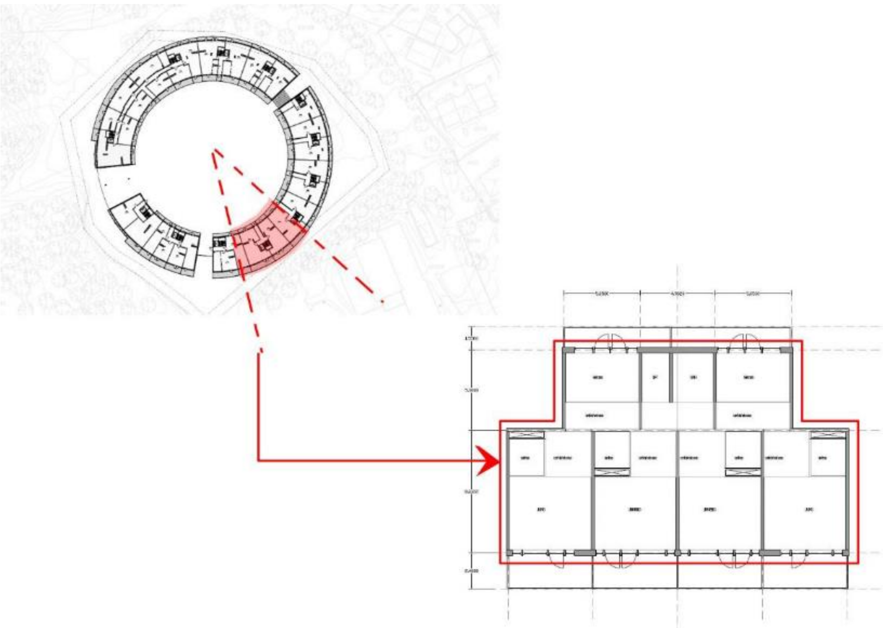


Figure 34 Plan view of the OEN demonstration building based on the cluster from circular shape of the building.

3D building model

Building description and model settings used as base case The base case geometry is based on the drawings provided by OBOS. The building is designed to be circular; therefore. it presents a curved external surface. To accommodate the thermal zones which in this version of the software require to have straight surfaces, the computational domain was adapted (Figure 35)

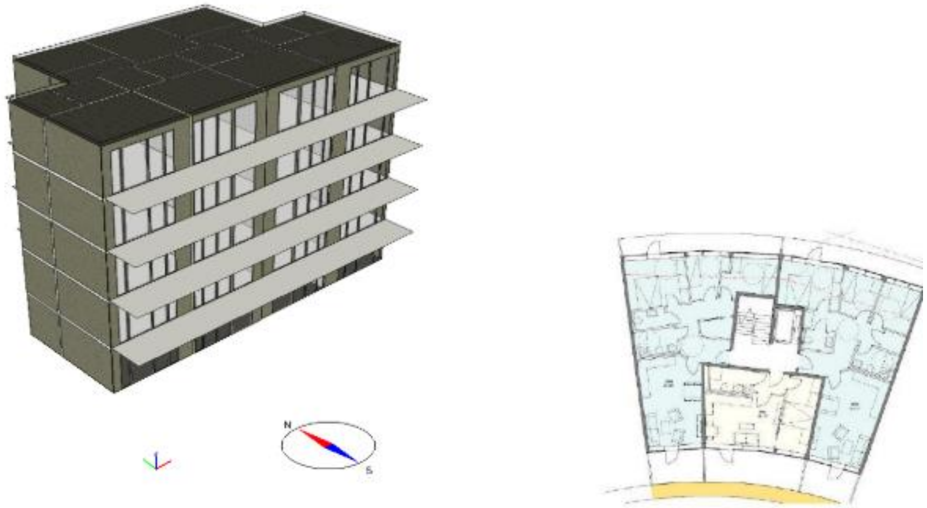


Figure 35 Thermal energy model of OEN building developed in IDA-ICE software.

Dynamic building performance model - software and simulation timestep

Simulations were carried out using the code IDA-ICE v.4.8. The model used is the Energy Zone Model embedded in the software. The calculations make use of a dynamic time step of maximum 1 hour. The climate file used was provided in the software, and it is the OSLO_GARDERMOEN_013840(IW2) with a default urban wind profile. The simulation time is 1 year (365 days). A digital model of the building in Grasshopper, a plugin for Rhino using Energy Plus engine, was used to quantify energy generation by the integrated photovoltaic system. The description of the modelling approach related to simulating building loads (heat transfer) and HVAC system performance designed in the Verket Panorama demonstration project is presented in Tables 24 and 25, respectively.

Table 24 Heat transfer models implemented in the dynamic performance model of the initial planned Subarctic Climate Demonstration Project – OEN, Oslo.

Heat transfer model	Modelling description
Conduction	The two-dimensional conduction model was used to analyse heat transfer by conduction through a building envelope. This model solution was obtained using the Finite Difference Method. The thermal resistance of the envelope is represented by an R-value, which is calculated based on the thermal conductivity and thickness of each material layer. The thermal capacitance of the envelope is represented by a heat capacity, which is based on the density and specific heat of each material layer.
Convection	The Airflow Network model incorporated with the convective heat transfer coefficients was used to analyse heat transfer by convection through a building envelope. The model considers the effects of natural ventilation, such as wind-driven ventilation and stack-driven ventilation, and the effects of mechanical ventilation systems. The convective and infiltration/exfiltration heat transfer modes are considered to model heat transfer using the Airflow Network model.
Radiation	The radiation model used in the dynamic building model is based on the view factor method for calculating the radiative heat transfer between surfaces in a building. In addition to simulating the radiative heat transfer between surfaces, the radiation model in IDA ICE also

	considers the effects of solar radiation entering the building through windows and other openings. This considers the sky model that allows users to simulate diffuse sky radiation, which is the radiation that is scattered by the atmosphere and enters the building through windows and other openings. The sky model considers the location and time of year, as well as the cloud cover and atmospheric conditions.

Table 25 Summary of HVAC system modelling implemented in the dynamic performance model the initial planned Subarctic Climate Demonstration Project – OEN, Oslo.

