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Achieving near Zero and Positive Energy Settlements in Europe using Advanced Energy Technology

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D7.7 REPORT ON THE ENERGY PERFORMANCE ANALYSIS OF THE 4 SETTLEMENTS

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Executive Summary

ZERO-PLUS is a comprehensive, cost-effective approach for the design, construction and monitoring of Net Zero Energy Settlements (NZESs). Focusing on the settlement-level instead of single buildings, the ZERO-PLUS approach aims to bring together settlement planners, building designers, technology developers and suppliers, energy efficiency and renewable energy experts, contractors, and building owners to work together from the earliest stages of project conception to optimise the NZES design. The ZERO-PLUS approach is described in the ZERO-PLUS Guidebook for Designing Net Zero Energy (NZE) Settlements[1] [1]. It consists of a series of guidelines for designing and implementing NZE Buildings and Settlements in Europe that can be used by subsequent similar projects and by the building industry.

The ZERO-PLUS approach was successfully applied in four pilot projects in different climatic settings (in France, the UK, Italy, and Cyprus) as part of the ZERO-PLUS project (Table 1).

Table 1: ZERO-PLUS case studies and installed technologies

Location	Climate	Type of buildings	Energy conservation	Energy generation	Energy management
York, UK	Temperate	Detached and semi-detached dwellings		PV system on roof	·Powerwall II batteries for the management of electricity demand from PV and off-peak reduced rate charging by Tesla ·BEMS with learning thermostat by HIVE
Granarolo dell'Emilia, Italy	Temperate and Mediterranean	Villas	XPS (composite cool thermal insulation on walls and roof) by FIBRAN	PV system on roof	·REACT Storage and inverter system by ABB ·Load control by ABB ·BEMS system by ABB
Voreppe, France	Semi-continental	Social housing apartment block		·MRE C05 PV system on roof by ANERDGY ·Spring 310M (electrical and thermal solar panels on roof) by DUALSUN ·Connection to district heating network (biomass)	·Thermal energy stored in hot water tank ·Energy regulation (low temperature at night)
Nicosia, Cyprus	Intense Mediterranean	Prefabricated container system	·freescoo HVAC (solar air conditioning system) by SolarInvent ·ETICS XPS (composite cool thermal insulation on walls) by FIBRAN	FAE HCPV (combined heat and power generation system) by Idea	

1 http://www.zeroplus.org/pdf/ZERO%20PLUS%20GUIDEBOOK%20FINAL.pdf

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This report presents the validation procedure for the energy and environmental performance of the four settlements along with the results of the analysis. The results of the real-life implementation of the ZERO-PLUS approach vs the ZERO-PLUS ambition set, validating its success, are demonstrated in the table below (Table 2).

Table 2: Actual performance for the French, Italian and the UK case studies and simulated performance for the Cypriot case study

#	Key Performance Indicator (KPI)	France	Italy	UK	Cyprus[2]
1	**Net Regulated energy (kWh/m^2/year)** (target: < 20 kWh/m2/year)	-10.1	-11	-1	18.9
2	**Renewable energy production (kWh/m^2/year)** (target: > 50 kWh/m2/year)	123	47.6	51.2	54.3
3	**Cost reduction (%)** (target: 16% reduction compared to the reference case)	26.7	24.8	17.8	17
4	**Carbon emission reduction** (kgCO_2/m^2/year) (target varies per case study; FR >=4.6; IT>=23; UK>=18; CY>=34)	17.1	49.6	21.1	16.8

Monitoring activities and the Web-GIS platform are at the core of the project as they were used for fine-tuning the simulation models, for checking in real-time the performance of the settlements to ensure timely interventions and troubleshooting of the installed systems and technologies where needed, and finally for evaluating the total energy performance of the settlements, by performing the Post Occupancy Evaluation (POE) and making the transition from building to settlement level. The post occupancy monitoring for all case studies lasted for over 10 months with the exception of the Cypriot case study where the post occupancy monitoring period was 4.5 months long. The monitoring period of ZERO-PLUS includes the first COVID-19 outbreak. Despite the challenges, the monitoring activities continued to run to the extent possible and both the monitoring and the POE surveys and interviews and their effect are taken into account in the energy performance analysis.

A ZERO-PLUS specific overarching internal document for designing and implementing a robust measurement and verification (M&V) plan was developed. It is organized in relation to the project's phases of development, thus spanning from pre-design to post-occupancy. For each phase, quality control procedures were identified. Mostly the Post-Construction/Installation- Pre-occupation Phase and Post-occupation Phase procedures are considered here.

[2] The concept of the Cyprus case study is to create a zero-energy settlement formed by few ZERO-PLUS demohouses. For the purpose of this task, we assume that two ZERO-PLUS demohouses are built at the Cyprus Institute (CyI) premises and connected to 2 FAE HCPV/T modules with 20 mirrors each, even if they are not built along the duration of the project. The performance of this settlement will be indicated as-built although it is the result of dynamic simulation. Given the theoretical nature of the task it is not possible to compare the as-built performance with the "actual" performance of the settlement. The ZERO-PLUS technologies were installed and tested in an existing demobox in the CyI premises.
Definitions:
"As-built results": Simulation results by taking into account the as-built designs and the technologies installed. The model is calibrated to the possible extent by using the monitored data from the pre-occupancy checks and pre-occupancy monitoring.
"Actual results": Results obtained from the analysis of the monitored data provided by the end of the project.

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Simulations were carried out for all case studies many times in different phases of the project from design until the construction of the settlements and even after the end of the monitoring period. In each phase they serve a different purpose from optimizing the settlements' design to estimating its performance and finally verifying the accuracy of the models with the use of measured data.

The transition from building level to settlement level is modelled to observe the energy balance that could be achieved through such an arrangement. It is simulated by using an energy management system that in each case takes full advantage of the renewable energy production of the installed technologies.

It was concluded that the feasibility of the ZERO-PLUS approach in the different climatic regions is fully supported by the results and the developed methodology. The successful implementation of the ZERO-PLUS approach is proven by the actual monitored performance results. However, the legacy of the ZERO-PLUS approach lies in the developed tools and methods, tailored to the settlement level, the acceptable as-built results and the developed methodology for the transition from building to settlement level. All these can be used to successfully support the transferability and replicability of the ZERO-PLUS approach.

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1. Introduction

ZERO-PLUS is a comprehensive, cost-effective approach for the design, construction and monitoring of Net Zero Energy Settlements (NZES). Focusing on the settlement-level instead of single buildings, the ZERO-PLUS approach aims to bring together settlement planners, building designers, technology developers and suppliers, energy efficiency and renewable energy experts, contractors, and building owners to work together from the earliest stages of project conception to optimise the NZES design.

The added-value of the ZERO-PLUS approach lies in the cost-effectiveness of the construction process, thanks to the application of an integrated approach to building design, and in the optimisation of the energy load for each building by designing the energy generation system at the settlement level.

The benefits of applying the ZERO-PLUS approach were demonstrated in four pilot projects in different climatic settings (in France, the UK, Italy and Cyprus), thus demonstrating the adaptability and wide applicability of the ZERO-PLUS approach [2].

ZERO-PLUS settlements exceed the state of the art by setting performance objectives requiring improvement relative to other energy-efficient buildings:

- The Net regulated energy usage in residential buildings in a ZERO-PLUS settlement is reduced to an average of 0-20 kWh/m² per year.
- The Net Zero Energy (NZE) settlement generates a minimum of 50 kWh/m² of renewable energy per year.
- The investment cost of the ZERO-PLUS building is reduced by at least 16%, compared to a regular Net Zero Energy Building (NZEB).
- Support the shift towards resource-efficient, low-carbon and climate-resilient buildings and districts, by enhancing the role of Europe’s construction industry in the reduction of the EU’s carbon footprint.

The objectives of this report are:

- to evaluate the in-use energy and environmental performance of the settlement versus the ZERO-PLUS ambition set.
- to demonstrate how a transition from building to settlement level can be achieved.
- to showcase the transferability and replicability potential of the ZERO-PLUS approach.

For each case study the following are presented:

- Overview information: description of the case studies (Section 2).
- Monitoring and quality of measured data (Section 3).

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- Simulations: calibrated models, Monitoring & Verification (M&V) plan- Option D (Section 4).
- Energy performance: results and impacts of the settlements (KPIs and impacts), Section 5.
- Transition from building to settlement level (Section 6).

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2. ZERO-PLUS case studies

2.1 Introduction to the settlements and their climate

2.1.1 French case study

The French case study is located in the town of Voreppe, in an urban area with medium density housing in the eastern part of France about 15 km North-West of Grenoble city. Voreppe is a city of 10 000 inhabitants and is located in a lowland between two mountains with a little variable wind direction.

The climate in this area is continental with a temperature gradient that can range from -11°C in the Winter season and up to + 36°C in the Summer season. The rainfalls average is around 1000 mm per year.

The ZERO-PLUS building was constructed 200 m away from the railway station linked to Grenoble (10 minutes) and Lyon (1h). It is a collective building with 18 apartments on 4 floors. It includes 7 one- bedroom, 6 two-bedroom, 4 three--bedroom, and 1 four-bedroom apartments, as depicted in Figure 1.

Figure 1: View of the French case study ZERO-PLUS building

2.1.2 Italian case study

The Italian case study is part of a housing development area close to completion in Granarolo dell'Emilia, located at 28 m above sea level (a.s.l.) at about 10 km northeast of Bologna, in Emilia-Romagna. Granarolo dell'Emilia has more than 12,000 inhabitants and is characterized by a population density of 350person/km^2.

The case study belongs to the climatic zone E (2162 heating degree days and about 110 cooling degree days) and is characterized by the temperate and Mediterranean climate. Throughout the year, the average maximum temperature is 24.6°C, while the average minimum temperature is 2.5°C.

An entire high- performing neighborhood was conceptualized to being built within a growing urban area belonging to an on-going regeneration local program. The aim was to improve the microclimate conditions, the livability, and the energy efficiency of the entire area. The surrounding is a residential area rich in social services (e.g.,

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schools, administrative offices, stores, banks, etc.) and public transportation utilities. Also, it is close to a public green area.

The total flat area covered by the Net Zero Energy (NZE) settlement is approx. 9600 m² (not including public spaces). Here, six single-family villas are close to their completion, while the two demonstration high-energy efficient single-family villas IT1 and IT2 (Figure 2) that are characterized by a similar architectural design (i.e. one ground floor villa and one two-story villa) were already completed according to the ZERO-PLUS guidelines.

The standard ground floor villa has one kitchen, one living room, one hall, two bathrooms, three bedrooms, one utility room, and a private garage. Each villa has private access and a garden, which become a connected area within the settlement. The villas are each located in one lot. The total floor area of each villa is about 250 m² distributed into an approximately rectangular ground sub-lot of about 800 m². The entrance is oriented to the North-West side of the lot. The accommodations are designed to host one family of three to five people. Two families relocated in the two buildings IT1 and IT2 after construction was completed, i.e. in summer 2018 and spring 2019, respectively.

The total area dedicated to the demonstration case study, i.e. the two ZERO-PLUS buildings and the vicinity, is close to 2760 m².

Figure 2: Italian ZERO-PLUS demonstration single-family villas: IT1 in the bottom and IT2 in the top

2.1.3 UK case study

The UK case study is in an area called Derwenthorpe, located on the edge of the city of York, England. The case study, located in the North of England, experiences a temperate climate, resulting in average winter temperatures between 1^{o}C and 5^{o}C, and average summer temperatures between 11^{o}C and 18^{o}C. As a result of these climate conditions, there is a greater focus on heating demand in properties, with a total of 1975 heating degree days compared to 298 cooling degree days.

The Derwenthorpe settlement will consist of 489 dwellings of various house types. For the ZERO-PLUS project, a total of three properties were built to meet the project targets. In addition to the three dwellings that are part of the project, other parts of the settlement will be used to support the renewable energy targets of the project.

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The concept of the UK case study is to create a sustainable community through a settlement level approach for energy generation in order to retain the traditional characteristics of a Derwenthorpe home. Energy reduction targets are achieved at the dwelling level, with renewable energy generation targets achieved at the settlement level, which in turn contributes to the cost reduction target.

The ZERO-PLUS dwellings are representative of typical UK homes including two, two-storey semi-detached properties and one two-storey detached property. Figure 3 shows the final constructed dwellings before PV installation. The plot numbering is from right to left in the images. UK1 and UK2 are both 2-bedroom semi-detached properties, consisting of two stories. These two properties are mirrored, and both share the party wall along the Lounge wall. UK3 is a 3-bedroom detached property, also with two stories.

Figure 3: Exterior images of the UK case study buildings UK3, UK2, UK1, from left to right

2.1.4 Cypriot case study

The settlement is located in the Cyprus Institute (CyI) campus in Aglantzia (35.14 N and 33.38 E), a suburb in the southern part of Nicosia, the capital of the Republic of Cyprus. It is situated in a low-density area and borders with the Athalassa National Forest Park (Figure 4).

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Figure 4: Location of the Cyprus case study

The climate in the area is intense Mediterranean, with mild winters ($T_{min, average}$ = 10°C) and hot summers (T_{max} up to 46.7 °C). As a result of these climate conditions, there is a greater focus on space cooling demand.

The Cypriot case study is based on the design of a theoretical prefabricated container system structure (ZERO-PLUS demohouse), displayed in Figure 5, which is intended for residential use and more specifically for student housing.

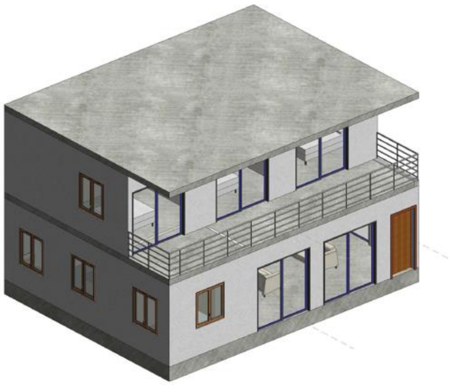

Figure 5: The future ZERO-PLUS demohouse

Figure 6: The existing demobox with the selected technologies

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The ZERO-PLUS demohouse itself will not be erected under the ZERO-PLUS project. However, the technologies, selected to meet the project's goals, were installed and are monitored on a preexisting prefabricated container system structure that already exists in the CyI premises (the "existing demobox") (Figure 6). In the future, the Cyprus Institute will install multiple copies of this demohouse on a demonstration site reserved on its premises for this purpose (Figure 7).

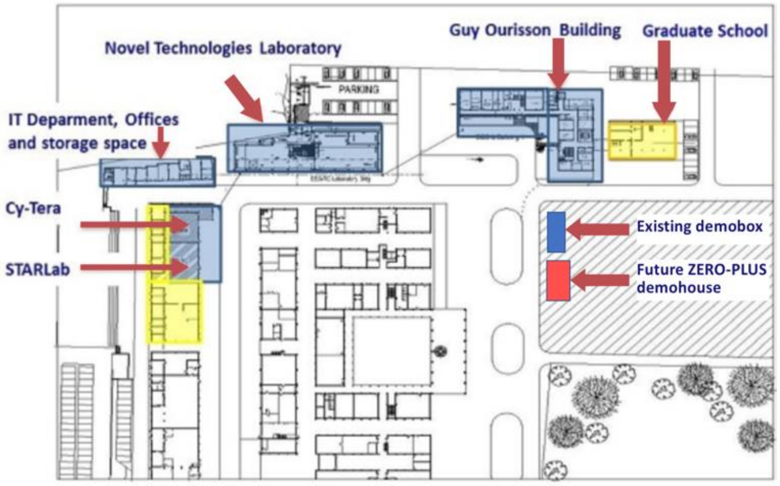

Figure 7: Site plan for the Cyprus case study within the premises of CyI

The concept of the Cypriot case study is to create a zero-energy settlement formed by numerous ZERO-PLUS demohouses that will be realized in the near future, the existing demobox and the RES technologies installed by ZERO-PLUS.

In the current demobox, 1 module of FAE HCPV and 1 system of freescoo HVAC are installed. The freescoo HVAC system is mounted into a fake wall that is filled with FIBRAN insulation. For the construction of the future ZERO-PLUS demohouse, the use of 40 mm of FIBRAN insulation on the walls and 80 mm on the roofs is considered (Table 3).

Table 3: Overview of the building parameters for the Cypriot case study

General information	Existing demobox	Future ZERO-PLUS demohouse
Gross floor area in m^2	130	390
Orientation of the building	North – South	North – South
Storeys	2	2
Bedrooms	0	3
Thermal transmission coefficients		
U-Values of walls in $W/(m^2 K)$	0.4	0.21
U-Values of roof in $W/(m^2 K)$	0.4	0.21
U-Values of floor in $W/(m^2 K)$	0.644	0.644
Other specific parameters		
Shading	None	Overhanging slab extension / External shading in bedrooms
Type of glazing (U-value in $W/(m^2 K)$; g-value is adimentional)	Common LowE double glazing (U = 2.40: g = 0.56)	Common LowE double glazing (U = 2.40: g = 0.56)

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2.2 Implementation of the ZERO-PLUS technologies

Technologies considered for use in the ZERO-PLUS pilot projects and that contribute to the achievement of the Key Performance Indicators include energy conservation, energy production and energy management solutions.

Life Cycle Cost Analysis (LCCA) was utilised to determine the costs incurred by operating the energy and environmental systems chosen for the initial design of the settlements. Energy performance and cost have both been optimized through iteration and eventual changes in the initial set of technologies. The technologies' configuration eventually installed in the settlements is summarized in Table 1.

2.2.1 French case study

Firstly, a heat exchanger of the biomass urban heating network was used to provide the heat (hot water). The heat exchanger can deliver approximately 44 000 kWh (heating and hot water) and is connected to the Domestic Hot Water (DHW) tank for the supplement to the production of hot water. The consumption is reduced via Spring 310M modules developed by DUALSUN.

For energy storage, a boiler with a capacity of 750 litres for Domestic Hot Water (DHW) – in addition to the DUALSUN system – was used, see Figure 4. The building's DHW boiler, which is connected to the urban heating network and the solar boiler supplied with DUALSUN modules, is firstly powered with the DUALSUN energy and then assisted with the Distric Heating System when needed.

The Spring 310M modules developed by DUALSUN exploit solar radiation to generate electricity and heat simultaneously. One Dualsun Spring 310M module has dimensions of standard photovoltaic panel (60 6-inch cells). An ultra-thin heat exchanger is added, completely integrated into the panel, generating an excellent heat transfer between the photovoltaic frontside and the water circulation on the backside. The nominal PV power is 310Wp, and the Thermal power output is 570W/m². For the electricity and heat production in the French case study, 20 modules were implemented on the rooftop of the building.

An additional producer of renewable energy in the French case study is the MRE C05 module developed by ANERDGY. The MRE C05 represents a modular all-in-one smart roof edge system, which is flexible in units, energy generation, design option and functions. It exploits solar radiation to generate electricity, thanks to standard photovoltaic panel implemented on an innovative baseframe. With this baseframe, other technical installations, which are normally built in the inner part of the rooftop, can be repositioned under the MRE C05 system. This cleans up the rooftop inner area allowing the architect flexibility for alternative uses e.g. greening, urban farming or a terrace (Figure 9). In the French case study, a total of 6 MRE C05 modules were used.

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Figure 8: View of Spring 310M modules developed by DUALSUN, installed on the roof of the building

Figure 9: View of MRE C05 modules developed by ANERDGY installed on the roof of the building

2.2.2 Italian case study

In the Italian case study, the following technologies were selected: FIBRAN insulation (Figure 10) for energy conservation at building level; ABB Load Control for energy management; ABB Home Energy Management System (HEMS) for energy management at building level; PV panels (Figure 11) for energy production at both building and settlement level; ABB REACT+ (Figure 12) for energy storage at both building and settlement level.

The technologies that were implemented at the building level, like FIBRAN insulation, HEMS and Load control by ABB, contribute together for energy conservation. PV panels at both building and settlement levels contribute to the energy production and allow, together with the energy storage, the use of renewable energy at different times during the day.

The XPS FIBRAN insulation system was integrated into the wall and the sloped roof of one villa. In the sloped roof, a thickness of 7 + 7.5 cm is used, while in the ground floor and external walls 10 + 5 cm and 22 cm are used, respectively.

In the Italian case study, 40 polycrystalline PV panels are used for energy production. 14 PV panels were installed on the roof of each villa with 8 kWp of total power producing about 39 kWh/m² y. Furthermore, 6 additional PV panels are mounted on the roof of each villa with 4 kWp of total power producing more than 9 kWh/ m² y, to cover community needs. The energy produced by the RES technologies (i.e., PV

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panels) is firstly used to cover the buildings' consumption. Secondly, it is stored in the energy storage to be used for private purposes when the RES technologies are not producing energy. Lastly, the excess of energy is being provided to the national grid.

One module of ABB REACT+ was installed in the technical room of each villa to store the energy produced by the PV panels both at the building and settlement levels. This system allows the villas to improve their energy self- consumption and save on their energy bills together with the ABB load control and the ABB Home Energy Management System (HEMS).

The selection of the ZERO-PLUS technologies is performed with the aim of achieving simultaneously the three main goals of the project in terms of energy production, energy consumption, and cost. For example, the thickness of the insulation panels is optimized in order to reduce the predicted energy consumption of the two villas. The number and typology of PV panels at the building and settlement level are defined in order to reach the total amount of 50 kWh/m² y of energy production.

Figure 10: Location of FIBRAN insulation in the Italian case study

(a) (b)

Figure 11: Location of the PV panels in the Italian case study

Figure 12: ABB REACT+ for electric storage installed in both villas

2.2.3 UK case study

To meet the ZERO-PLUS targets, the final technologies selected are PV, battery storage, and BEMS.

For energy reduction in the dwellings, standard UK produced insulation is used in lieu of ZERO-PLUS partner insulation product due to UK certification requirements. Dynamic thermal modelling was used to analyze the impact of insulation and the need to meet thermal requirements of the dwellings. Specifically, each dwelling type is modelled in Integrated Environmental Solutions Virtual Environment (IES VE) suite of software, specifically ModelIT for modelling the external physical characteristics of the dwellings and Apache for setting thermal parameters and running simulations. In Apache the thermal conductivity and thickness of each material was entered into the software for the respective elements of the building fabric. Following simulation of the fabric in association with heating system efficiency, occupant behavior and weather data modelling, the final consumption of the dwellings were checked against the primary ZERO-PLUS key performance indicator: reduce the net-regulated energy usage in residential buildings to an average of 0-20 kWh/m2 per year. Though several insulation options could meet this, ultimately, cost analysis of material, shipment, and installation have justified the use of the Derwenthorpe standard spec. insulation products, which could be locally sourced.

To meet the energy generation requirements of the ZERO-PLUS project, a large PV array is spread across four neighboring (two contiguous) dwellings with southwest facing roofs (Figure 13).

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Figure 13: PV on rear (southwest facing) roof of the two semi-detached dwellings

This provides a settlement approach as opposed to forcing the 15,000-kWh generation capacity needed onto the three ZERO-PLUS dwellings which would reduce efficiency and increase costs. At 16 kWp, the PV produces an estimated 15,200 kWh of electricity annually. To complement the generation requirements, a 13.5 kWh Tesla Powerwall II battery was installed for each ZERO-PLUS dwelling (Figure 14).

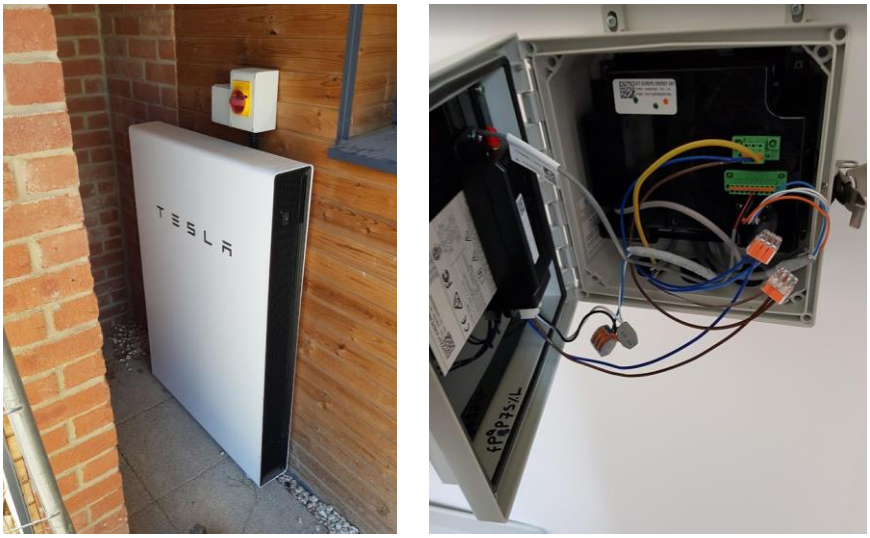

Figure 14: Tesla Powerwall II and Tesla Gateway

The batteries are used to balance demand and ease grid pressure. The Tesla batteries automatically drive the smart consumption of PV and battery power. PV to home connection is prioritized and when the home does not require power from the PV it is routed to the battery. If the home does not require power and the battery is full the PV generation is fed into the grid. When the sun is not shining, the home uses battery power before the grid (Figure 15).

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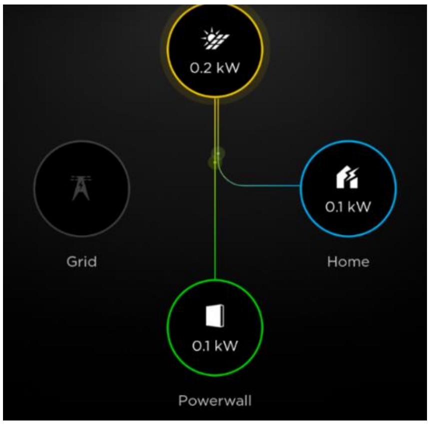

Figure 15: Tesla battery management

HIVE active heating, smart home systems were installed to serve as an energy management tool for the occupants of the dwellings. HIVE allows smart home learning for ideal heating, and remote control of heating, lighting and selected appliances. The HIVE active heating system allows users to control heating and hot water from their smartphone, tablet or laptop. The system allows add-ons for home power management including lighting, home motion sensing, window and door sensing and smart socket controls for any appliance. Dynamic thermal modelling resulted in an estimated 5% reduction in heating fuel consumption and a 10% reduction in lighting energy consumption (Figure 16 to Figure 18).

The HIVE home energy management system improves further the energy conservation in the dwellings by allowing the user to control the magnitude and timing of heat consumption at a fine detail. The HIVE home energy management system is a wireless thermostat control device that communicates with a hub that is connected to homes broadband router, and the receiver which allows the thermostat to communicate with the boiler. HIVE allows for more detailed control over the heating system while away from home. More information about HIVE can be found in Annex G.

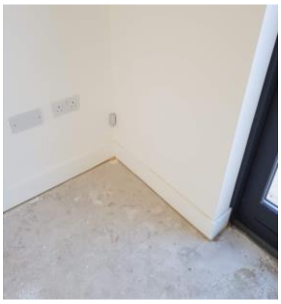

Figure 16: HIVE smart learning thermostat and occupancy detector

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Figure 17: HIVE plug meter

Figure 18: HIVE door and window sensor

2.2.4 Cypriot case study

Innovative energy conservation and renewable energy generation are numerically tested for the Cyprus ZERO-PLUS demohouse, in order to reach the project's performance targets and achieve a better integration of the technologies, which can help with the installation and maintenance processes. Table 4 shows the selected technologies.

Advanced insulation provides a needed reduction in space heating and cooling for the case study buildings. In addition, one feature that makes the advanced insulation particularly important for Cyprus is that it is coated with a highly reflective surface material, which mitigates overheating risk. More specifically, FIBRAN technology conserves 1525.7 kWh/year (i.e. 3.8 kWh/(m^2 year)) from the addition of 80 mm insulation on the roofs and 1232.5 kWh/year (i.e. 3.0 kWh/(m^2 year)) from the addition of 40 mm insulation on the walls.

Table 4: Overview of used technologies, their functions and expected performance

Case study: CyI's Aglantzia campus, Cyprus				
Technology	**Installation location**	**Function**	**Performance**	**Number of units**
FIBRAN	Building	Energy conservation	Wall: 3.0 kWh/(m^2 year) Roof: 3.8 kWh/(m2 year)	40 mm external walls 80 mm roof
HVAC freescoo	Building	Energy conservation	14.8 kWh/(m^2 year)	1 system
FAE HCPV	Settlement	Energy production	Electrical energy: 917.1 kWh/year; Thermal energy: 1207.1 kWh/year	1 array with 20 modules

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Extruded polystyrene production is based on the extrusion of the mixture of raw material, with the appropriate blowing agents and fire retardant. The extrusion makes the molecular structure of the XPS to have almost 97% of closed shells. This is why XPS material has an extremely high resistivity towards water. Furthermore, the coherence of the structure provides a board with very high compressive strength. The innovation in the XPS production is the creation of a waffle surface (Figure 19) which allows the best possible coherence between XPS and plaster or primer.

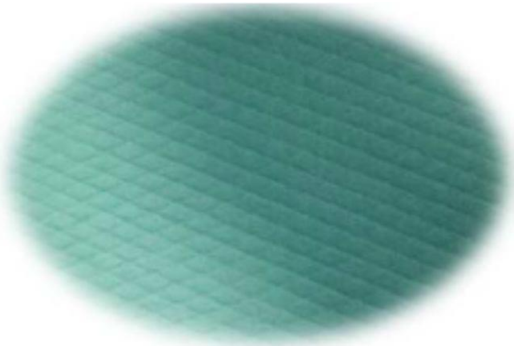

Figure 19: Waffle surface of Extruded Polystyrene board provided by FIBRAN

HVAC freescoo is an innovative compact solar air conditioning system. It is designed for ventilation, space cooling, dehumidification and space heating of buildings (Figure 20). The system is based on a new solar Desiccant Evaporative Cooling (DEC) concept. Solar heat and water are used to drive the cooling process that conditions the space the unit is connected to. The air handling process ensures temperature and humidity control. In addition, the system is designed to provide air flow in the conditioned space.

The HVAC freescoo technology has an important energy conservation of 6001.4 kWh/year (i.e. 46.2 kWh/(m^2 year). Moreover, the fuel that the HVAC freescoo technology uses for heating is the hot water provided by the FAE HCPV technology and the fuel that it uses for space cooling is the electricity provided by the FAE HCPV technology.

The FAE HCPV (Figure 21) developed by IDEA, associated to ARCA Consortium, is a technology which exploits solar radiation to generate electricity and heat at the same time, with a high combined efficiency. A non-image optic system is concentrating the sunrays on multifunction cells that are actively cooled on their backside. An array of 20 of such receivers are integrated upon a double-axis tracking system that is precisely following the position of the sun. To maximize the energy harvest of the FAE HCPV system the main axis must always be oriented in a north-south direction.

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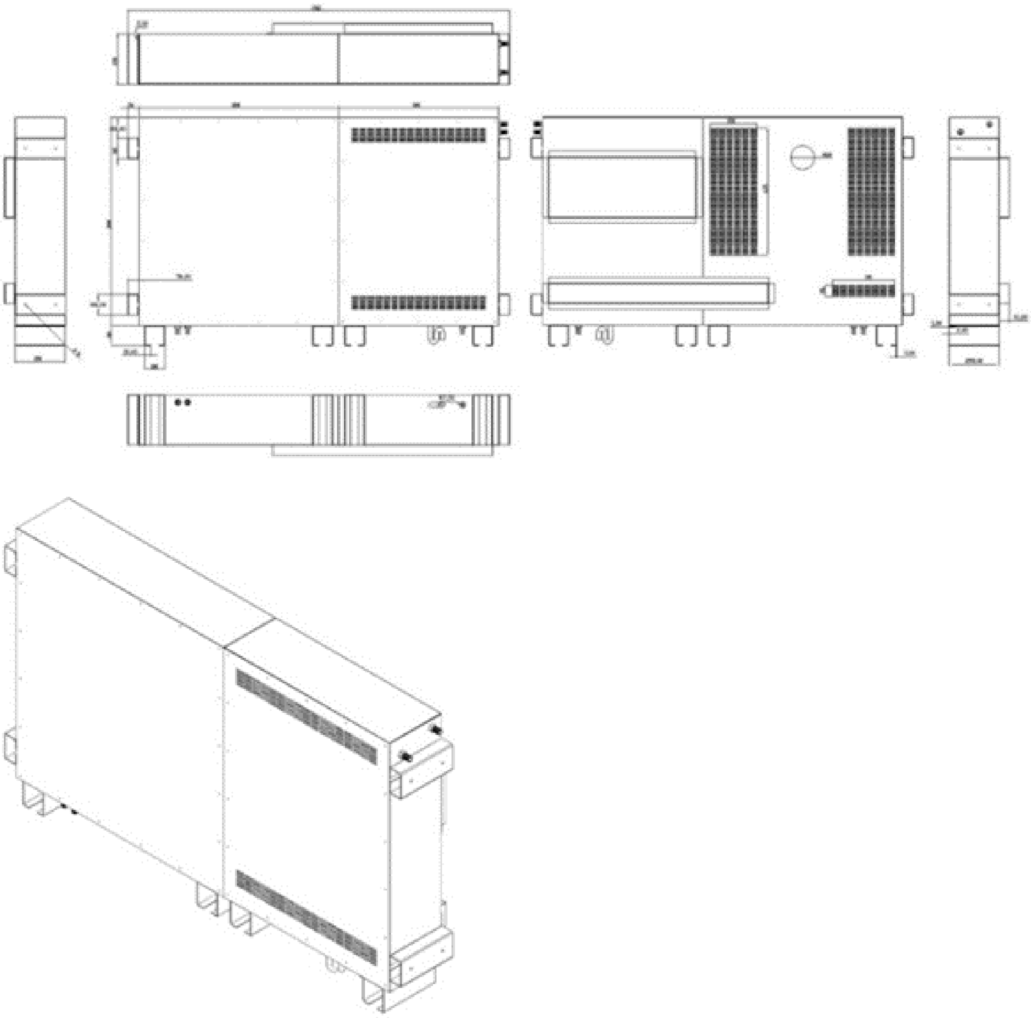

Figure 20: Drawings of freescoo air conditioner provided by SolarInvent

Figure 21: FAE HCPV developed by IDEA

The FAE HCPV technology generates electrical energy of 917.1 kWh per year, while it also generates 1207.1 kWh thermal energy per year, which, as mentioned above, can be used by the HVAC freescoo technology. It therefore generates

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52.46 kWh/(m^2 year). The excess thermal energy by the FAE HCPV system can be used in order to produce distilled water for various functions of the demobox and the future ZERO-PLUS demohouse (Figure 22).