Information	Modelling description
Model structure and algorithm	The integrated solution manager in IDA ICE software coordinates the simulation of the building, system, and plant components to comprehensively simulate the HVAC system performance. The software uses a predictor-corrector approach to simulate the performance of the HVAC system, which involves predicting the system response based on the current state and inputs and then correcting the prediction based on the actual response. The simulation algorithm used in the HVAC system modelling inside IDA ICE is a time-stepping approach that combines a system-level simulation with a zone-level simulation. It calculates the performance of the HVAC system components and the thermal loads on each thermal zone of the building. The simulations are iterated at each time step until convergence is achieved. This approach provides a detailed and accurate simulation of the HVAC system performance.
System configuration and HVAC elements	The system configuration in HVAC modelling inside the BPS software is a network of interconnected components, including air handling units, chillers, boilers, pumps, fans, ducts, and terminals (Figures 36 and 37). It is organised into zones and includes the distribution network, which is designed to minimise pressure drop and energy losses while maintaining required airflow and water flow rates. The system configuration determines the system components' performance and the occupants' thermal comfort. In this building performance model simplified HVAC system based on the standard plant with district heating, radiative floor heating and mechanical ventilation system with heat-recovery was implemented.
Zoning	The building was divided into thermal zones based on their thermal loads and usage patterns. In developed model four different residential units per floor are included; living areas are facing south, sleeping areas are facing north. In each residential unit, separate thermal zones were developed for: living room, bedroom, corridor and bathroom (Fig.38).
Control strategies	The HVAC system control strategy implemented in the BPS model is mainly based on PID control, using a proportional-integral-derivative algorithm to adjust the supply air temperature and flow rate based on sensor feedback. This allowed for precise indoor climate control, minimising temperature and humidity fluctuations and improving occupant comfort.

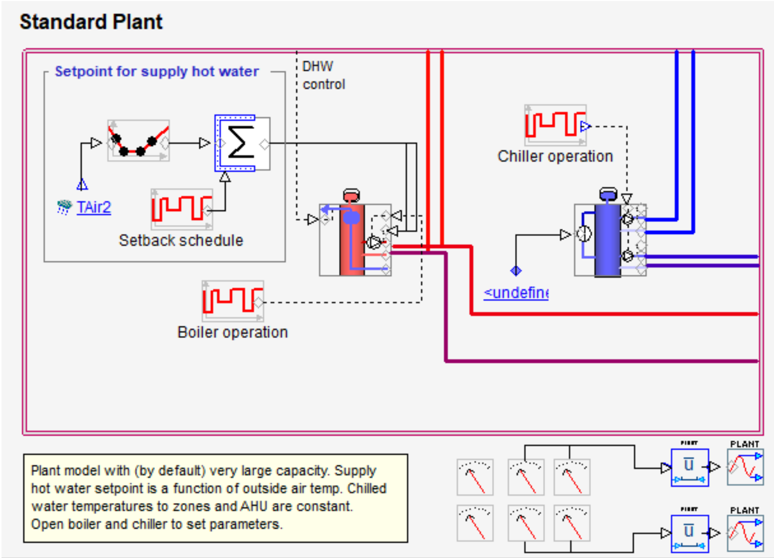


Figure 36 Space heating and domestic water system plant based on district heating modelled in IDA-ICE software. Subarctic Climate Demonstration Project – OEN, Oslo.

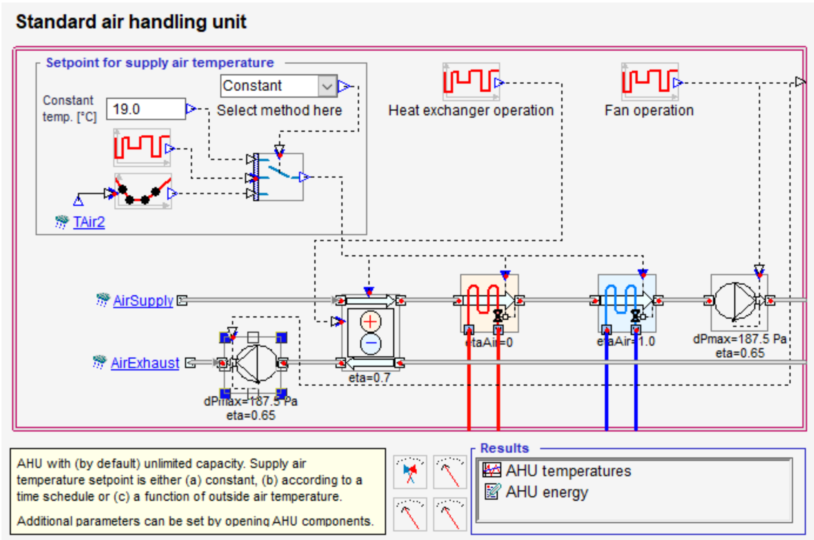


Figure 37 Mechanical ventilation system with heat recovery system based on the apartment airhandling unit modelled in IDA-ICE software. Subarctic Climate Demonstration Project – OEN, Oslo.

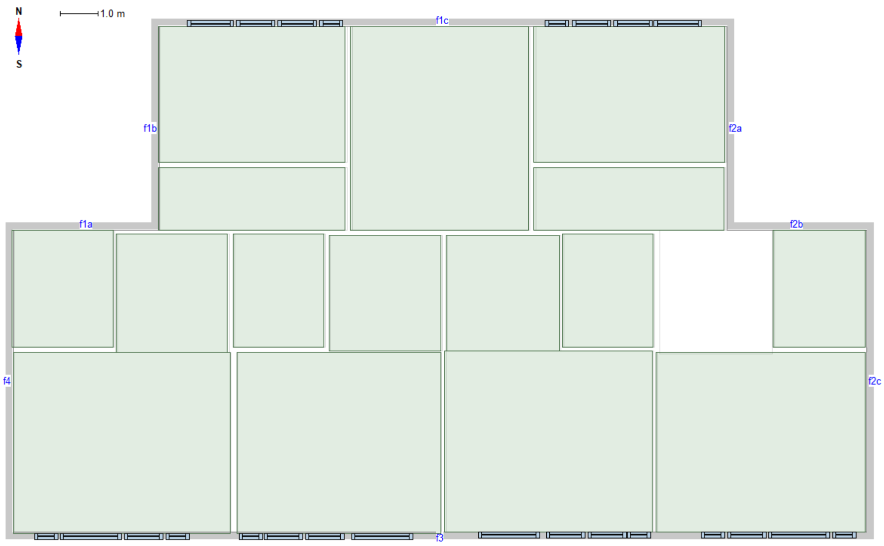


Figure 38 – Thermal zoning. Subarctic Climate Demonstration Project – OEN, Oslo.