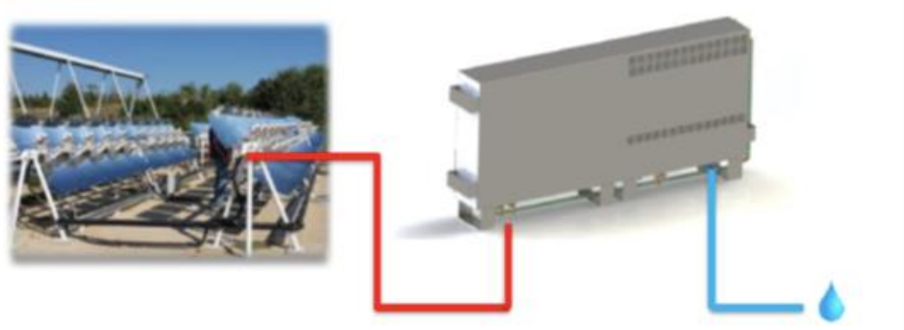

Figure 22: Systems integration supporting the Cyprus ZERO-PLUS demohouse: the FAE HCPV produces electricity that is used by the HVAC freescoo unit to provide ventilation, dehumidification and space cooling and heating

HVAC freescoo system

freescoo is a plug and play compact HVAC solution fed by low-grade thermal energy (e.g., solar thermal systems, heat pumps, gas boilers or waste heat), that provides indoor thermal comfort. It is designed for satisfying the needs for ventilation, space cooling, dehumidification and space heating of buildings in the residential and tertiary sectors. The energy input comes from a water-heat distribution loop that can be connected to a solar thermal plant or a gas boiler as a back-up energy source. The supply air is sent directly to the conditioned room, but air exchange with an outdoor space is also required. In the ZERO-PLUS project, the system design was completely revised to form a compact unit, which can be integrated into the building façade. One freescoo system was installed in the Cypriot case study on the ground floor of the existing demobox, see Figure 23. More information about the freescoo system can be found in Annex G

Figure 23: freescoo system assembly location

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FAE HCPV/T system

The FAE HCPV/T system exploits the property of optics (lenses or curved mirrors) to focus a wide area impacted by the sun radiation on a small area occupied by one or more high efficiency photovoltaic cells (up to 44% of conversion rate) to generate electricity, see Figure 83. In the Cypriot case study, one module of the FAE HCPV/T system is installed at the in front of the existing demobox away from overshadowing from the neighbouring property, see Figure 24. More information about the FAE HCPV/T system can be found in Annex G.

Figure 24: Installation location of the FAE HCPV/T system

2.3 Case study occupants

Post Occupancy Evaluation (POE) deals with the overall assessment of the project performance, mainly the interface between data considered objective (spot-measured, monitored) and those considered subjective (questionnaires, interviews, surveys). In the current context, the former data are coupled with the latter in an attempt to draw a comprehensive picture of the actual use and usability of the buildings perceived as systems, including the physical building attributes, incorporated mechanical and other systems and equipment, and the actual use by the occupants.

To reach such understandings, the surveyors need to identify the physical, cultural and behavioural attributes and peculiarities of the building user, among them age, gender, health, education, occupation, attire and even the hours of the day a specific occupant uses the specific building unit, and the tasks they perform there and then. All these may affect the individual's perception of their indoor environment, and need to be considered under changing conditions – hours of the day, sunny or cloudy conditions and seasons of the year, as described in the POE protocol flow chart in Figure 25.

To promote a fruitful collaboration between occupants and the on-ground survey teams, a Welcome Package was prepared in all four languages of the case studies (English, French, Greek, Italian). An Informed Consent Form (ICF) accompanied each Welcome Package explaining the purpose and attributes of the ZERO-PLUS project case study, the data to be collected and the purpose for their collection, the

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ways in which the survey would be conducted, the protection of privacy and personal data and the right of the building user/occupant not to agree to participate, or decide to withdraw at any given moment, having the right to ask that all previously collected data be shredded from all storage banks and devices if the building user/occupant so desire [3].

The aim was to survey each case study's units in at least three seasons, both on a sunny and a cloudy day for each season, three times for each day (morning, noon, evening) (see Figure 25). While planning the POE module of the project and after consultations with the relevant consortium partners, it was decided that occupants should be allowed a minimal period of 2-3 months to get acquainted with and accustomed to their unit and its support and monitoring systems before the POE commencement.

Table 5 below shows the surveys conducted as well as when the occupants moved in each of the case study dwellings.

Although the original intentions were to conduct all the surveys in person, due to COVID-19 restrictions surveys were conducted by phone and in some cases via email. Especially in the email surveys some input was missing making it challenging to extract meaningful information. In some cases, some technical issues were also preventing in obtaining the full series of the measured data for the POE period thus limiting the ability to decipher certain votes by the interviewees. Although some of the complications were anticipated and therefore countermeasures were prepared (e.g Risk Registry[3], Rescue Teams[4]), the pandemic exacerbated them.

94 scanned questionnaire forms or Excel files of questionnaires were completed online (self-administered) and received (including the 15 of the preliminary Italian case study). Several of the latter were only partially completed, often with specific items (e.g., personal attributes) being omitted by the interviewees.

Table 5: Occupancy commencement and surveys conducted

Case Study	Occupancy commencement	Summer 2019	Winter 2020	Spring 2020	Summer 2020
France	End of Sep. 2019	Unoccupied yet	Feb.11 &20	May 7	June 30 - July 8
Italy	Aug 2018 March 2019	July 23	Feb.15	Postponed due to monitoring equipment and associated COVID-19 complications	July 15
UK	UK1: 15/07/19 UK2: 13/01/20 UK3: 05/08/19	Unoccupied yet	Feb.18	May 8-15	July 31 Aug.12

[3] Risk Registry: A Register where implementation risks have been identified along with provisions for - alternative actions.

[4] For each case study a "Rescue Person" had been defined, leading a Rescue Team. The role of each Rescue Person was to be notified of faults (e.g measurement, technologies installed on site etc), verify the fault and take corrective action.
The Rescue Person and the Rescue team would also provide clarifications and support to the occupants. The member of each Rescue Team and contact details were also given in the Welcome Packages that were prepared for the occupants of each case study.

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Case Study	Occupancy commencement	Summer 2019	Winter 2020	Spring 2020	Summer 2020
Cyprus	24/2/2020	Change of case-study building	February 28	April 29 May 04 May 11-19 June 6 June 12-18	July 7-15

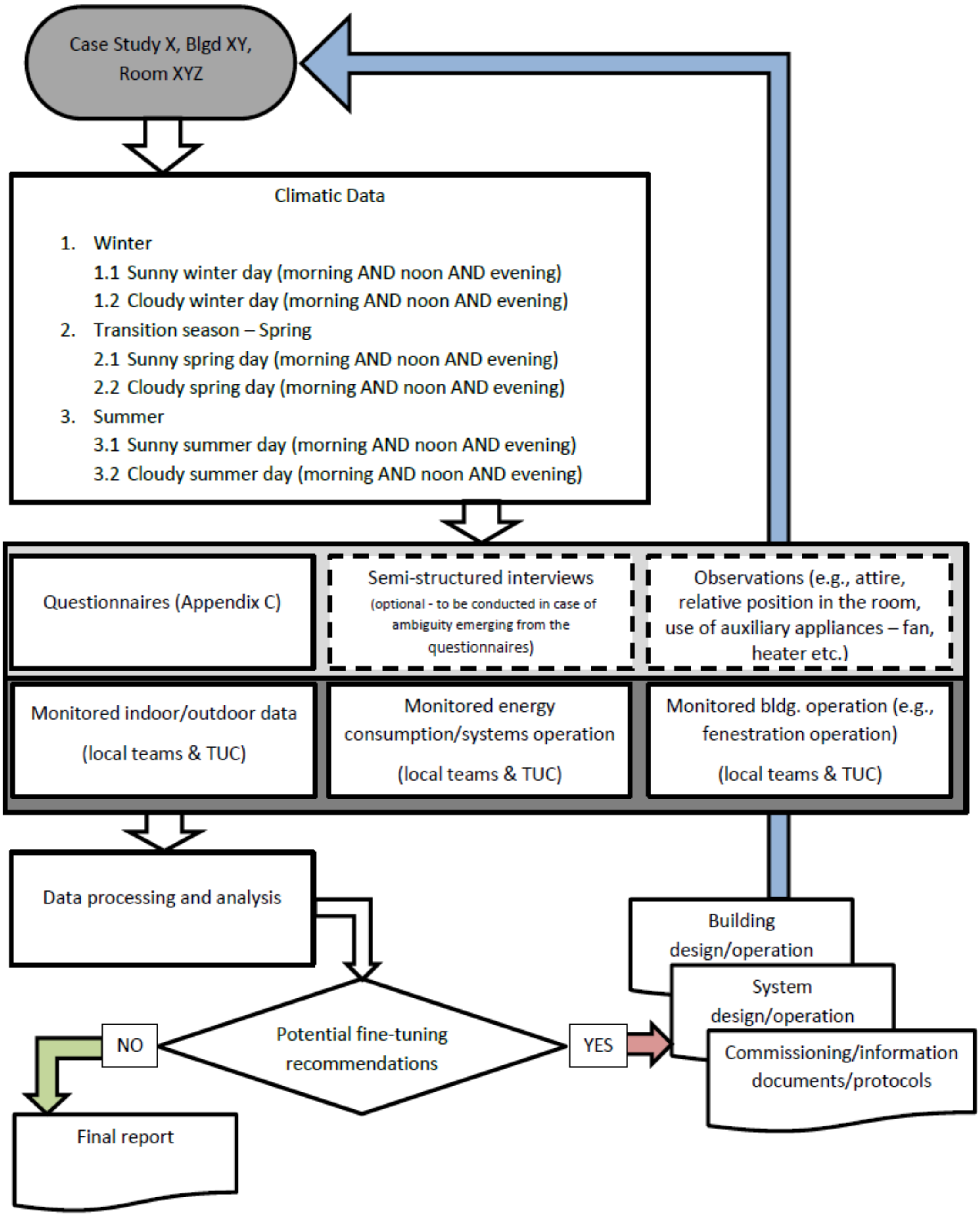

Figure 25: POE protocol flowchart

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3. Monitoring

A Web-GIS platform was created in order to support effective monitoring of the ZERO-PLUS case studies. An effective and reliable monitoring scheme was designed to record and transfer data to the platform. In order to be functional and effective in communicating with the Web-GIS platform, the commercial monitoring equipment that was purchased and installed in each case study should conform to the prescribed requirements. Two main monitoring activities have been performed in the ZERO-PLUS project. The Post Occupancy Evaluation (POE) with the cooperation of the building occupants and the performance monitoring [4]

The monitoring scheme of the houses was based on open protocols and included the following monitoring equipment:

- Monitoring equipment for Indoor Environmental Quality data.
- Monitoring equipment for Building and Settlement energy consumption data.
- Monitoring equipment for energy production data
- Weather station.

More information about the development of a framework for reliability centered maintenance of the NZE settlements can be found here [4].

In general, data was gathered through the monitoring systems and weather stations installed in each case study and through surveys. The monitored data was used both for the performance analysis and the POE in correlation with the data gathered from the surveys. The latter (POE) is part of an independent deliverable and will not be further discussed here.

The data sets (monitoring system & weather station) that were used for the energy performance analysis of the settlements and the POE hold a core role to the success of the project. This is why a plan comprised by different procedures was designed to ensure the quality of the data [5], [6].

3.1 Monitored Data

Data used in this report were gathered in the following phases of the project:

- Pre-occupancy checks
- Pre-occupancy monitoring (including the weather data) and
- Post-occupancy monitoring (including the weather data)

The location of the monitoring devices was decided by each case study team considering:

- space availability
- obstructions
- interaction with occupants

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In Annex A, the monitoring timeline and duration as well as the monitored data for each case study are presented. [5]

3.2 Quality of the monitored data

As mentioned before the data sets (monitoring system & weather station) that are used for the energy performance analysis of the settlements and the POE hold a core role to the success of the project. This is why a plan comprised by different procedures was designed to ensure the quality of the data.

The project's Measurement and Verification (M&V) Plan [6] is the overarching internal document specifically developed for designing and implementing a robust measurement and verification. The M&V Plan was developed in relation to the project's phases of development, thus spanning from pre-design to post-occupancy, and for each phase quality control procedures were identified.

Defining measurement specifications at the design phase is the first step that sets quality requirements (see Annex A) on the collection of data. The next step towards ensuring collection of quality data is the implementation of quality control procedures during installation of the measuring equipment. These procedures include:

- Calibration and testing proper function of the monitoring equipment at installation phase
- Total monitoring system testing post-installation for checking proper communication between components and verifying performance and accuracy of the system.

A set of procedures was incorporated to the Web-GIS platform to minimize the lost measurements and discover fault measurements [7].

Finally, the M&V Plan includes Quality Control provisions for the post-installation phase, when continuous monitoring is functioning.

The evaluation of the measured data and associated troubleshooting includes:

- Assessment of measurement errors (sensor' errors) and associated corrective actions
- Assessment of collection errors (communication errors) and associated corrective actions
- Identification of lost data
- Data re-creation
- Use of quality metrics for the final datasets

[5] In order to secure the protection of personal data of the occupants Annexes I to VI that contain the exact monitoring equipment used, the location of the sensors and the weather stations as well as the pre-occupancy checks reports for all case studies are kept confidential.

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Monthly report No X for : villa1, Settlement: italy

From 01/11/2019 to 01/12/2019 generated on 01/04/2020 11:47:12

Indoor Environmental Quality

	Temperature (℃)	Relative Hummidity (%)	CO_2 (ppm)
Average	20.74	57.78	8605.70
Maximum	24.36	76.05	9210.88
Minimum	18.25	24.59	7654.40
Lost Measurements (%)	11.04	11.04	11.04

Energy Consumption

Building HVAC (kWh)

	November	November -1Y	October	Expected from Simulation	Difference
Total energy	255.70	0.00	141.32	391.68	-135.98
Average energy workday	9.28	0.00	4.71	12.89	-3.61
Average energy weekend	8.82	0.00	4.04	13.45	-4.63
Lost Measurements	11.04	100.00	8.43	-	-

Building domestic hot water consumption (kWh)

	November	November -1Y	October	Expected from Simulation	Difference
Total energy	0.00	0.00	0.00	112.78	-112.78
Average energy workday	0.00	0.00	0.00	3.84	-3.84
Average energy weekend	0.00	0.00	0.00	3.57	-3.57
Lost Measurements	100.00	100.00	100.00	-	-

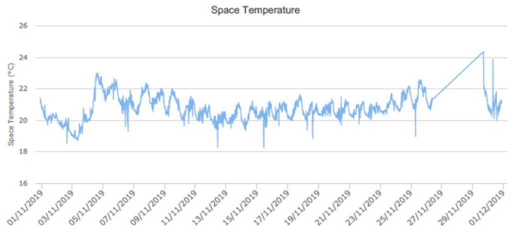
Energy Producion

Energy for PV (kWh)

	November	November -1Y	October	Expected from Simulation	Difference
Total energy	-3184.85	0.00	-97.74	127.97	-3312.82
Average energy workday	-153.02	0.00	-9.02	4.31	-157.33
Average energy weekend	3.16	0.00	9.40	4.16	-1.00
Lost Measurements	-0.03	100.00	41.63	-	-

KPIs

	November	November -1Y	October	Expected from Simulation	Difference
Regulated energy kWh per m2	2.08	0.00	1.15	4.10	2.02
Renewable energy kWh per m2	-25.89	0.00	-0.79	1.04	26.93
Net regulated energy kWh per m2	27.97	0.00	1.94	3.06	-24.91



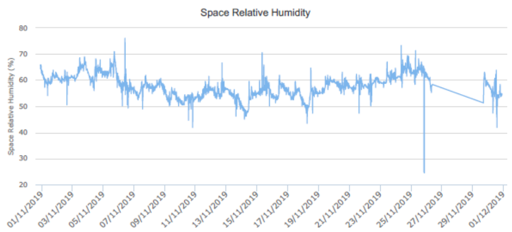


Figure 26: Sample monthly report

Furthermore, a Problem Identification Procedure was designed. In case the measured performance of the case studies is not as expected for a defined period of time, the Problem Identification Procedure should assist the identification of the cause; whether it is due to faulty installation of the technologies, poor performance of the technologies, faulty settings or occupant intervention.