Design inputs and outputs

The detailed description of design inputs and assumptions implemented in the dynamic building model of the Subarctic demonstration project OEN in Oslo Norway, is presented in Table 26. In contrast, simulated outputs are presented in Table 27.

Table 26 Description of the main simulation design inputs and assumptions of the simulation model – Subarctic climate demonstration project- OEM building, Oslo, Norway.

Simulation input	Input description
Weather data	ASHRAE 2013 weather file for Oslo (OSLO_GARDERMOEN_013840(IW2))
Building Geometry	Building description and model settings used as base case The base case geometry is based on the drawings provided by OBOS. The building is designed to be circular; therefore. it presents a curved external surface. To accommodate the thermal zones which in this version of the software require to have straight surfaces, the computational domain was adapted. Gross area of the building cluster: 1360m^2, heated floor area: 1258m^2.
Building envelope and shading	Designed thermal properties of the building envelope: U – values [W/m^{2}K]: • exterior wall = 0.10 • slab on ground = 0.08 • roof = 0.11 • windows = 0.8 Normalised thermal bridge value = 0.03 W/m^{2}K Air tightness: 0.6 ACH at 50 Pa Normalised thermal capacity: 120 Wh(m^{2}K)
HVAC system specifications	Since the building is in an area served by district heating. all the space heating energy is considered coming from this system. Fresh air is provided by an AHU that preheats the external air to 19°C, recovering heat from collected exhausted air. The rest of the heating is provided by floor heating connected to the district heating system and running at a temperature of 40 degrees. The floor heating surface is modelled as ideal heating unit to fulfil the setpoint requirements. and the amount of thermal energy is calculated as the load on the district heating independently by the temperature at which the heat is provided. The domestic hot water (DHW) needs are fulfilled by means of an ideal electric boiler common for the whole domain. The consumption associated to DHW is 25 kWh/m^2 floor area per year.
Renewable energy specification	PV panels covers the whole roof area of the building.
Internal loads and schedule	**Occupancy:** The occupancy schedule was based on the NS3700 standard and the occupancy internal load of 1.5W/m^2 was assumed. **Lighting:** The lighting load was estimated as 1.95 W/m^2, and the operation time (schedule) was set as 06:00-22:00 **Equipment** The equipment load was estimated as 3 W/m^2, and the operation time (schedule) was set as 06:00-22:00
Occupant behaviour	The dynamic building model considers different user behaviour scenarios, including active and passive user profiles, where the active user is energy conscious and takes action to reduce energy consumption. In contrast, the inactive user does not consider energy consumption.

Validation	The simulation output results were quality checked, such as space temperatures, CO_2 concentration, operative temperatures, hot water flow, temperatures in the radiant system, etc., which were not validated in the current scope of the work.

Table 27 Description of the main simulation design inputs and assumptions of the simulation model – Subarctic climate demonstration project- OEN building, Oslo.

Simulation outputs	Output Description
Energy and Environmental performance indicators	Time series with the following items are outputted: Delivered energy Renewable energy generation Non-renewable energy consumption
Indoor environmental quality indicators	Operative temperatures PMV indicators

5. Performance results from dynamic building models related to energy and indoor air quality

The following section present in detail final design simulation-based results related to the energy and indoor air quality performance which are in line with methodology framework for plus energy buildings and neighbourhoods based on developed dynamic performance models from six demonstration multifamily buildings in the syn.ikia project located in four different European climate zones.

5.1 Mediterranean climate demonstration project – Barcelona, Santa Coloma de Gramenet

Energy performance results

The results of energy performance simulation results based on the developed building performance simulation model of Mediterranean climate demonstration project are Presented in Tables 28 -30. The simulation results give a total annual primary energy consumption of 43.0 kWh/m2 with a non-renewable primary energy of -10.23, indicating energy export. The annual average supply cover factor is 0.24, indicating that relatively small fraction of the on-site generated electricity is used directly in the building for EPB uses (Table 26).

Additionally, based on performed simulations, the final demonstration design is considered to be an energy efficient design; the imported electricity for EPB uses is low, the supply cover factor is high, and the ground source is in balance. The results show that it is a net zero energy building (for EPB uses): on a yearly basis the EPB uses (18.19 kWh/m^2) are less than the energy generated on-site (23.42 kWh/m^2) (Table 28). In this building, the supply cover factor is higher in winter because in summer there is a combination of two effects that decreases this indicator: higher PV production and lower energy demand. When the energy demand is lower, the Load Cover Factor becomes higher, meaning that a greater fraction of the demand is covered by on-site energy generation (Table 29).

Table 228 Simulated annual energy performance indicators – Mediterranean climate demonstration project

Performance indicators	Unit	Annual value
Heating demand	kWh/m^2	12.1
Cooling demand	kWh/m^2	-
DHW demand	kWh/m^2	30
Lighting demand	kWh/m^2	2.9
Renewable energy production	kWh/m^2	23.42
Total primary energy consumption	kWh/m^2	43.04
Non-renewable primary energy demand (A)	kWh/m^2	35.54
Renewable primary energy delivered (B)	kWh/m^2	23.42
Non-renewable primary energy consumption (A-B)	kWh/m^2	-10.23
Imported EPB uses	kWh/m^2	19.67
Exported EPB uses	kWh/m^2	14.44
Supply cover factor	-	0.24

Table 29 Detailed simulated results of the building energy performance with indicators in line with ISO 52000-1:2017 standard. Mediterranean climate demonstration project

			Monthly values											
Performance indicators	Unit	Annual value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
EPB uses	kWh/m^2	18.19	2.73	2.12	1.65	1.15	1.12	0.97	0.96	0.99	1.06	1.19	1.59	2.67
non-EPB uses	kWh/m^2	39.87	3.43	2.97	3.33	3.32	3.33	3.28	3.34	3.41	3.28	3.4	3.31	3.48
EPB used electricity	kWh/m^2	3.75	0.53	0.61	0.39	0.24	0.2	0.17	0.15	0.16	0.21	0.21	0.35	0.54
Energy produced on-site	kWh/m^2	23.42	0.98	1.37	2.2	2.27	2.56	2.63	2.72	2.58	2.06	2	1.08	1
Exported electricity	kWh/m^2	19.67	0.45	0.76	1.81	2.04	2.36	2.46	2.57	2.42	1.85	1.78	0.72	0.45
Environmental energy	kWh/m^2	32.01	5.05	3.91	2.65	2.01	1.96	1.78	1.82	1.79	1.77	1.88	2.41	4.97
Grid exported	kWh/m^2	7.21	0.11	0.15	0.72	0.7	0.99	0.9	1.04	0.96	0.61	0.72	0.19	0.12
Grid delivered, EPB uses	kWh/m^2	14.44	2.2	1.51	1.26	0.92	0.91	0.8	0.81	0.83	0.85	0.97	1.23	2.13
Total greenhouse gas emissions	$kgCO_{2eq}/m^2$	-1.87	0.62	0.27	-0.19	-0.4	-0.51	-0.59	-0.63	-0.57	-0.36	-0.29	0.18	0.6