A monthly report (Figure 26) was automatically generated by the platform for each one of the settlements. The report contains the IEQ, weather conditions, and energy consumption and production data. The percentage of missing data is also calculated. Moreover, using the results of the calibrated simulations (in hourly time step), the monthly difference between the simulated and actual values of the Net regulated energy and RES production KPIs is computed. If the difference between the computed and simulated values of the KPIs is above 15%, the Problem Identification Procedure is initiated. The Problem Identification Procedure is elaborated in Annex F.

The results of the Problem Identification should be documented in a report. In the ZERO-PLUS monitoring period the Web-GIS platform has produced monthly performance reports as shown in Figure 26. Nevertheless, it was not necessary to initiate the Problem Identification Procedure.

Implementation risks along with provisions for alternative actions are identified in the Risk Registry.

4. Simulations

Simulations were carried out for all case studies many times in different phases of the project from design until the construction of the settlements and even after the end of the monitoring period. In each phase they served a different purpose from optimizing the settlements design to estimating its performance and finally verifying the accuracy of the models with the use of measured data. In this chapter the software used in each case study, model calibration and the M&V plan are discussed.

4.1 Modelling and simulation software

4.1.1 French case study

The software Pleiades was used. It is developed and maintained by Izuba energy, which also use it for their own calculations. It combines a calculation module for energy needs and comfort indicators (COMFIE), a module for checking the French Thermal Regulation (RT2012) requirements and a module for dimensioning heating and cooling equipment. It integrates the 3D modelling of the building. It is used to run Dynamic Thermal Simulations.

The software calculates consumptions for space heating and DHW (thermal consumption). Regarding electricity consumption, only common equipment is calculated: ventilation, lighting, appliances. The individual consumption of private flats is not considered by the simulation.

4.1.2 Italian case study

EnergyPlus with DesignBuilder graphical interface v4-v6 (license upgraded according to the release of the new versions) program chosen in this project for modelling building heating, cooling, lighting, ventilating, and other energy flows related to the Italian demonstration case study. EnergyPlus is the U.S. DOE building energy simulation program. It builds on the most popular features and capabilities of BLAST and DOE-2 but also includes many innovative simulation capabilities such as time steps of less than an hour, modular systems and plant integrated with heat balance-based zone simulation, multizone air flow, thermal comfort, and photovoltaic systems. EnergyPlus is a stand-alone simulation program without a 'user friendly' graphical interface, but it can be integrated with the graphical interface of DesignBuilder.

The two software programs, i.e. EnergyPlus and DesignBuilder, have also been chosen for their capability to perform all the details requested for building energy and environmental assessment in the project and all the simulated scenarios within a whole unique calculation tool, being able to take into account:

- Innovative and traditional HVAC systems;
- Innovative and traditional materials for building envelope;
- Renewable energy systems;
- Control and operation systems;

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- Occupancy schedules.

4.1.3 UK case study

Integrated Environmental Solutions Virtual Environment (IES VE) suite of software has been used for the UK case study modeling and simulations, specifically ModelIT for modelling the external physical characteristics of the dwellings and Apache for setting thermal parameters and running simulations. IES VE thermal calculation and dynamic simulation software was selected as it is an approved industry standard, audited by the Chartered Institution of Building Services Engineers and the United Kingdom Accreditation Service as well as being an accredited software for producing Energy Performance Certificates (EPCs) by the Building Research Establishment (BRE).

4.1.4 Cypriot case study

The Cypriot case study simulations were carried out in free-running and thermostatically controlled conditions using the dynamic energy simulation engine EnergyPlus through the DesignBuilder interface. EnergyPlus was chosen because it is a versatile and thorough simulation environment for building performances providing several and advanced modelling tools for modelling HVAC, daylighting, airflow exchanges, cost, energy uses and carbon emissions. Except from assessing the energy efficient technologies, it can also be used for assessing building level energy generation even if the available template and modeling classes are limited to components currently available in the market, and innovative and advanced systems like HCPV FAE and freescoo cannot directly be modelled. These systems are modelled using average performance descriptive metrics like generation efficiency and seasonal EER. EnergyPlus also enables the calculation of thermal comfort indices according to the standards ISO 7730 and EN 16798 and ASHRAE 55 referring to the Fanger model and the European and ASHRAE models.

4.2 Calibration of the simulation models

Calibration is a process where the results of a computer simulation are compared with measured data to improve the agreement of the simulation outcomes with respect to a chosen set of benchmarks through the adjustment of independent parameters that are implemented in the building model.

The simulation models of each case study, namely “as-designed” models, were updated according to the as-built drawings and considering the installed ZERO-PLUS technologies. This first calibration of the models was created by using where possible the gathered data during the pre-occupancy checks and pre-occupancy monitoring (see Annex A and Annex H), providing the “*as-built*” model and results.

The final calibration of the models aiming at the evaluation and validation of the ZERO-PLUS simulation models was performed at the end of the project by using all monitored data collected during the whole monitoring period (pre-occupancy and post-occupancy). (Section 4.3)

The lists of data for calibrated simulations for all case studies can be found in Annex B.

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4.2.1 French case study

For the French case study, calibration consists on an update of the simulation taking into account the final building:

- As-built simulation: final plans of the buildings, technical equipment (solar panel…) actually implemented, building air permeability measured.
- Final calibration: actual temperature requested, actual occupancy (number of people), and actual use of DHW (see section 4.3.1).

Actual weather conditions and measured U-value have not been integrated as the software does not allow modification of these data assumptions.

4.2.2 Italian case study

4.2.2.1 Pre-occupancy-based calibrations

In the Italian case study, the initial calibration of the two building models was carried out thanks to the data gathered during the pre-occupancy checks and pre-occupancy monitoring (see Annex A and Annex H). The models were updated according to (i) the measured U-values of the external walls and (ii) the air permeability obtained from the blower door test (Table 6). Moreover, they were updated according to the final as-built design. In accordance, the following changes were made to the calibrated models:

- IT1:
  - different coloring of the external walls in the central part of the building characterized by lower reflectance brown color;
  - different layering of the external walls;
  - different layering of windows;
  - different type of window shutters with high reflectivity slats;
  - final configuration of the 20 PVs on the building roof.
- IT2:
  - different layering of the external walls;
  - different layering of windows;
  - different type of window shutters with low reflectivity slats;
  - final configuration of the 20 PVs on the building roof.

Table 6: Final U-values and air permeability values used to calibrate as-built model

#	Element	IT1		IT2	
		As-designed target	As-built	As-designed target	As-built
1	External walls W/(m^2 K)	0.12	0.25	0.12	0.164
2	Roof W/(m^2 K)	0.117	Not measured	0.117	Not measured
3	Ground floor W/(m^2 K)	0.167	Not measured	0.167	Not measured

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#	Element	IT1		IT2	
		As-designed target	As-built	As-designed target	As-built
4	Air tightness rate h^{-1} @50 Pa	0.5	0.575*	0.5	-

*Average value from two tests.

Therefore, the models were calibrated in free-running conditions based on the comparison with the indoor air temperature data monitored in two rooms for each building. No energy data was measured in the pre-occupancy phase. In detail, in IT1 indoor air temperature data were collected from June 19th to July 6th 2018 in one bedroom and in the double-height living room, while in IT2 indoor air temperature data were collected from February 1st to March 5th 2019 in one bedroom and in the living room (the data from the first and the last day of monitoring were not considered for the calibration). For the calibration, a specific weather file was developed by considering outdoor monitored data during the pre-occupancy monitoring in terms of outdoor dry-bulb temperature and relative humidity.

Two validation indices were used to quantify the model accuracy: Mean Bias Error (MBE) and Root Mean Square Error (RMSE), as defined in the following equations.

$$MBE = \frac{\sum_{i=1}^{n}(M_i - S_i)}{n}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(M_i - S_i)^2}{n}}$$

Where S are the simulated values and M are the measured values.

According to the validation criteria specified in the ASHRAE Guideline [8], the reference tolerance values correspond to ±0.5 °C for MBE and to 1 °C for RMSE, considering sub-hourly temperature values.

The results of the envelope performance calibration for the two building models are depicted in Figure 27 (IT1) and Figure 28 (IT2). The visual comparison shows an acceptable accuracy of the calibrated model compared to the initial as-designed model. It has to be specified that the peaks of simulated indoor air temperature during daytime in IT2 are due to the fact that the outdoor air temperature monitoring probe was not perfectly shaded from solar radiation. However, based on the obtained MBE and RMSE, both rooms can be considered calibrated; even more if we consider that those peaks will not occur in the final calibrated model. In fact, the calibration indexes calculated for the two buildings confirm the reliability of the models. MBE is equal to -0.06 °C and -0.09 °C for IT1 and IT2, respectively, while RMSE is equal to 0.57 °C and 0.84 °C for IT1 and IT2, respectively, namely inside the maximum limit.

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Figure 27: Comparison of measured and simulated indoor air temperature values for the two monitored rooms in IT1

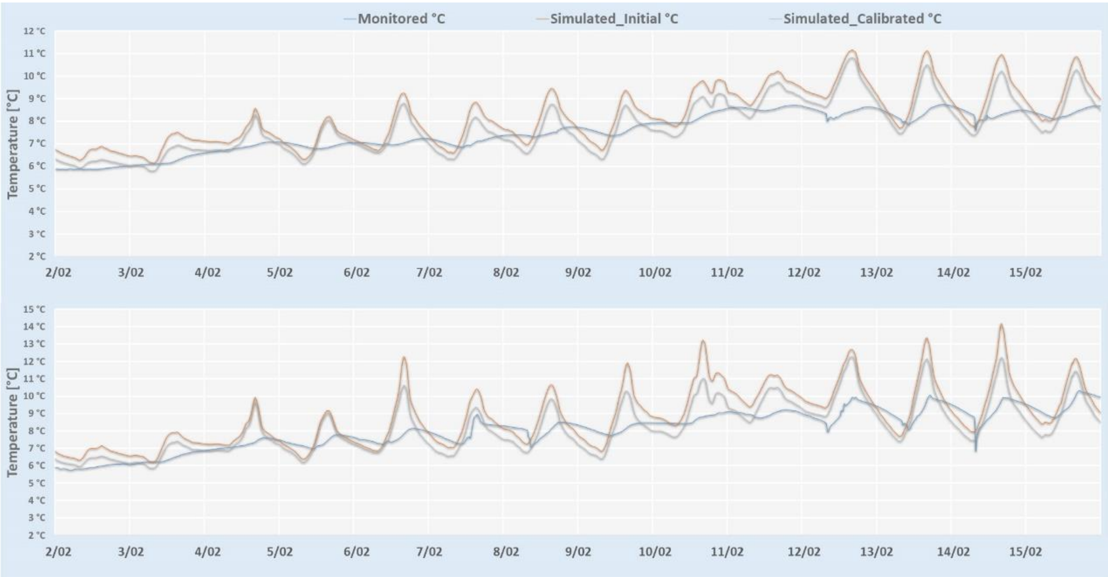

Figure 28: Comparison of measured and simulated indoor air temperature values for the two monitored rooms in IT2

<u>4.2.2.2 Final calibration</u>

The final calibration in operating conditions was carried out following a similar procedure. The buildings' model was integrated with the as-built energy systems (HVAC, ventilation, lighting, electrical devices, energy generation) and by modeling occupancy and occupant-building interaction according to the post-occupancy monitoring (Table 62) and observations during the POE. In particular, heating and cooling set-point and setback temperatures were defined based on the monitored data, as detailed in Table 7. Moreover, for DHW, the outlet temperature at the generator was set to 45° according to its real operation in IT2. Therefore, the modeling was carried out considering the real usage profiles in order to validate the model with respect to the available monitored building energy consumption in terms

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of Regulated energy use and total electricity energy use. In particular, energy consumption and renewable energy production data monitored in IT1 and IT2 from June 2019 to March 2020 were considered for the calibration in order to i) have at least full summer, full winter, and one full middle season and ii) exclude the period of the lockdown due to COVID-19 pandemic that does not represent the standard building operation. In detail, HVAC and DHW energy consumption data (including heat pump electrical auxiliaries) monitored in IT1 and IT2 from June 2019 to March 2020 were considered for the Regulated energy consumption calibration. Moreover, renewable energy generation (from PV panels) was monitored in IT1 and IT2 from August 2019 to March 2020 and was considered for settlement energy production calibration, since these data have not been available before August 2019.

Table 7: Heating and cooling settings for the two buildings

		IT1	IT2
Heating	Set-point [°C]	20	21
	Setback [°C]	18	20
Cooling	Set-point [°C]	24	24
	Setback [°C]	25	26

For the calibration, again a specific weather file was developed by considering outdoor monitored data during the post-occupancy in terms of outdoor dry-bulb temperature, relative humidity, and global solar radiation (Table 62).

Two validation indices, similar to the previous ones, were used to quantify the model accuracy: Normalized Mean Bias Error (NMBE) and the coefficient of variation of the Root Mean Square Error (CV(RMSE)), as defined in the following equations.

$$NMBE = \frac{\sum_{i=1}^{n}(M_i - S_i)}{(n-1)\,\overline{M}} \times 100 \quad [\%]$$

$$CV(RMSE) = \frac{1}{\overline{M}}\sqrt{\frac{\sum_{i=1}^{n}(M_i - S_i)^2}{(n-1)}} \times 100 \quad [\%]$$

Where S are the simulated values, M are the measured values and $\overline{M}$ is the mean of measured values (see section 4.3.2)

According to the validation criteria specified in the ASHRAE Guideline [8], the simulation model can be considered calibrated with NMBE < 5% and CV(RMSE) < 15%, considering monthly calibration values.

4.2.3 UK case study

The following section breaks down the methods that were used to calibrate the UK models. Section 4.2.3.1, pre-occupancy-based calibration, covers the calibration method used early on, when monitoring began. First, the heat flux and air permeability measurements taken from the pre-occupancy assessment (Annex H) are presented as these are the starting point for revising the models to match actual existing conditions. Then space heating calibration and non-space heating

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extrapolation are separated and presented as different methods were used. In section 4.2.3.2, the method for the final, end-of-project calibration is presented. This was performed after almost a year of in-use data was collected. The focus here is entirely on space heating as this is the use for which the thermal simulation model was employed.

4.2.3.1 Pre-occupancy-based calibration

Heat flux and air permeability measurements used to calibrate the model

Though the heat flux measurement process lasted for 14 days, the selected areas only represented two spot measurements on a single wall, showing the worst-case scenario for those walls. The following U-values (Table 8) and air permeability (

Table 9) were calculated through heat flux measurements and from blower door tests respectively.

Table 8: U-values calculation though heat flux measurements on site for the UK case study

	Specification	Measured good area	Measured poor area	Units
Wall UK1	0.17	0.47	1.39	W/(m².K)
Wall UK3	0.17	0.56	1.95	W/(m².K)
Roof UK2	0.16	0.19	1.28	W/(m².K)

Table 9: Case study form and air permeability details

	UK1	UK2	UK3
Total floor area (TFA) (m^2)	84.4	84.4	129.6
Envelope area (m^2)	245.8	245.8	321.1
Design AP (m^3 h^{-1} m^{-2}@50pa)	4	4	4
Completion AP (m^3 h^{-1} m^{-2}@50pa)	3.94	3.97	2.77
Current AP (m^3 h^{-1} m^{-2}@50pa)	5.39	5.44	7.53

UK2 was unoccupied throughout all of 2019. For this reason, this dwelling was used to calibrate the model using internal temperature data. Throughout this period; however, because the heating system was malfunctioning there were random times when the heating was on, e.g. in August 2019. During the time of this analysis, this left only from 4 – 12 September available for un-occupied temperature-based model calibration in the UK dwellings.