Table 30 Simulated results of syn.ikia KPIs related to energy performance – monthly distribution. Mediterranean climate demonstration project

			Monthly values											
Performance indicators	Unit	Annual value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Non-renewable energy balance	kWh/m^2	-10.23	3.42	1.48	-1.07	-2.18	-2.82	-3.25	-3.44	-3.11	-1.96	-1.58	1	3.28
Renewable energy ratio	-	1.24	Not simulated											
Grid purchase factor	-	0.71	0.82	0.73	0.7	0.63	0.59	0.53	0.57	0.59	0.62	0.7	0.78	0.81
Load cover ratio	-	0.29	0.18	0.27	0.3	0.37	0.41	0.47	0.43	0.41	0.38	0.3	0.22	0.19
Supply cover ratio	-	0.24	0.54	0.45	0.23	0.2	0.18	0.17	0.15	0.16	0.2	0.18	0.33	0.54
Net energy	kW	-4.6	1.90	0.89	-0.49	-1.03	-1.43	-1.66	-1.75	-1.59	-1.00	-0.80	0.56	1.84
Peak delivered	kW	57	Not simulated											
Peak exported	kW	34	Not simulated											
Grid connection capacity	-	0.8	Not simulated											
Energy produced on-site	kWh	48862	2041	2848	4579	4736	5335	5485	5679	5375	4295	4169	2245	2076

Indoor environment quality performance results

The simulated annual category level of thermal comfort (using an adaptive approach) and operative temperature according to European Standard EN15251:2007, recently revised to the EN16798-1-2019, which defines four categories of the indoor environmental quality related to the level of expectations of the building occupant is presented in Table 31 below. The results show that the building provides comfortable conditions to the users more than 90% of the time considering a Category IEQ1 and IEQ2, which is recommended for new residential buildings.

Table 31 Simulated results of syn.ikia KPIs related to thermal comfort - Mediterranean climate demonstration project.

	Quality of indoor environment in % of time in four categories			
Thermal comfort – performance indicator	IEQ1 (%)	IEQ2(%)	IEQ3(%)	IEQ4 (%)
Operative Temperature	82.1%	11.1%	6.5%	0.3%

5.2 Marine climate demonstration project – Apartment building in Uden (Netherlands)

Energy performance

The results of energy performance simulation results based on the developed building performance model of the Marine climate demonstration project are presented in Tables 32-34. The simulation results give a total annual primary energy consumption of 82.4 kWh/m2 with a non-renewable primary energy consumption of -1.84, indicating slight energy export. The annual average supply cover factor is as 0.33, indicating that relatively small fraction (33%) of the on-site generated electricity is used directly in the building for EPB uses (Table 32).

The results show that it is a net zero energy building (for EPB uses): on a yearly basis the EPB uses (23.18 kWh/m^2) are less than the energy generated on-site (24.45 kWh/m^2) (Table 33). This is due to the high energy efficiency of the ground-source heat pump.

Table 32 Simulated annual energy performance indicators - Marine climate demonstration project.

Performance indicators	Unit	Annual value
Heating demand	kWh/m^2	32.3
Cooling demand	kWh/m^2	40.8
DHW demand	kWh/m^2	30.6
Lighting demand	kWh/m^2	5.2
Renewable energy production	kWh/m^2	24.5
Total primary energy consumption	kWh/m^2	82.4
Non-renewable primary energy demand (A)	kWh/m^2	33.6
Renewable primary energy delivered (B)	kWh/m^2	35.5
Non-renewable primary energy consumption (A-B)	kWh/m^2	-1.84
Imported EPB uses	kWh/m^2	15.6
Exported EPB uses	kWh/m^2	16.8
Supply cover factor	-	0.33

Table 33 Simulated results of the building energy performance with indicators in line with ISO 52000-1:2017 standard. Marine climate demonstration project

			Monthly values											
Performance indicators	Unit	Annual value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
EPB uses	kWh/m^2	23.18	3.31	2.62	2.03	1.61	1.27	1.32	1.35	1.33	1.28	1.6	2.36	3.1
non EPB uses	kWh/m^2	48.62	4.01	4.08	4.04	4.04	4.08	4.02	4.09	4.01	4.06	4.07	4.03	4.09
EPB used electricity	kWh/m^2	7.61	0.39	0.51	0.62	0.86	0.83	0.88	0.89	0.83	0.6	0.55	0.36	0.29
Energy produced on-site	kWh/m^2	24.45	0.59	1.07	1.47	3.06	3.37	3.55	3.4	3.12	2.14	1.47	0.7	0.51
Exported electricity	kWh/m^2	16.84	0.21	0.55	0.85	2.21	2.54	2.67	2.51	2.29	1.54	0.92	0.34	0.22
Environmental energy	kWh/m^2	48.74	10.1	6.77	4.07	1.96	1.82	1.82	1.88	1.82	1.89	1.96	5.58	9.07
Grid exported	kWh/m^2	7.36	0.03	0.14	0.25	1.05	1.27	1.32	1.22	1.1	0.59	0.29	0.06	0.02
Grid delivered, EPB uses	kWh/m^2	15.58	2.92	2.11	1.41	0.75	0.45	0.44	0.46	0.5	0.68	1.05	2	2.82
Total greenhouse gas emissions	kgCO_{2eq}/m^2	-0.43	0.92	0.53	0.19	0.49	-0.71	-0.76	-0.7	-0.61	-0.29	0.04	0.56	0.88

Table 34 Simulated results of syn.ikia KPIs related to energy performance – monthly distribution. Marine climate demonstration project

			Monthly values											
Performance indicators	Unit	Annual value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Non-renewable energy balance	kWh/m^2	-1.84												
Renewable energy ratio	-	Not simulated												
Grid purchase factor	-	0.67												
Load cover ratio	-	0.32												
Supply cover ratio	-	0.33												
Net energy	kW	Not simulated												
Peak delivered	kW	47.6	Not simulated											
Peak exported	kW	45.6	Not simulated											
Grid connection capacity	-	Not simulated												
Energy produced on-site	kWh	54646	1329	2382	3283	6845	7522	7941	7599	6982	4772	3292	1570	1133

Indoor environment quality performance results

The simulated annual category level of thermal comfort and operative temperature according to European Standard EN15251:2007, recently revised to the EN16798-1-2019, which defines four categories of the indoor environmental quality related to the level of expectations of the building occupant is presented in Table 34b below. The results show that the building provides comfortable conditions to the users more than 80% of the time considering a Category IEQ1 and IEQ2, which is recommended for new residential buildings.

Table 34b Simulated results of syn.ikia KPIs related to thermal comfort – Marine climate demonstration project.

	Quality of indoor environment in % of time in four categories			
Thermal comfort – performance indicator	IEQ1 (%)	IEQ2(%)	IEQ3(%)	IEQ4 (%)
Predicted mean vote (PMV) and predicted percentage dissatisfied (PPD)	67.8	15.5	4.3	1.2
Operative Temperature	55.7	25.6	15.7	0.8

5.3 Continental Climate Demonstration Projects in Austria

5.3.1 GNICE in Salzburg, Austria

Energy performance results

The results of energy performance simulation results based on the developed building performance simulation model of Continental climate demonstration project – GNICE are presented in Tables 35 -37. For the detailed final design, the simulation results give a total annual primary energy consumption of 21.74 kWh/m^2a with a non-renewable primary energy consumption of -6.03 kWh/m^2a, indicating energy export. The annual average supply cover factor is calculated as 0.27, indicating that relatively small fraction (27%) of the on-site generated electricity is used directly in the building for EPB uses (Table 35). The results show that it is a net zero energy building (for EPB uses): on a yearly basis the EPB uses (21.74 kWh/m^2) are less than the energy generated on-site (21.92 kWh/m^2) (Table 36). The syn.ikia energy balance for the final design is positive, with 16.07 kWh/(m^2yr) exported to the grid. This excess energy can also be used in the future to provide electricity for EVs and other mobility solutions, in line with the future project goals.

Table 35 Simulated annual energy performance indicators. Continental climate demonstration project – Gnice, Salzburg

Performance indicators	Unit	Annual value
Heating demand	kWh/m2	78.3
Cooling demand	kWh/m2	0
DHW demand	kWh/m2	10.2
Lighting demand	kWh/m2	5.3
Renewable energy production	kWh/m2	21.92
Total primary energy consumption	kWh/m2	21.74
Non-renewable primary energy demand (A)	kWh/m2	15.88
Renewable primary energy delivered (B)	kWh/m2	21.92
Non-renewable primary energy consumption (A-B)	kWh/m2	-6.03
Imported EPB uses	kWh/m2	4.36
Exported EPB uses	kWh/m2	2.04
Supply cover factor	-	0.27

Table 36 Simulated results of the building energy performance with indicators in line with ISO 52000-1:2017 standard – Continental climate demonstration project – Gnice, Salzburg

			Monthly values											
Performance indicators	Unit	Annual value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
EPB uses	kWh/m^2	21.74	3.73	2.92	2.32	1.34	0.75	0.7	0.67	0.68	0.76	1.44	2.66	3.7
non-EPB uses	kWh/m^2	6.41	0.54	0.49	0.54	0.52	0.54	0.52	0.54	0.54	0.52	0.54	0.52	0.54
EPB used electricity	kWh/m^2	21.74	3.73	2.92	2.32	1.34	0.75	0.7	0.67	0.68	0.76	1.44	2.66	3.7
Energy produced on-site	kWh/m^2	21.92	0.81	1.1	1.8	2.18	2.97	2.55	2.95	2.64	1.97	1.39	0.76	0.74
Exported electricity	kWh/m^2	16.07	Not simulated in detail											
Environmental energy	kWh/m^2	Not simulated												
Grid exported	kWh/m^2	14.02	Not simulated in detail											
Grid delivered, EPB uses	kWh/m^2	15.88	Not simulated in detail											
Total greenhouse gas emissions	kgCO_{2eq}/m^2	Not calculated												

Table 37 Simulated results of syn.ikia KPIs related to energy performance – monthly distribution – Continental climate demonstration project – Gnice, Salzburg.

			Monthly values											
Performance indicators	Unit	Annual value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Non-renewable energy balance	kWh/m^2	-0.18	Not simulated in detail											
Renewable energy ratio	-	1.01	Not simulated in detail											
Grid purchase factor	-	Not simulated												
Load cover ratio	-	Not simulated												
Supply cover ratio	-	0.27	Not simulated in detail											
Net energy	kW	Not simulated												
Peak delivered	kW	307	Not simulated in detail											
Peak exported	kW	442	Not simulated in detail											
Grid connection capacity	-	-0.18	Not simulated in detail											
Energy produced on-site	kWh	574 228	Not simulated in detail											

Indoor environmental quality performance

The simulated annual category level of indoor environmental quality performance indicators according to European Standard EN15251:2007, recently revised to the EN16798-1-2019, which defines four categories of the indoor environmental quality related to the level of expectations of the building occupant is presented in Table 38 below. The simulated performance is characterised by high quality, corresponding mostly to the first indoor environmental quality category (IEQ1) relating carbon dioxide and predicted mean vote indicators.

Table 38 Simulated results of syn.ikia KPIs related to indoor environment quality. Continental climate demonstration project – Gnice, Salzburg.