Space heating calibration specifications

The weather station was not installed on site until November 2019. For this reason, temperature data were accessed online at Weather Underground[6].

To calibrate the model using the monitored temperature data, the following steps have taken in the as-designed model:

[6] https://www.wunderground.com/history/daily/gb/leeds/EGNM/date/2019-9-10

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- All internal gains from occupant activity were removed from the model, that is, occupant body heat, appliance energy, DHW energy, and lighting energy.
- Occupant window opening patters were removed from the model.
- Heating patterns were removed.

The following details were used to change the model for calibration:

- Air permeability of 5.42 $m^3 \cdot h^{-1}/m^2$ at 50 Pa was used. This is the average of the final air-permeability result for both UK1 and UK2.
- External wall thermal transmittance of 0.26 W/m^2K was used. This value was the change variable for finding the match between the monitored temperature data and model temperature data at the lowest point for the space simulated. This U-value is higher than the designed U-value but about half the 'good area' measurement from the heat flux measurements.
- Roof thermal transmittance of 0.19 W/m^2K was used. This is the 'good' heat flux measurement.

ASHRAE validation indices method to model uncertainty

Though the thermal transmittance calibration was performed through manipulation of external wall thermal transmittance and matching of temperature measurements from data logging, ASHRAE validation was performed to check the error. Two validation indices were used to quantify the model's accuracy: Normalized Mean Bias Error (NMBE) and Coefficient of Variation of the Root-Mean-Square Error (CV[RMSE]) (refer to the linked standard for terminology used in the calculations) [8].

$$NMBE = \frac{\sum_{i=1}^{n} (y_i - \hat{y}_i)}{(n-p) \times \bar{y}}$$

$$CV(RMSE) = \sqrt{\frac{\sum_{i=1}^{n} (y_i - \hat{y}_i)^2}{(n-p)}} \div \bar{y}$$

According to the Whole Building Calibrated Simulation Performance Path of [8], if hourly calibration data are used, these requirements for NMBE is 10% and for CV(RMSE) is 30%.

As the weather data does not include solar radiation, the temperature data for a north facing bedroom in the dwelling was tested to avoid amplification of solar gain in the space on temperature data either measured or modelled. For the UK2 dwelling this is the upstairs front bedroom.

The result of NMBE was 0.8% and the result of CV(RMSE) was 5% for the as-built calibration.

As the model changes were carried into the other dwellings, the assumption was that the same construction team and practices would result in similar results throughout. The outcome of **the first, as-built, model calibration** on the dwellings was as follows:

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Table 10: As-built model results

	UK1 / UK2		UK3	
	As-designed	As-built	As-designed	As-built
Space heating (kWh)	2575	4499	4491	5733
Net regulated (kWh/m2)	9	27	4	14

Results of as-built calibration of non-space heating uses from initial monitoring data:

As the as-built calibration process was not taking place in the heating season, no space heating data were registered on the monitoring platform, nor would there be reason to collect these data. The current relevant incoming energy data were domestic water heating (DHW), fans, pumps and ventilation, lighting, and appliances.

The following analyses extrapolated consumption of these areas from one month of occupancy for dwellings 362 and 364. The data used were from the monitoring period of 22 July – 18 August (four full weeks in UK1; occupied 19 July) and 5 August – 18 August (two full weeks in UK3; occupied 2 August). UK2 was not occupied during the analysis.

Domestic hot water

During this analysis (Jan 2020), the domestic hot water (DHW) consumption data from the ORSIS Energize platform was incorrect. As a result, published consumption data for the UK were used. An Energy Saving Trust study[7] of DHW consumption in 113 dwellings in the UK was used to extrapolate the data. According to this study 122 litres/day is the annual mean consumption among this dataset. In addition, the study created a DHW consumption regression model from this dataset. The model is:

$$litres\ per\ day = 46 + 26\ \times\ N$$

Where *N* is the number of occupants in the dwelling.

This was used to update the as-built KPIs based on actual occupants. The B3 dwellings were set at two occupants (based on one currently occupied dwelling) and the C4 dwelling was set at three occupants (based on its occupancy). In this assumption, young children were counted as 0.5 occupant. The result of liters/day was then entered into an online calculator[8] which provides kWh/day.

As a result, there is little change to the assumptions (these are still estimated at this stage, Table 11).

Table 11: Estimated annual DHW consumption

House	House Type	Occupants	As-designed DHW	As-built DHW	change
UK1	Semi-detached	1 adult, 2 children	2,477 kWh/yr	2,080 kWh/yr	-16%
UK2	Semi-detached	No occupants	2,477 kWh/yr	2,080 kWh/yr	-16%

[7] assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48188/3147-measure-domestic-hot-water-consump.pdf

[8] https://power-calculation.com/hot-water-heater-cost-energy-consumption.php

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House	House Type	Occupants	As-designed DHW	As-built DHW	change
UK3	Detached	2 adults, 2 children	2,613 kWh/yr	2,631 kWh/yr	0.70%

Lighting

Lighting data were successfully being metered in the dwellings. The data were downloaded for the period of availability and were extrapolated using seasonal lighting data from a Defra report on *Household Electricity Survey: A study of domestic electrical product usage*.[9] Table 12 summarises all electricity as-designed and as-built data.

Table 12: Monitored and estimated electricity consumption

		UK1 / UK2			UK3		
#		As-designed	As-built	Change	As-designed	As-built	Change
1	**Total electricity** (monitored / extrapolated)	3,467	1,679	-52%	4,478	3,607	-19%
2	**Lighting electricity** (monitored / extrapolated)	333	100	-70%	413	105	-75%
2	**Fans, pumps and ventilation** (monitoring failure / estimated)	173	92	-47%	270	249	-8%
3	**Appliances** (estimated)	2,961	1,487	-50%	3,795	3,253	-14%

Fans pumps and ventilation

As the fans, pumps and ventilation metering appeared to not be working on the ORSIS energize platform, the data were estimated. This was calculated by taking the proportion of as-designed ventilation consumption from total non-lighting electricity and multiplying it by the monitored total non-lighting consumption.

$$As\_built\ ventilation\ electricity\ consumption = \frac{as\_designed\ ventilation}{as\_designed\ appliances} \times total\ as\_built\ non\ lighting\ electrictiy$$

Table 12 provides the results.

Appliances

The remaining result of left-over electricity consumption was assumed to be appliances.

$$As\_built\ appliance\ electricity\ consumption = total\ as\_built\ nonlighting\ electricity\ - as\_built\ ventilation$$

9 http://randd.defra.gov.uk/Document.aspx?Document=10043_R66141HouseholdElectricitySurveyFinalReportissue4.pdf

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Table 12 provides the results.

4.2.3.2 Final calibration

The calibration of the thermal simulation model was only focused on space heating. All other uses e.g. lighting, fans, DHW, were based on simple occupancy based / standard UK residential calculations. This is because the ZERO-PLUS technologies installed in the dwellings had no effect on these other uses with the possible exception of the HIVE smart home energy system promising up to a 5% reduction in lighting use if the user controls are applied. This will be reviewed later.

Space heating calibration

Data used for space heating calibration:

- Actual weather data monitored via the weather station onsite: weather file for use in simulation software formulated and provided by TUC. The weather dataset was not completely formulated from onsite gathered data due to the measurement timeframe (86% gathered onsite via weather station, 14% from closest weather station data available online)
- Occupancy pattern measured through activity on HIVE, number of people (POE survey)
- Heating pattern and magnitude of control from HIVE
- Pre-occupancy fabric assessment / as-built calibration details for air permeability, external wall thermal transmittance and roof thermal transmittance
- Measured indoor temperature data from ORSIS / HIVE
- Measured space heating energy from ORSIS

Air permeability, thermal transmittance, occupancy pattern, occupancy count, heating pattern, and heating set point were updated in all models to align the simulation with reality.

Dwelling UK2

Dwelling UK2 was somewhat limited in data as the occupants moved into the home at the middle/end of January 2020; therefore, in-use data were taken from 1 February 2020. Table 13 shows the beginning model details and then the final model details following calibration. Aside from the fabric details, the occupant heating pattern also had to be manipulated to fine tune the model (Figure 29).

Table 13: UK2 model calibration specifications

Dwelling UK2	As-designed specifications	Pre-occupancy evaluation	As-built calibration	Final calibration
Occupancy	2 adults 1 child	N/A	2 adults 1 child	2 adults 2 children
Set point	Living room 21^{o}C, all others 19^{o}C	N/A	Living room 21^{o}C, all others 19^{o}C	Living room 20^{o}C, all others 18^{o}C
Air permeability ($m^3 \cdot h^{-1}/m^2$ at 50 Pa)	4	3.97 – 5.44	5.4	4

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Dwelling UK2	As-designed specifications	Pre-occupancy evaluation	As-built calibration	Final calibration
External wall U-value (W/m^2K)	0.17	Not measured (0.47 – 1.39 from UK1)	0.26	0.35
Party wall U-value (W/m^2K)	0.23	Not measured	No change	0.36
Roof U-value (W/m^2K)	0.16	0.19 – 1.28	0.19	0.19
Floor U-value (W/m^2K)	0.14	Not measured	No change	
Window U-value (W/m^2K)	1.33	Not measured	No change	

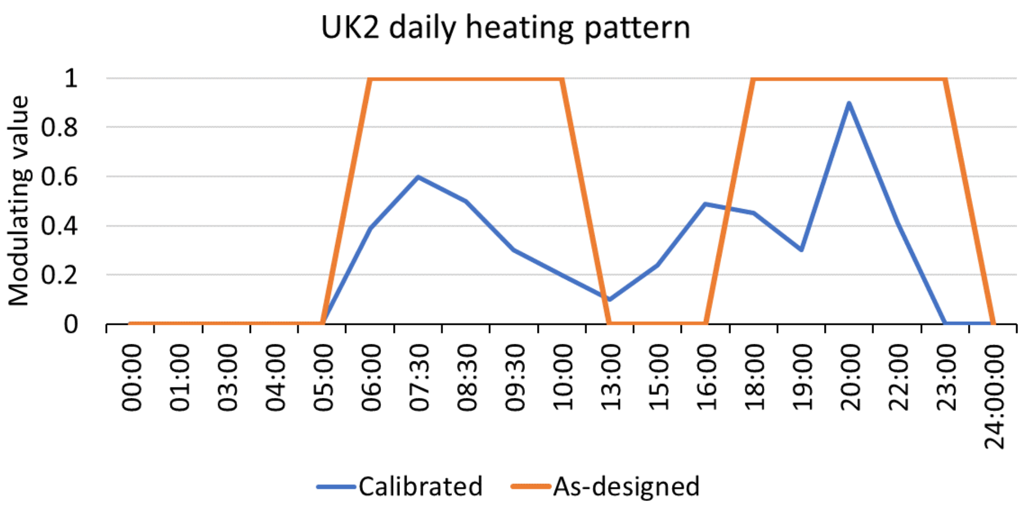

Figure 29: UK2 heating pattern compared between in-use and as-designed

Monthly space heating energy data were used to calibrate the model. According to the Whole Building Calibrated Simulation Performance Path of [8], if monthly calibration data are used, these requirements for NMBE is 5% and for CV(RMSE) is 15%.

The result of NMBE was 0.4% and the result of CV(RMSE) was 7.2%.

Hourly winter temperature data were used to assess calibration of the interior temperature regulation. In the calibrated model, the result of simulated vs. monitored temperature was NMBE: 1.6% and the result of CV(RMSE) was 6.6%.

Dwelling UK1

Dwelling UK1 had a monitoring error with space heating for the entirety of the project, that is, no space heating data was collected. For this reason, calibration of the model used monitored internal temperature data to align the model with simulated temperature data. This was done to estimate the space heating consumption in the dwellings from the final calibrated model. As no monitored space heating data were available, no error assessment was performed for space heating. Table 14 shows the beginning model details and then the final model details following calibration. Aside from the fabric details, the occupant heating pattern also had to be manipulated to fine tune the model (Figure 30).

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Table 14: UK1 model calibration specifications

UK1	As-designed specifications	Pre-occupancy evaluation	As-built calibration	Final calibration
Occupancy	2 adults 1 child	N/A	2 adults 1 child	1 adult 2 children
Set point	Living room 21°C, all others 19°C	N/A	Living room 21°C, all others 19°C	Living room 21°C, all others 20°C
Air permeability ($m^3 \cdot h^{-1}/m^2$ at 50 Pa)	4	3.94 – 5.39	5.42	4.7
External wall U-value (W/m^2K)	0.17	0.47 – 1.39	0.26	0.35
Party wall U-value (W/m^2K)	0.23	Not measured	No change	0.36
Roof U-value (W/m^2K)	0.16	Not measured (0.19 – 1.28 from UK2)	0.19	0.19
Floor U-value (W/m^2K)	0.14	Not measured	No change	
Window U-value (W/m^2K)	1.33	Not measured	No change	

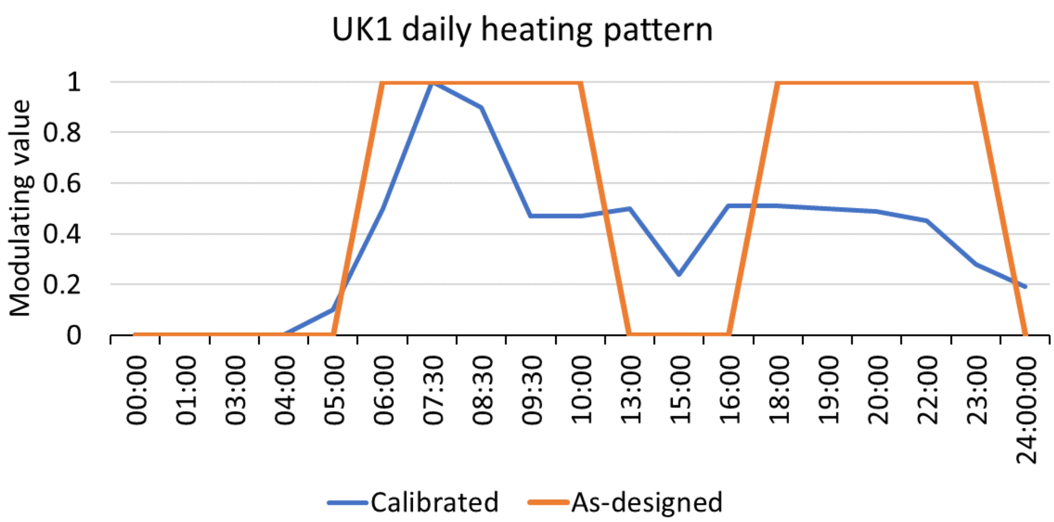

Figure 30: UK1 heating pattern compared between in-use and as-designed

Fabric specifications from the calibrated model of UK2 and monitored internal temperature data from UK1 were used to calibrate the model. Without monitored space heating data, the model was calibrated using temperature data. According to the Whole Building Calibrated Simulation Performance Path of [8], if hourly calibration data are used, these requirements for NMBE is 10% and for CV(RMSE) is 30%.

The result of NMBE was 1.6% and the result of CV(RMSE) was 8.2%.

Dwelling UK3

Dwelling UK3 is the only dwelling with a full monitoring period of space heating data. Table 15 shows the beginning model details and then the final model details following calibration. Aside from the fabric details, the occupant heating pattern also had to be manipulated to fine tune the model (Figure 31).

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Table 15: UK3 model calibration specifications

UK3	As-designed specifications	Pre-occupancy evaluation	As-built calibration	Final calibration
Occupancy	2 adults 2 child	N/A	2 adults 2 child	2 adults 2 children
Set point	Living room 21°C, all others 19°C	N/A	Living room 21°C, all others 19°C	Living room 20°C, all others 18°C
Air permeability ($m^3 \cdot h^{-1}/m^2$ at 50 Pa)	4	2.77 – 7.53	5.42	4.7
External wall U-value (W/m^2K)	0.17	0.56 – 1.95	0.26	0.35
Party wall (garage wall) U-value (W/m^2K)	0.23	Not measured	No change	0.29
Roof U-value (W/m^2K)	0.16	Not measured (0.19 – 1.28 from UK2)	0.19	0.19
Floor U-value (W/m^2K)	0.14	Not measured	No change	
Window U-value (W/m^2K)	1.33	Not measured	No change	

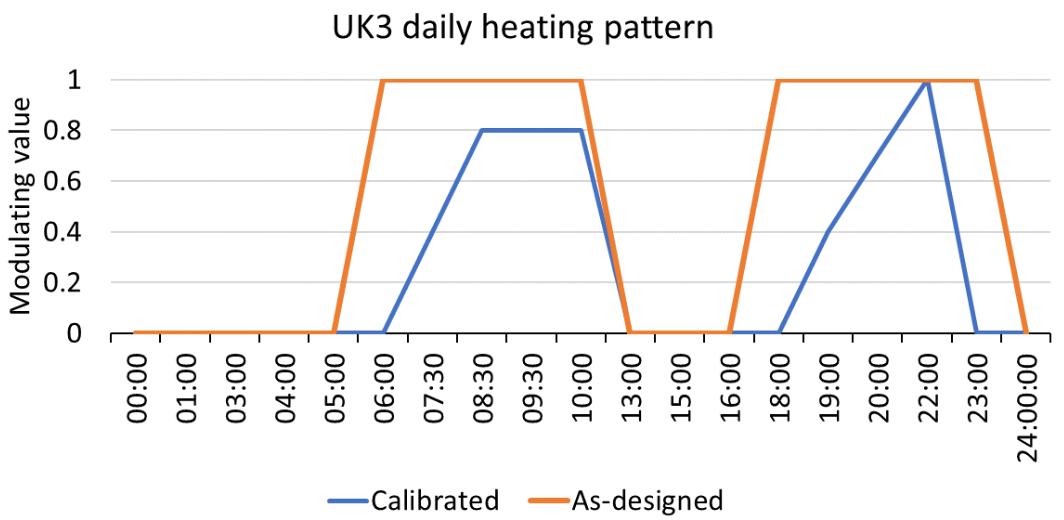

Figure 31: UK3 heating pattern compared between in-use and as-designed

Fabric specifications from the calibrated model of UK2 and monitored internal temperature data from UK3 were used to calibrate the model. Without monitored space heating data, the model is calibrated using temperature data. According to the Whole Building Calibrated Simulation Performance Path of [8], if monthly calibration data are used, these requirements for NMBE is 5% and for CV(RMSE) is 15%.

The result of NMBE was 0.5% and the result of CV(RMSE) was 14.6%.

Hourly winter temperature data were used to assess calibration of the interior temperature regulation. In the calibrated model, the result of simulated vs. monitored temperature was NMBE: -0.2% and the result of CV(RMSE) was 11.2%.

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4.2.4 Cypriot case study

For the Cypriot case study, we conducted the calibration of the numerical model of the existing demobox following the recommendations provided by the ASHRAE Guideline 14 [8]. Specifically the following six steps were implemented:

1. Production of a calibrated simulation plan,
2. Collection of data from the field,
3. Creation of a numerical model of the building,
4. Comparison of simulation model output to measured data,
5. Refining of the model until an acceptable calibration is achieved,
6. Reporting on observations.

Each step is detailed below.

Calibrated simulation plan: We specified the technical and analytical features required by the simulation task (Table 16) and identified in EnergyPlus a suitable dynamic energy simulation engine; for the geometrical creation of the building model and the preliminary data entry, we used the DesignBuilder interface to EnergyPlus. Next, we identified a reliable temporal span on which to conduct the data collection and monitoring ranging from 1 January 2020 to 18 June 2020. The first two months were considered as stabilization period due to the installation and preliminary tests of the freescoo HVAC and FAE HCPV. Furthermore, due to the COVID-19 lockdown and the impossibility for users to access the building, the period from 1st March to 30th April was used to drive the calibration given the absence of the aleatory uncertainty due to user presence and interaction with building devices and openings. Then, we identified the major sources of specification uncertainty and estimated variation ranges for each input variable.

Table 16: Input variables of simulation runs according to the Calibrated simulation plan

Sim. n°	Air change factor	U-value wall (W/m^2K)	U-value floor (W/m^2K)	U-value roof (W/m^2K)	U-value windows (W/m^2K)	Type of glass	Detailed modelling of the entrance door	T. Ground	Operation mode
1	1	0.8	0.4	0.4	1.6	Double	N	Fixed	Free-running
2	1	0.8	0.4	0.4	5.87	Simple	N	Fixed	Free-running
3	1	0.8	0.4	0.4	5.87	Simple	Y	Fixed	Free-running
4	1	0.4	0.4	0.4	5.87	Simple	N	Fixed	Free-running
5	1.5	1	0.5	0.4	5.87	Simple	Y	Fixed	Free-running
6	1.5	1	0.5	0.4	5.87	Simple	Y	Dynamic	Free-running
7	1	0.8	0.5	0.4	5.87	Simple	Y	Dynamic	Free-running
8	1	0.8	0.65	0.4	5.87	Simple	Y	Dynamic	Free-running
9	1	0.8	0.67	0.45	5.87	Simple	Y	Dynamic	Heating in free-running, Cooling controlled (May-June)

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Finally, we tried to reduce as much as possible aleatory uncertainty by creating a detailed and complete weather file and developing a detailed schedule for occupant presence in the demobox. Starting from data provided by the weather station present at the CyI Campus, on a sub-hourly scale, the values were resampled on an hourly scale through the sum of the values for intensive quantities (precipitation, wind speed, wind direction) and the average for extensive quantities (temperature, relative humidity, global radiation). Once the hourly scale for the data was defined, it was introduced within the software Elements. This software was used to generate the climate file, capable of generating the file in EPW format useful for simulations in EnergyPlus. Elements consists of a graphical interface very similar to that of a spreadsheet, in which each column refers to a different climatic variable, in addition, there is the possibility of changing the header of the file, that is the recognition part of the EPW file within EnergyPlus. The header defines various information such as geographic location, latitude, longitude and elevation needed to develop the equations that govern the climatic variables. Once the insertion of the spreadsheet in the software was completed, the climatic file can be exported in EPW format so that it can be uploaded to EneryPlus in order to proceed with the simulations.

Data collection: Meteorological data were collected from a professional weather station available at the roof of the NTL building. The measured values were: outdoor dry bulb air temperature, relative humidity, atmospheric pressure, wind direction and speed, and global and direct solar radiation on a horizontal plane. Indoor environmental conditions (air temperature, relative humidity, carbon dioxide level) were collected through the sensors specified in Table 60 (Annex A). Furthermore, the state (open/close) of the door and window was recorded. The transmittance (U-value) of the walls of the building were measured with an in-field measurement campaign (see Annex H), and average minimum and maximum values were tested during the calibration process.

Creation of the numerical model of the building: We created the geometrical model of the existing demobox based on the available as-built drawings. The main dimensions reported in the as-built drawings were double-checked with on-site geometrical measurement. Next, the data collected in the pre- and post-occupancy phases were used to refine input variables in the numerical model. The zoning was set to reproduce the spatial layout of the demobox for a better representation of the thermal conditions inside the facility. To increase the case-study representativeness, the model was calibrated by comparing the measured internal air temperature with the simulated one in the office room occupied by the users and located on the ground floor of the facility. All available information about passive and active systems available at the facility was inputted in the simulation tool.

Comparing simulation model output to measured data: Several simulations were conducted according to the Calibrated Simulation Plan to identify the combination of input data that best replicate the trend of the indoor measured air temperatures. Data relating to the measured internal temperature, used for calibration, were obtained through post-occupation measurements with sub-hourly frequency (every quarter of an hour). Starting from these values, the hourly temperature was generated for the entire time span indicated in the Calibrated Simulation Plan. To evaluate the

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goodness-of-fit of each simulation run two validation indices were calculated according to the ASHRAE Guideline 14: the Normalized Mean Bias Error (NMBE) and the Coefficient of Variation of the Root-Mean-Square Error (CV [RMSE])

$$NMBE = \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)}{(n-p) \times \bar{y}}$$

$$CV(RMSE) = \frac{\sqrt{\frac{\sum(y_i - \hat{y}_i)^2}{(n-p)}}}{\bar{y}}$$

Where n represents the number of data points or periods in the baseline period, y represents measured values and $\hat{y}$ the simulated ones, $\bar{y}$ represents the arithmetic mean of the sample of n observations and p, that is equal to 1, represents the number of parameters or terms in the baseline model, as developed by a mathematical analysis of the baseline data.

According to ASHRAE Guideline 14, a model can be considered calibrated if, for hourly values, NMBE is in the range of ±10% and CV(RMSE) is lower than 30%. Simulation n. 9 (Table 17) reaches a NMBE of 7.51 and a CV(RMSE) of 21.57%, hence it can be considered calibrated according to the ASHRAE Guidelines 14.

Table 17: Comparison of the values of the input variable of the original simulation (Simulation n.1) with Simulation n.9

Sim. n°	Air change factor	U-value wall (W/m²K)	U-value floor (W/m²K)	U-value roof (W/m²K)	U-value windows (W/m²K)	Type of glass	N° of windows	T. Ground	Operation mode
1	1	0.8	0.4	0.4	1.6	Double	1	/	Free-running
9	1	0.8	0.67	0.45	5.87	Simple	2	Corrected	Heating in free-running, Cooling controlled (May-June)

Figure 32 shows the graphical comparison between the monitored indoor air temperature in the office building with those simulated between 1st March and 30th April for few of the simulation runs performed during the calibration process.

The calibrated simulation (Sim.n.9) can reproduce the thermal behaviour of the actual building in the considered time span although it may not meet the full daily fluctuation of the monitored data in some days (Figure 32). Also, a there are three spikes that cannot be explained by the data but the only appear at the beginning of the time period and seem not to affect the other days of the period.

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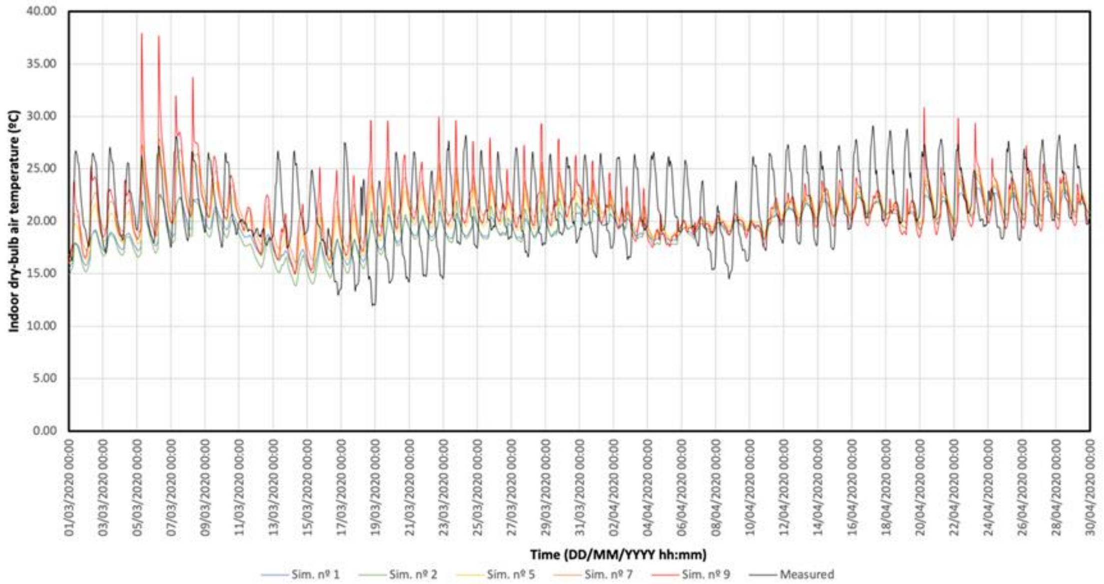

Figure 32: Comparison of time series of the indoor dry-bulb temperature for several simulation runs executed during the calibration process

4.3 M&V plan – Option D

IPMVP's option D is intended for determining energy savings through calibrated simulations. Option D is also an evaluation option when the studied boundary is the whole building as well as when a metered baseline does not exist.

In ZERO-PLUS IPMVP's option D was advised for the final calibration of the simulation models [9].

A first calibration of the models was done after completion of the pre-occupancy checks and pre-occupancy monitoring (Annex H). With the first calibration the simulation models were updated to as-built conditions of the buildings and technologies and were calibrated with pre-occupancy data (see Annex A).

The final calibration was done with all the data collected during the measurement and verification period. The measurement and verification period started with the beginning of pre-occupancy monitoring and includes the pre-occupancy data collection as well as the post-occupancy data collection. Since this is a new construction project, a period of a month after the occupancy was considered as the "house breaking" period". Data collected during the "house breaking" period" were excluded from the calibrated simulations. The measurement and verification period ended on the16th of August 2020 for all four case studies.

By "Actual" results" it is meant that the results were obtained from the analysis of the monitored data provided by the end of the project.

The final calibration involved the following steps:

Step1:

The models (i.e. the models that resulted after the 1st calibration) are updated to reflect actual conditions of operation during the M&V period. The models are calibrated by using all the data collected during the measurement and verification

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period. The measurement and verification period includes the pre-occupancy data collection as well as the post-occupancy data collection (see Annex A).

Step 2:

Final calibrated model simulations are run, and the results are compared to the Monitored Energy Use of the M&V period.

Step 3:

Possible variances between simulations and monitored energy data are identified and the models are recalibrated to the acceptable margin of error according to ASHRAE Guideline 14 [8].

The details of the calibrated simulations (calibration data etc.), are described in section 4.2.

After completion of Step 3 an as-built model calibrated according to monitored use was produced. This allows the evaluation and validation of the ZERO-PLUS simulation models and tools. The final calibration results for each case study are presented in the next sub-sections (4.4.1-4.4.4), including the following information:

- M&V Period: Start date (the M&V period started with the beginning of pre-occupancy monitoring) – End date (16 August 2020)
- Calibration data period: Start date – End date
- Error between final calibrated simulations and actual performance
- Final calibrated simulations' results compared to actual performance on monthly basis and total for the M&V period, as well as per consumption category
- Evaluation of the simulation models and tools

4.3.1 French case study

M&V and Calibration Period: 31 July 2019 – 16 August 2020

Final calibration results:

Final calibrated simulation results are compared to measured performance per consumption category in Table 18.

Table 18: Final calibrated simulation results compared to measured performance per consumption category in the French case study

All values kWh/m²/yr		Building		
		As-built Simulation	Final Calibrated Simulation	Actual
FRANCE	Space heating	27.19	46.66	70
	Ventilation, fan, pumps	4.98	5.26	1.96
	Domestic hot water	36	38.94	40.95
	Common areas (Lighting, elevator…)	5.33	5.33	12.75
	Appliances[1]	-	-	-

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	Regulated energy use[2]	**68.17**	**90.86**	**112.91**
	Electricity Production	11.8	11.8	12.02
	Hot Water Production	7.9	7.9	4.36
	Biomass production	55.3	77.7	106.59
	Total Renewable energy[3]	**75**	**97.4**	**122,97**
	Net regulated energy[4]	**-6.82**	**-6.54**	**-10.26**

[1]Appliances consumption is not modeled nor monitored, as this consumption is at flat level (and private), while the modelling is made as the building level

[2]Regulated energy use = heating, cooling, domestic hot water, fans, pumps and ventilation (otherwise known as the building load).

[3]Renewable energy: energy production from building integrated renewables and the energy produced by the community/settlement systems.

[4]Net regulated energy = (regulated energy use minus renewable energy)

Table 19 shows the error metrics between the final calibrated simulations and the actual performance and Figure 33 shows bar charts comparing final calibrated simulations' results and actual performance on monthly basis for the M&V period / calibration period. The error for both indicators is higher than the acceptable indicated in ASHRAE Guideline 14. This is due to limitations that are discussed in the following paragraphs.

Table 19: Error metrics between final calibrated simulations and actual performance

	NMBE	CVRMSE	Type	Period
FR	36.3%	45.7%	Monthly space heating (kWh)	31 July 2020 – 16 Aug 2020

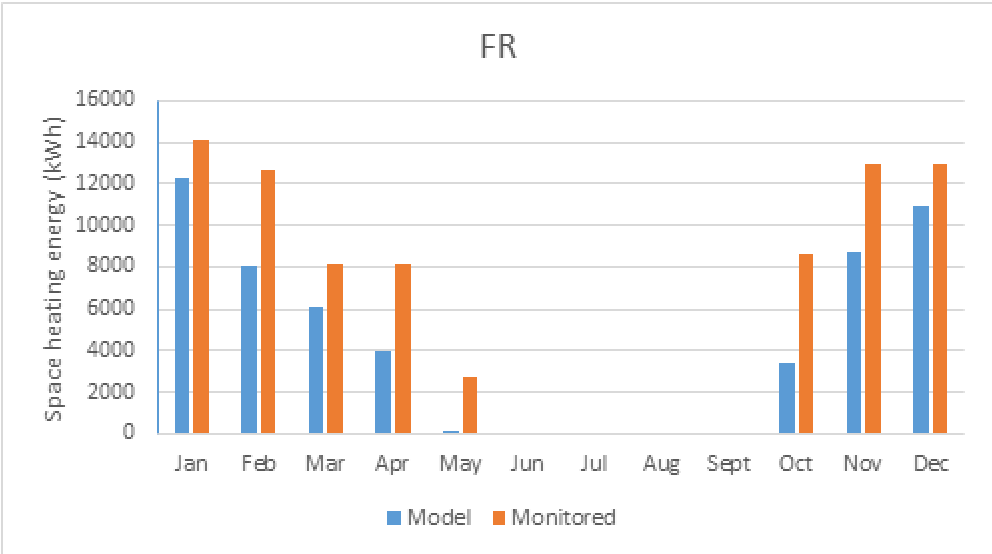

Figure 33: Comparison of final calibrated simulations and measured on monthly basis

Heating consumption: There is a significant difference in heating consumption, firstly between the as-built simulation (27.19) and the final calibrated simulation (46.66) and secondly between the calibrated simulation and the actual consumption (70). This difference is attributed to two reasons:

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- the interior temperature was measured during the winter at an average of 22°C, while the as-built simulation assumed a temperature of 20°C during the day and 18°C at night. The actual interior temperature was integrated in the final calibrated simulation.