	Quality of indoor environment in % of time in four categories			
Indoor environment quality (IEQ) performance indicator	IEQ1 (%)	IEQ2(%)	IEQ3(%)	IEQ4 (%)
Level of Carbon dioxide - CO2	100	0	0	0
Predicted mean vote (PMV) and predicted percentage dissatisfied (PPD)	97.8	2.1	0.1	0
Operative Temperature	2.2	95.4	4.6	0
Daylight factor*	74.2%			

*Percentage of time when the daylight factor is above 2%

5.3.2 Wir inHAUSer in Salzburg, Austria

Energy performance

The results of energy performance simulation results based on the developed building performance model of the retrofit continental climate demonstration project – Wir inHAUSer are presented in Tables 39 -41. For the detailed final design, the simulation results give a total annual primary energy consumption of 59.9 kWh/m^{2}a with a positive value of the non-renewable primary energy consumption of 10.06 kWh/m^{2}a, indicating lack of the energy export (Table 39). The results show that for this retrofit project the net-zero energy balance (for EPB) uses are not achieved – renewable energy produced on-site (7.9kWh/m^{2}a) annually covers around 66% of the EPB uses (11.9kWh/m^{2}a) (Table 40).

Table 39 Simulated annual energy performance indicators. Continental climate demonstration project – Wir inHAUSer, Salzburg.

Performance indicators	Unit	Annual value
Heating demand	kWh/m^2	32.39
Cooling demand	kWh/m^2	0
DHW demand	kWh/m^2	18.05
Lighting demand	kWh/m^2	Not simulated
Renewable energy production	kWh/m^2	7.89
Total primary energy consumption	kWh/m^2	59.49
Non-renewable primary energy demand (A)	kWh/m^2	17.94
Renewable primary energy delivered (B)	kWh/m^2	7.89
Non-renewable primary energy consumption (A-B)	kWh/m^2	10.06
Imported EPB uses	kWh/m^2	4.07
Exported EPB uses	kWh/m^2	0
Supply cover factor	-	Not simulated

Table 40 Simulated results of the building energy performance with indicators in line with ISO 52000-1:2017 standard. Continental climate demonstration project – Wir inHAUSer, Salzburg.

			Monthly values											
Performance indicators	Unit	Annual value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
EPB uses	kWh/m^2	11.96	1.41	1.27	1.33	0.91	0.69	0.66	0.68	0.69	0.73	0.9	1.28	1.41
non-EPB uses	kWh/m^2	Not simulated												
EPB used electricity	kWh/m^2	11.96	1.41	1.27	1.33	0.91	0.69	0.66	0.68	0.69	0.73	0.9	1.28	1.41
Energy produced on-site	kWh/m^2	7.89	0.81	1.1	1.8	2.18	2.97	2.55	2.95	2.64	1.97	1.39	0.76	0.74
Exported electricity	kWh/m^2	0	Not simulated in detail											
Environmental energy	kWh/m^2	29.91	3.52	3.17	3.31	2.29	1.73	1.65	1.69	1.73	1.82	2.24	3.21	3.53
Grid exported	kWh/m^2	0	Not simulated in detail											
Grid delivered, EPB uses	kWh/m^2	4.07	Not simulated in detail											
Total greenhouse gas emissions	$kgCO_{2eq}/m^2$	Not calculated												

Table 41 Simulated results of syn.ikia KPIs related to energy performance – monthly distribution. Continental climate demonstration project – Wir inHAUSer, Salzburg

			Monthly values											
Performance indicators	Unit	Annual value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Non-renewable energy balance	kWh/m^2	10.06	Not simulated in detail											
Renewable energy ratio	-	1.01	Not simulated in detail											
Grid purchase factor	-	Not simulated												
Load cover ratio	-	Not simulated												
Supply cover ratio	-	Not simulated												
Net energy	kW	Not simulated												
Peak delivered	kW	Not simulated												
Peak exported	kW	Not simulated												
Grid connection capacity	-	Not simulated												
Energy produced on-site	kWh	79 932	Not simulated in detail											

5.3.3 Berchtesgadner Straße 70-72 in Salzburg, Austria

Energy performance

The results of energy performance simulation results based on the developed building performance model of the retrofit Continental climate demonstration project – Berchtesgadner Straße 70-72 are presented in Tables 42-44. For the detailed final design, the simulation results give a total annual primary energy consumption of 90.8 kWh/m^{2}a with a positive value of the non-renewable primary energy consumption of 24.22, indicating a lack of energy export (Table 42). The results show that for this retrofit project, the net-zero energy balance (for EPB) uses is not achieved – renewable energy produced on-site (33.08 kWh/m^{2}a) annually cover around 42% of the EPB uses (79.04 kWh/m^{2}a) (Table 43).

Table 42 Simulated annual energy performance indicators. Continental climate demonstration project – Berchtesgadner Straße 70-72, Salzburg.

Performance indicators	Unit	Annual value
Heating demand	kWh/m^2	35.1
Cooling demand	kWh/m^2	-
DHW demand	kWh/m^2	18.43
Lighting demand	kWh/m^2	6.59
Renewable energy production	kWh/m^2	33.08
Total primary energy consumption	kWh/m^2	90.8
Non-renewable primary energy demand (A)	kWh/m^2	66.32
Renewable primary energy delivered (B)	kWh/m^2	42.1
Non-renewable primary energy consumption (A-B)	kWh/m^2	24.22
Imported EPB uses	kWh/m^2	8.01
Exported EPB uses	kWh/m^2	3.75
Supply cover factor	-	0.27

Table 43 Simulated results of the building energy performance with indicators in line with ISO 52000-1:2017 standard. Continental climate demonstration project – Berchtesgadner Straße 70-72, Salzburg

			Monthly values											
Performance indicators	Unit	Annual value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
EPB uses	kWh/m^2	79.04	Not simulated in detail											
non-EPB uses	kWh/m^2	11.76	Not simulated in detail											
EPB used electricity	kWh/m^2	36.7	Not simulated in detail											
Energy produced on-site	kWh/m^2	33.08	Not simulated in detail											
Exported electricity	kWh/m^2	24.25	Not simulated in detail											
Environmental energy	kWh/m^2	9.76	Not simulated in detail											
Grid exported	kWh/m^2	21.15	Not simulated in detail											
Grid delivered, EPB uses	kWh/m^2	24.22	Not simulated in detail											
Total greenhouse gas emissions	$kgCO_{2eq}/m^2$	-	Not simulated in detail											

Table 44 Simulated results of syn.ikia KPIs related to energy performance – monthly distribution. Continental climate demonstration project – Berchtesgadner Straße 70-72, Salzburg

			Monthly values											
Performance indicators	Unit	Annual value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Non-renewable energy balance	kWh/m^2	24.22	Not simulated in detail											
Renewable energy ratio	-	53%	Not simulated in detail											
Grid purchase factor	-	Not simulated												
Load cover ratio	-	Not simulated												
Supply cover ratio	-	Not simulated												
Net energy	kW	Not simulated												
Peak delivered	kW	Not simulated												
Peak exported	kW	Not simulated												
Grid connection capacity	-	Not simulated												
Energy produced on-site	kWh	61 013												

Indoor environmental quality performance

The simulated annual category level of indoor environmental quality performance indicators according to European Standard EN15251:2007, recently revised to the EN16798-1-2019, which defines four categories of indoor environmental quality related to the level of expectations of the building occupant is presented in Table 45 below. The simulated performance is characterised by high quality, mainly corresponding to the first and second indoor environmental quality categories (IEQ1-2).