- a faulty workmanship due to the heating subcontractor was discovered after the end of the heating period. This company had not installed heat insulation around pipes inside the collective boiler room, leading to significant heat losses, especially since this room was neither isolated, nor adjoining a heated space. The absence of heat insulation cannot be integrated into the simulation, which is why the result of 46.66 kWh/m^2/yr does not take it into account. This is probably the main cause of the difference between the simulated value of 46.66 kWh/m^2/yr and the measured value of 70 kWh/m^2/yr

Auxiliaries consumption: The difference in consumption of the auxiliaries (ventilation, fan, pumps) can be explained by the Pleiades software which calculates fixed consumption, without taking into account the equipment actually installed, which is visibly more energy efficient than the software's assumptions.

DHW consumption: the 3 domestic hot water consumption values are similar but conceal two errors which compensate each other:

- the as-built simulation assumes that 52 people occupy the building, while actually 42 people live in it. Consequently, the as-built simulation overvalues the hot water consumption. The actual occupation was integrated into the final calibrated simulation.

- both simulations assume a yearly consumption of hot water consumption of 8m^3 per person, while the actual consumption was measured at 10.7m^3. This actual consumption was integrated into the final calibrated simulation.

To conclude, the as-built simulation assumed a 416m^3 consumption of hot water per year, while the actual consumption was measured to 450m^3 (+8%). The same difference of 8% can be observed between the as-built simulated energy consumption and the actual consumption.

The remaining difference between the final calibrated simulated consumption (38.94 kWh/m^2/yr) and the actual consumption (40.95 kWh/m^2/yr) is very low (+5%) and can be explained by the absence of heat insulation in the boiler room.

Common areas electric consumption: the actual consumption is quite higher than the simulated value, because the elevator consumption is not taken into account in the simulation.

Electricity production: the actual production is very close to the simulated value (+1.9%), which can validate the modeling of this equipment.

Hot water solar production: production is lower than expected. This may be explained by the late choice to install Dualsun technology as a replacement for unavailable technology, which forced us to use the manufacturer's data without further analysis.

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Biomass production (district heating network): The biomass production is much higher than simulated (+37% compared to the final calibrated simulation). This is quite normal, considering the overconsumption of heat: the heating network is used to meet the heating and hot water needs which are not provided by solar production. As heating consumption is higher than simulated, the building has to produce more heat from biomass. So if we consider the differences between the results of the calibrated simulation and the measured values, we see that the biomass overproduction (+29) corresponds to the overconsumption of heat (heating + hot water + solar hot water production deficit: 23 + 2 + 4 = 29).

4.3.2 Italian case study

M&V period for each house in the case study of Italy:

- IT1:

Pre-occupancy monitoring: 18/6/2018 - 6/7/2018

Occupied: August 2018

Post-occupancy monitoring: 09/06/2019 - 15/08/2020

- IT2:

Pre-occupancy monitoring: 1/2/2019 - 5/3/2019

Occupied: March 2019

Post-occupancy monitoring: 09/06/2019 - 15/08/2020

Calibration period:

June 2019 - March 2020 for Regulated energy use calibration in order i) to have at least full summer, full winter, and one full middle season and ii) to exclude the period of the lockdown due to COVID-19 pandemic that does not represent the standard building operation. On the other hand, renewable energy generation (from PV panels) in IT1 and IT2 was not available before August 2019. Therefore, data monitored from August 2019 to March 2020 were considered for settlement energy production calibration.

Final calibration results:

The results of the final Regulated energy use calibration for the two building models are depicted in Figure 34 (IT1) and Figure 35 (IT2), while Figure 36 (IT1) and Figure 37 (IT2) report the calibration of renewable energy production. The visual comparison shows an acceptable accuracy of the calibrated model, even if the building models tends to slightly overestimate both the Regulated energy consumption and renewable energy production. However, based on the obtained MBE and RMSE, both buildings can be considered calibrated in terms of Net regulated energy consumption. In fact, the calibration indexes further calculated for the two buildings confirm the reliability of the models also in operating conditions. NMBE for energy consumption is equal to -

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0.26% and -2.53% for IT1 and IT2, respectively, while CV(RMSE) is equal to 6.36% and 8.15% for IT1 and IT2, respectively, namely inside the maximum limit. Similar results are obtained for renewable energy production, i.e. NMBE equal to -3.82% and -1.30% for IT1 and IT2, respectively, while CV(RMSE) equal to 8.69% and 9.72% for IT1 and IT2, respectively.

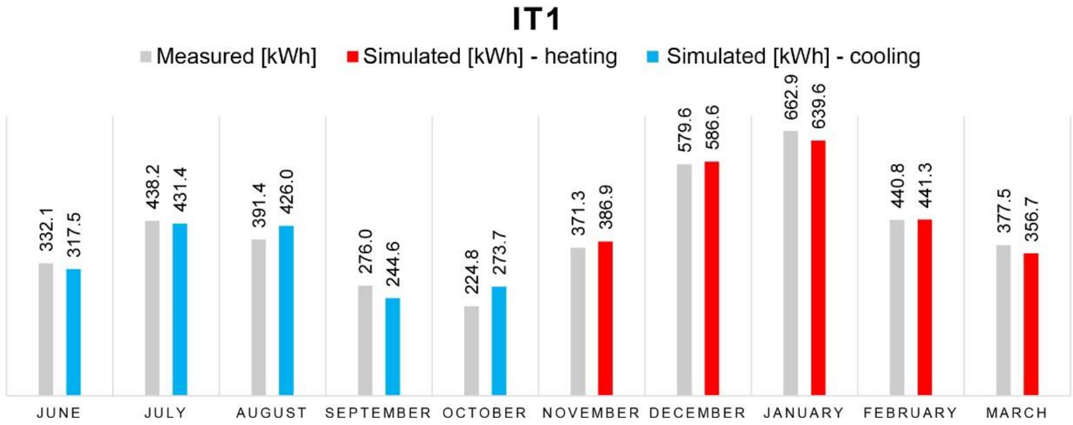

Figure 34: Comparison of measured and simulated Regulated energy use values for IT1

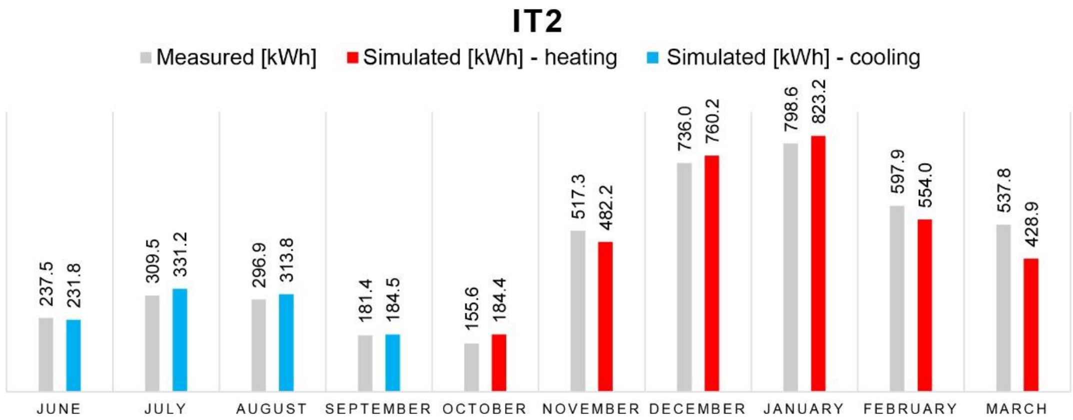

Figure 35: Comparison of measured and simulated Regulated energy use values for IT2

Table 20 presents the final calibration results along the actual energy use results for each consumption category. Lighting was not sub-metered in the Italian case study.

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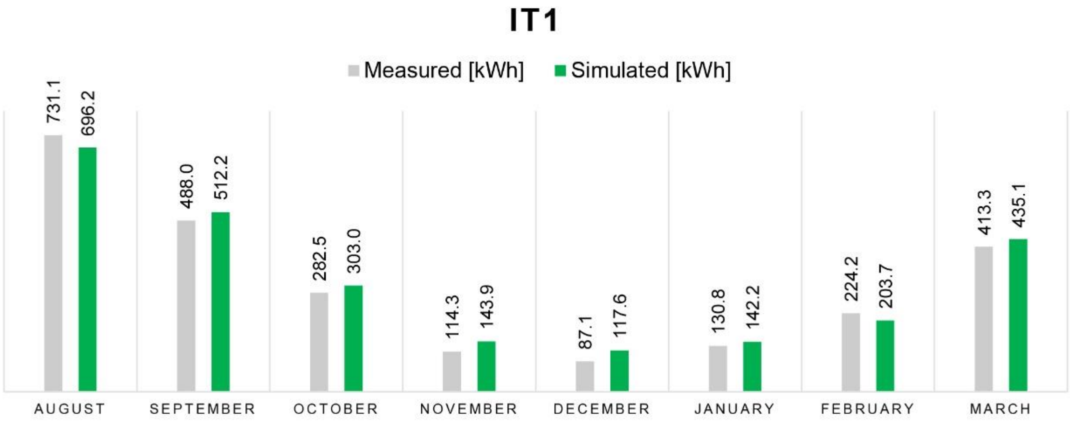

Figure 36: Comparison of measured and simulated renewable energy production values for IT1

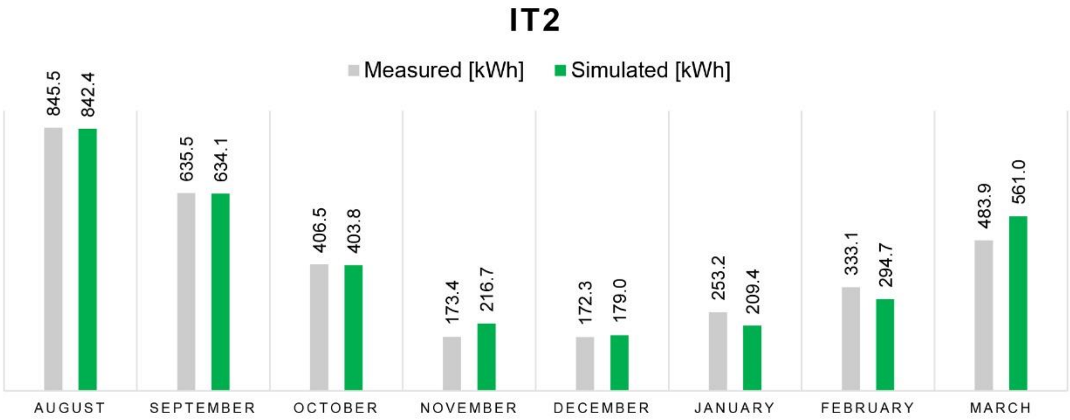

Figure 37: Comparison of measured and simulated renewable energy production values for IT2

Table 20: Final calibrated simulation results compared to measured performance per consumption category in the Italian case study

All values kWh/m²/Calibration data period		IT1		IT2	
		Final Calibrated Simulation	Actual	Final Calibrated Simulation	Actual
ITALY	Space heating	14.5	14.4	25	26.2
	Cooling/ventilation	5.2	4.7	3.7	3.6
	Domestic hot water	4	4.4	1.5	1.1
	Lighting	6.2	Not available	3.5	Not available
	Appliances	4.3	5	1.8	1.9
	Regulated energy use[1]	23.7	23.4	30.2	30.9
	Renewable energy[2]	**22.2**	**17.4**	**22.2**	**26.7**
	Net regulated energy[3]	**1.5**	**6**	**7.9**	**4.2**

[1]Regulated energy use = heating, cooling, domestic hot water, fans, pumps and ventilation (otherwise known as the building load).

[2]Renewable energy: energy production from building integrated renewables and the energy produced by the community/settlement systems.

[3]Net regulated energy = (regulated energy use minus renewable energy)

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4.3.3 UK case study

M&V Period and calibration data period:

- Dwellings UK1 & UK3 M&V period dates: 1 October 2019 - 16 August 2020
- Dwellings UK2 M&V period dates: 1 February 2020 - 16 August 2020

Final Calibration results:

Figure 38 shows bar charts comparing final calibrated simulations' results and actual performance on monthly basis for the M&V period / calibration period. The figure shows the results for UK2 and UK3. As UK1 did not have space heating monitoring data it is not shown. Table 21 shows the error metrics between final calibrated simulations and actual performance for each dwelling.

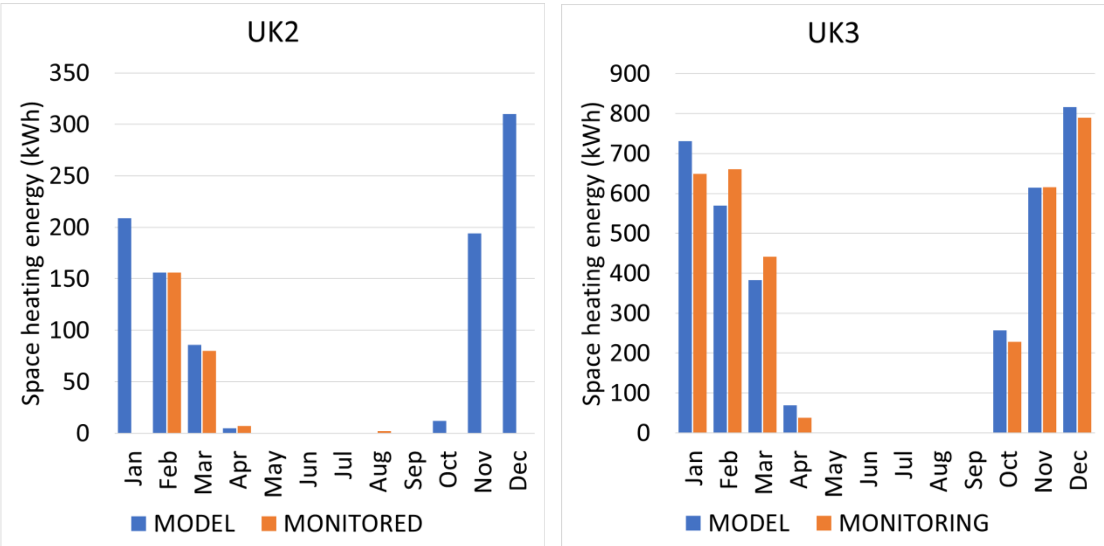

Figure 38: Calibration results on a monthly basis; UK2 (left) and UK3 (right)

Table 21: Error metrics between final calibrated simulations and actual performance in UK case study

Dwelling	NMBE	CVRMSE	Type	Period
UK1	1.60%	8.20%	Hourly interior temperature	1 Nov 2019 – 31 Mar 2020 (heating period)
UK2	0.40%	7.20%	Monthly space heating (kWh)	1 Feb 2020 – 31 Aug 2020
UK2	1.60%	6.60%	Hourly interior temperature	1 Feb 2020 – 31 Mar 2020 (heating period)
UK3	0.50%	14.60%	Monthly space heating (kWh)	1 Oct 2019 – 31 Aug 2020
UK3	-0.20%	11.20%	Hourly interior temperature	1 Nov 2019 – 31 Mar 2020 (heating period)

In UK3 there is a much greater disparity between model and monitoring results in the months of January – March as opposed to October – December. Possible reasons are the weather file which had to be composed of both weather onsite and weather from a nearby weather station and/or the possibility of significant variation in occupant behavior (e.g. heating patterns, heating set points). The occupant behavior

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was assessed closely in February – March for UK2. The result of creating different heating patterns for each month can be seen in UK2. This method is, however, impractical for calibration and simulation of potential consumption.

Table 22 shows the calibration results with the in-use results for each segment of measured data in the dwellings. Note that as space heating is the only modeled figure, it is the only one with variation from actual monitored results.