Table 45 Simulated results of syn.ikia KPIs related to indoor environment quality. Continental climate demonstration project – Gnice, Salzburg.

	Quality of indoor environment in % of time in four categories			
Indoor environment quality (IEQ) performance indicator	IEQ1 (%)	IEQ2(%)	IEQ3(%)	IEQ4 (%)
Level of Carbon dioxide - CO_2	100	0	0	0
Predicted mean vote (PMV) and predicted percentage dissatisfied (PPD)	51.1	44.8	4.1	0
Operative Temperature	97.9	2.1	0	0
Daylight factor*	93.14%			

*Percentage of time when the daylight factor is above 2%

5.4 Subarctic climate demonstration projects in Norway

5.4.1 Verket Panorama

Energy performance

The energy performance simulation results based on the developed building performance simulation model of the Subarctic climate demonstration project – Verket Panorama are presented in Tables 46-48. The simulation results give a total annual primary energy consumption of 37.2 kWh/m^2 with a non-renewable primary energy of -2.8, indicating slight energy export. The average yearly supply cover factor is calculated as 0.68, indicating that a significant share (68%) of the on-site generated electricity is used directly in the building for EPB uses (Table 46). Additionally, based on performed simulations, the final demonstration design is considered energy efficient; the imported electricity for EPB uses is low (7.2kWh/m^{2}a). The results show that the net zero energy building (for EPB uses) level is achieved: on a yearly basis the EPB uses (37.0 kWh/m^2) are less than the energy generated on-site (38.0 kWh/m^2) (Table 47).

Table 46 Simulated annual energy performance indicators. Subarctic climate demonstration project – Verket Panorama

Performance indicators	Unit	Annual value
Heating demand	kWh/m2	5.5
Cooling demand	kWh/m2	-
DHW demand	kWh/m2	11
Lighting demand	kWh/m2	11.4
Renewable energy production	kWh/m2	38
Total primary energy consumption	kWh/m2	37.2
Non-renewable primary energy demand (A)	kWh/m2	4.6
Renewable primary energy delivered (B)	kWh/m2	32.6
Non-renewable primary energy consumption (A-B)	kWh/m2	-2.8
Imported EPB uses	kWh/m2	7.2
Exported EPB uses	kWh/m2	12.2
Supply cover factor	-	0.68

Table 47 Simulated results of the building energy performance with indicators in line with ISO 52000-1:2017 standard. Subarctic climate demonstration project – Verket Panorama

			Monthly values											
Performance indicators	Unit	Annual value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
EPB uses	kWh/m^2	37	Not simulated in detail											
non-EPB uses	kWh/m^2	10.5	Not simulated in detail											
EPB used electricity	kWh/m^2	25.8	Not simulated in detail											
Energy produced on-site	kWh/m^2	38	Not simulated in detail											
Exported electricity	kWh/m^2	12.2	Not simulated in detail											
Environmental energy	kWh/m^2	-	Not simulated in detail											
Grid exported	kWh/m^2	12.2	Not simulated in detail											
Grid delivered, EPB uses	kWh/m^2	7.8	Not simulated in detail											
Total greenhouse gas emissions	$kgCO_{2eq}/m^2$	-0,65	Not simulated in detail											

Table 48 Simulated results of syn. ikia KPIs related to energy performance – monthly distribution. Subarctic climate demonstration project – Verket Panorama

			Monthly values											
Performance indicators	Unit	Annual value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Non-renewable energy balance	kWh/m^2	-2.85	Not simulated in detail											
Renewable energy ratio	-	0.88	Not simulated in detail											
Grid purchase factor	-	0.22	Not simulated in detail											
Load cover ratio	-	0.78	Not simulated in detail											
Supply cover ratio	-	0.68	Not simulated in detail											
Net energy	kW	4.8	Not simulated in detail											
Peak delivered	kW	0.01	Not simulated in detail											
Peak exported	kW	0.02	Not simulated in detail											
Grid connection capacity	-	0.39	Not simulated in detail											
Energy produced on-site	kWh	68514	Not simulated in detail											

Indoor environmental quality performance

The simulated annual category level of indoor environmental quality performance indicators according to European Standard EN15251:2007, recently revised to the EN16798-1-2019, which defines four categories of indoor environmental quality related to the level of expectations of the building occupant is presented in Table 49 below. The simulated performance is characterised by acceptable quality, mainly corresponding to the second and third indoor environmental quality categories (IEQ2-3).

Table 49 Simulated results of syn.ikia KPIs related to indoor environment quality. Subarctic climate demonstration project – Verket Panorama.

	Quality of indoor environment in % of time in four categories			
Indoor environment quality (IEQ) performance indicator	IEQ1 (%)	IEQ2(%)	IEQ3(%)	IEQ4 (%)
Level of Carbon dioxide - CO_2	34	17	30	19
Predicted mean vote (PMV) and predicted percentage dissatisfied (PPD)	36	15	28	21
Operative Temperature	77	18	5	0
Daylight factor	Not simulated			

5.4.2 OEN residential building in Oslo

Energy performance

The energy performance simulation results based on the developed building performance simulation model of the Subarctic climate demonstration project – OEN building, Oslo, are presented in Tables 50-52. The simulation results give a total annual primary energy consumption of 60 kWh/m^2 with a non-renewable primary energy of -7.6, indicating slight energy export. The average yearly supply cover factor is calculated as 0.49 indicating that a significant share (49%) of the on-site generated electricity is used directly in the building for EPB uses (Table 50). The results show that the net zero energy building (for EPB uses) level is achieved: on a yearly basis, the EPB uses (47.8 kWh/m^2) are less than the energy generated on-site (55.8 kWh/m^2) (Table 51).

Table 50 Simulated annual energy performance indicators. Subarctic climate demonstration project – OEN building, Oslo.

Performance indicators	Unit	Annual value
Heating demand	kWh/m^2	3.99
Cooling demand	kWh/m^2	-
DHW demand	kWh/m^2	25
Lighting demand	kWh/m^2	13
Renewable energy production	kWh/m^2	55.8
Total primary energy consumption	kWh/m^2	60.0
Non-renewable primary energy demand (A)	kWh/m^2	48.3
Renewable primary energy delivered (B)	kWh/m^2	55.9
Non-renewable primary energy consumption (A-B)	kWh/m^2	-7.6
Imported (delivered) EPB uses	kWh/m^2	26.6
Exported for non-EPB uses	kWh/m^2	12.18
Supply cover factor	-	0.49

Table 51 Simulated results of the building energy performance with indicators in line with ISO 52000-1:2017 standard. Subarctic climate demonstration project – OEN, Oslo.

			Monthly values											
Performance indicators	Unit	Annual value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
EPB uses	kWh/m^2	47.8	Monthly data only documented for the base case scenario (not the optimized one)											
non-EPB uses	kWh/m^2	18.5												
EPB used electricity	kWh/m^2	21.3												
Energy produced on-site	kWh/m^2	55.8												
Exported electricity	kWh/m^2	34.5												
Environmental energy	kWh/m^2	0												
Grid exported	kWh/m^2	22.3												
Grid delivered, EPB uses	kWh/m^2	26.6												
Total greenhouse gas emissions	kgCO$_{2eq}$/m^2	-												

Table 52 Simulated results of syn.ikia KPIs related to energy performance – monthly distribution. Subarctic climate demonstration project – OEN building, Oslo.

			Monthly values											
Performance indicators	Unit	Annual value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Non-renewable energy balance	kWh/m^2	-7.6	Monthly data only documented for the base case scenario (not the optimized one)											
Renewable energy ratio	-	Not simulated												
Grid purchase factor	-	Not simulated												
Load cover ratio	-	Not simulated												
Supply cover ratio	-	0.49												
Net energy	kW	Not simulated												
Peak delivered	kW	Not simulated												
Peak exported	kW	Not simulated												
Grid connection capacity	-	Not simulated												
Energy produced on-site	kWh	807 032												

6. References

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NTNU
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DTU Technical University of Denmark

BPIE

SINTEF

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area

INCASÒL
Institut Català del Sòl

TNO innovation for life

ENFOR

ABUD
Advanced Building & Urban Design

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SALZBURGER INSTITUT FÜR RAUMORDNUNG & WOHNEN

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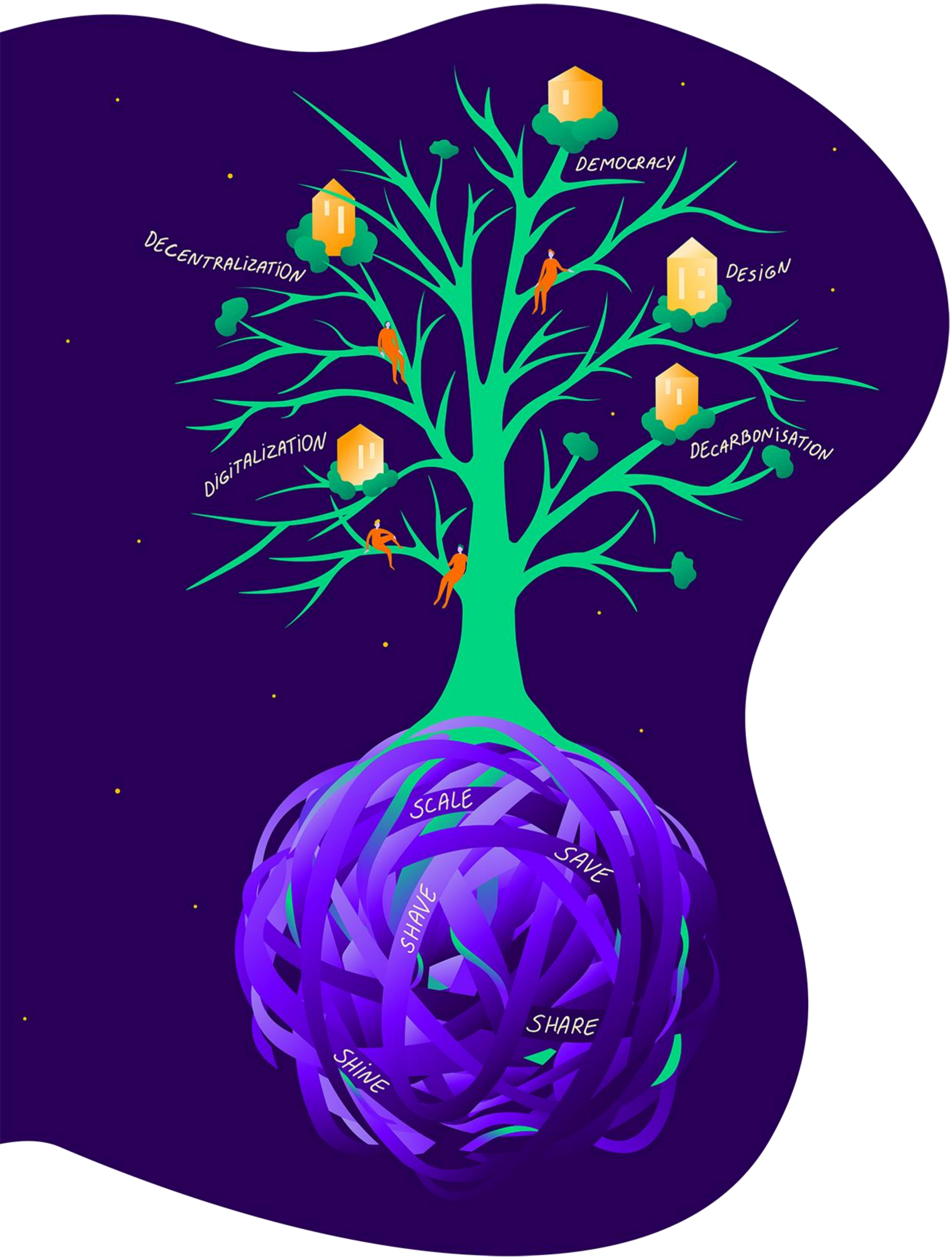
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SCALE
SAVE
SHAVE
SHARE
SHINE