Table 22: Case studies' energy use breakdown – calibration and in-use for the UK case study

	All values kWh/m^2/M&V period	Final Calibrated Simulation	Actual
Dwelling UK1	Space heating	36.4	37.1
	Cooling/ventilation	N/A	0.6
	Domestic hot water	N/A	29
	Lighting	N/A	1.1
	Appliances	N/A	21.6
	Regulated energy use[1]	N/A	66.6
	Renewable energy[2]	N/A	**58.4**
	Net regulated energy[3]	N/A	**8.2**
	All values kWh/m^2/M&V period	**Final Calibrated Simulation**	**Actual**
Dwelling UK2	Space heating	11.5	11.6
	Cooling/Ventilation	N/A	0.6
	Domestic hot water	N/A	33.1
	Lighting	N/A	0.3
	Appliances	N/A	24.3
	Regulated energy use[1]	N/A	45.3
	Renewable energy[2]	N/A	**57.9**
	Net regulated energy[3]	N/A	**-12.6**
	All values kWh/m^2/M&V period	**Final Calibrated Simulation**	**Actual**
Dwelling UK3	Space heating	26.5	26.4
	Cooling/Ventilation	N/A	2
	Domestic hot water	N/A	14.2
	Lighting	N/A	1
	Appliances	N/A	26.6
	Regulated energy use[1]	N/A	42.6
	Renewable energy[2]	N/A	**37.3**
	Net regulated energy[3]	N/A	**5.3**

4.3.4 Cypriot case study

M&V Period and calibration data period:

- Existing demobox M&V period dates: 1 January 2020 – 30 July 2020

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- Air Quality Observatory (Existing demobox) calibration period: 1 March 2020 - 30 April 2020

Final Calibration results:

Since the occupants have had not influence on the energy balance of the facility the calibration was made on the hourly indoor dry-bulb air temperature. Figure 39 shows the final calibrated simulations' results and actual performance on hourly basis for the M&V period / calibration period while Table 23 shows the error metrics between final calibrated simulations and actual performance.

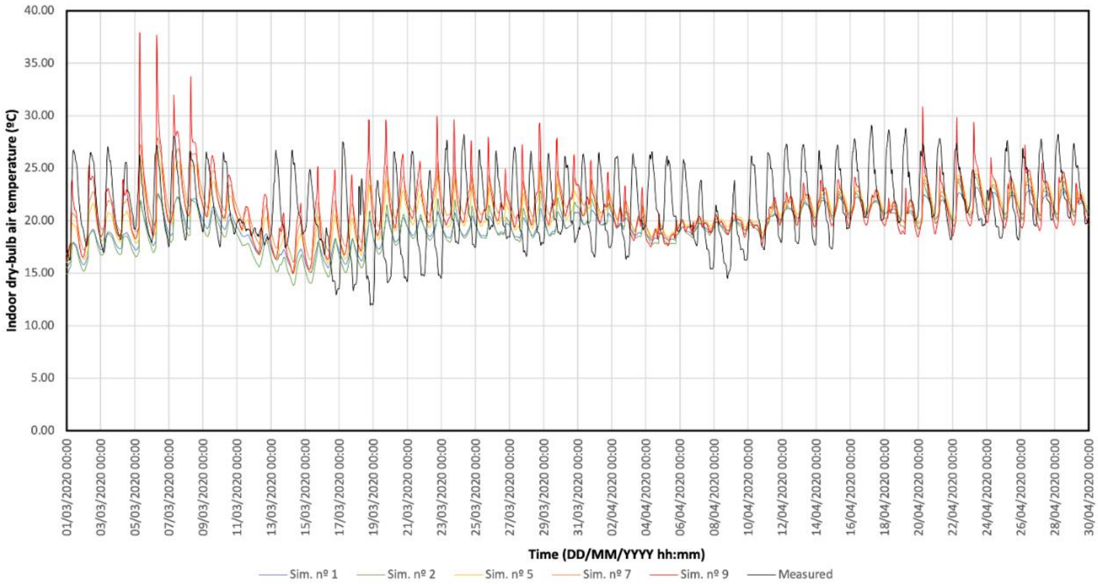

Figure 39: Final calibrated simulations' results and actual performance on hourly basis for the calibration period

Table 23: Error metrics between final calibrated simulations and actual performance

	NMBE	CVRMSE	Type	Period
Air Quality Observatory (existing demobox)	7.51	21.57%	Hourly indoor dry-bulb air temperature	1 March 2020 – 30 April 2020

Figure 40 shows bar charts comparing final calibrated simulations' results and actual performance on monthly basis for the M&V period. The Figure depicts the total electric energy required by the existing demobox, i.e. the Air Quality Observatory.

The model follows the monitored data although there is a significant disparity between simulated and monitoring results in the months of January and July. Possible reasons are (1) the weather file where the direct and diffuse components of solar irradiance was mathematically derived from global irradiance incident on the horizontal plane, and information on cloud coverage and presence of dust into the air were not available, and (2) the lack of information on the use of the first floor of the facility that is used by personnel not involved into the ZERO-PLUS project.

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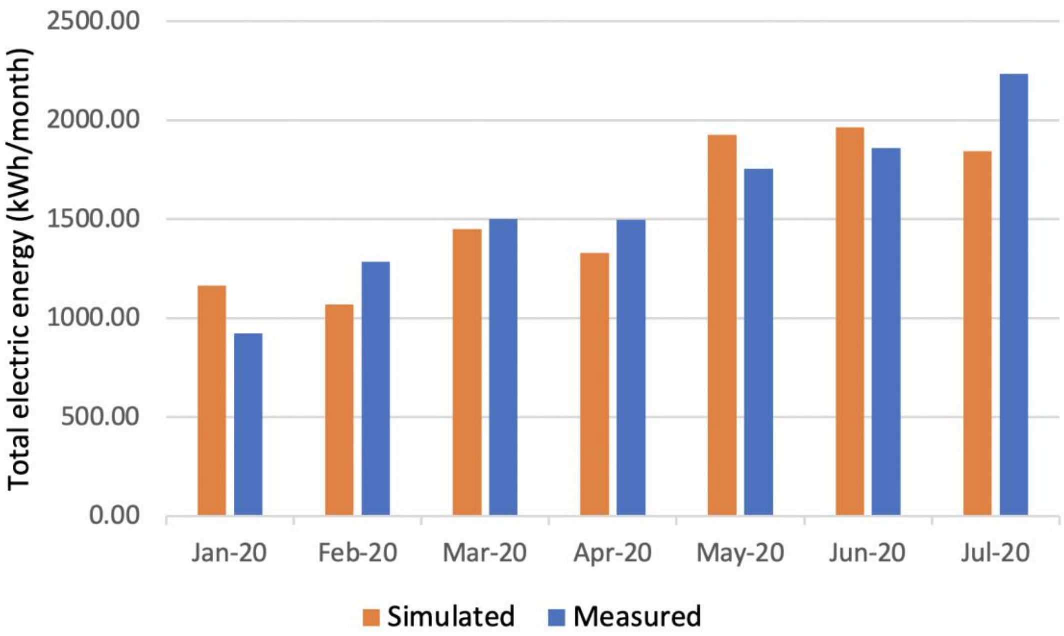

Figure 40: Calibration results on a monthly basis

Table 24 shows the calibration results with the in-use results for each segment of measured data in the facility. Note that space heating is zero because the heating system was not used as the facility was not constantly occupied during the winter period.

Table 24: Case study's' energy use breakdown – calibration and in-use

All values kWh/m²/M&V period		Final Calibrated Simulation	Actual
Cyprus	Space heating	0	0
	Cooling/ Ventilation	3.09	N/A
	Domestic hot water	-	-
	Lighting	0.03	N/A
	Appliances	8.69	N/A
	Regulated energy use[1]	11.81	12.15
	Renewable energy[2]	N/A	**N/A**
	Net regulated energy[3]	11.81	**12.15**

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5. Energy performance and impacts of the settlements

5.1 Key Performance Indicators

Application of the ZERO-PLUS approach ensures achievement of cost, energy use and renewable energy production targets. In this section the as-built and actual performance of the four ZERO-PLUS settlements against their targets, specified below, are presented.

- **Regulated energy usage (kWh/m²/year)**:

$$regulated\ energy\ use = heating + cooling + DHW + fans + pumps + ventilation$$

- **Net regulated energy usage (kWh/m²/year)**: To meet the ZERO-PLUS operational energy target, this must be ≤ 20 kWh/m² per year.

$$net\ regulated\ energy = regulated\ energy\ use - renewable\ energy\ production$$

- **Renewable production (kWh/m²/year)**: To meet the ZERO-PLUS generation target, the combined total must be ≥ 50kWh/m² per year.

$$Total\ renewable\ production = building\ integrated\ renewables + settlement\ renewables$$

- **Cost reduction (%)**: To meet the 16% cost reduction target, the difference between the ZERO-PLUS building and a net-zero energy reference building with equivalent energy KPIs must be modeled and costed:

$$TCZP = Total\ Cost\ Zero\ Plus = \Sigma(Zero\ Plus\ technologies)$$

$$TCRZ = Total\ Cost\ Net\ Zero\ Energy\ Reference\ Building = \Sigma(equivalent\ technologies)$$

$$Cost\ reduction = \frac{TCRZ - TCZP}{TCRZ}$$

- **Carbon emission reduction ($kgCO_2/m^2/year$)**: as per the project's objective "*To support the shift towards resource-efficient, low-carbon and climate-resilient buildings and districts, by enhancing the role of Europe's construction industry in the reduction of the EU's carbon footprint by almost 77kgrCO_2/m² with a total of approximately 200 tonnes CO_2 offset for all ZERO-PLUS case studies".*

Though the carbon footprint of the household(er) is not quantified as the project did not intend to capture all aspects of the household(er)s' lifestyle, the carbon emission reduction of the dwellings' total energy use can be quantified here. Specifically, this is the difference in carbon emissions from total energy consumed between a reference case dwelling and the ZERO-PLUS dwelling. The following equations provide guidance on calculating the carbon emission reduction:

$$Cer = Carbon\ emission\ reduction$$ [10]

[10] Note that carbon footprint reduction calculation considers total final regulated and non-regulated energy consumption.

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$$CeTyp = Carbon\ emissions\ of\ typical\ dwelling\ in\ home\ country\ (used\ as\ ref.case)$$

$$CeZP = Carbon\ emissions\ of\ Zero\ Plus\ case$$

$$CeTyp = Total\ electricity\ consumption\ of\ typical\ dwelling \times electricity\ carbon\ factor + Total\ \{other\ fuel\}\ consumption\ of\ typical\ dwelling \times \{other\ fuel\}\ carbon\ factor$$

$$CeZp = Total\ electricity\ consumption\ of\ ZP\ dwelling\ a \times electricity\ carbon\ factor + Total\ \{other\ fuel\}\ consumption\ of\ ZP\ dwelling\ a \times \{other\ fuel\}\ carbon\ factor$$

If 3 dwellings:

$$Cer = CeTyp\ \times 3 - (CeZP_{dwelling}a\ +\ CeZP_{dwelling}b\ +\ CeZP_{dwelling}c)$$

$$Cer/m2\ (kgCO2/m2/yr)\ = Cer/settlement\ area$$

- **Self-consumption ratio**

Different regions have different regulations with respect to renewable energy generation and how it is used. For example, in France, the PV system was only used by the common services in the flat, e.g. lighting. In the Italian case study, due to national law, the PV system could not be used on site but all of it had to be exported to the grid. For reasons like these, there can be a concern that if and when renewable energy is not utilized, i.e. self-consumed in a dwelling, it should not be counted to reduce the officially reported net regulated energy of the dwelling.

Although not a KPI, the theoretical or actual (depending on case study) self-consumption ratio was calculated. The method to calculate the **theoretical self-consumption ratio** is based on the following formula from [10].

$$F = \frac{\sum_{n=1}^{N} \min\ (Pn\ , Cn)}{\sum_{n=1}^{N} Pn}$$

Here Pn is the PV power at the n'th time point, Cn is the consumption power at the same time, N is the number of points in the time series, and F is the fraction of PV power that is self-consumed. If a battery storage system is used as well, the relation becomes the following [10]

$$F = \frac{\sum_{n=1}^{N} \min\ (Pn + Pb\ , Cn)}{\sum_{n=1}^{N} Pn}$$

Here Pb is the power delivered by the battery. This in turn depends on the availability of energy in the battery, which is determined by the model for charging and discharging the battery [10]

The tables in the following sub-sections provide the As-built and Actual energy performance and KPIs for each case study.

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5.1.1 French case study

The energy values for the Actual performance are reported for the monitored period of September 2019 - August 2020.

Table 25: Energy performance for all case study dwellings, FR

	All values kWh/m²/yr	FR	
		As-built	**Actual**
Common areas (FRANCE	Space heating	27.19	70
	Ventilation, fan, pumps	4.98	1.96
	Domestic hot water	36	40.95
	Common areas (lighting, elevator, etc.)	5.33	12.75
	Flat lighting / Appliances[1]	-	-
	Regulated energy use[2]	**68.17**	**112.91**
	Electricity production	11.8	12.02
	Hot water production	7.9	4.36
	Biomass production	55.3	106.59
	Total Renewable energy[3]	**75**	**122.97**
	Net regulated energy[4]	**-6.82**	**-10.06**

[1] Flat level lighting and appliances consumption are not modelized nor monitored, as this consumption is at flat level (and private), while the modelization is made as the building level

[2]Regulated energy use = heating, cooling, domestic hot water, fans, pumps and ventilation (otherwise known as the building load).

[3]Renewable energy: energy production from building integrated renewables and the energy produced by the community/settlement systems.

[4]Net regulated energy = (regulated energy use minus renewable energy)

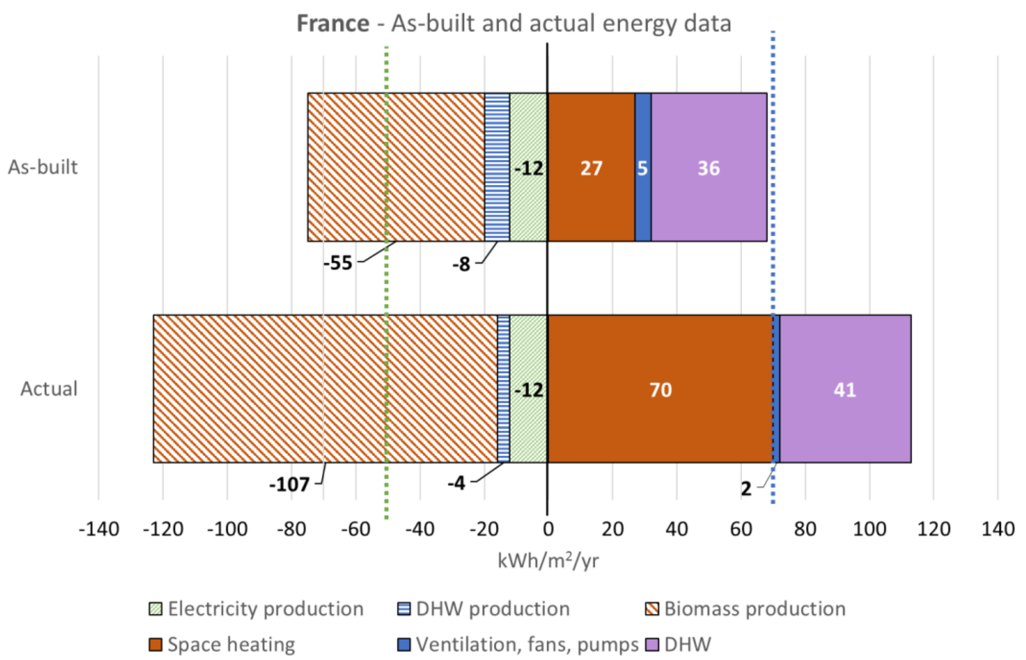

Figure 41: Energy data for all case study dwellings, FR

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Table 25 and Figure 41 show the energy breakdown for the case study dwellings. Actual space heating is much higher than the as-built estimates; however, this energy is supplied through biomass, considered carbon neutral. Overall, the French case study met the renewable energy production target and the net regulated energy target. These targets are also better than the as-built projections.

Table 26 also shows that the cost reduction target is also achieved.

Table 26: KPI's for the FR case study

#	KPIs	As-built	Actual
1	Net Regulated energy usage (kWh/m^2/year) (target: < 20 kWh/m2/year)	-6.82	-10.06
2	Renewable production (kWh/m^2/year) (target: > 50 kWh/m2/year)	74.99	122.97
3	Cost reduction (%) (target: 16% reduction compared to the reference case)	26.70%	26.70%
4	Carbon emission reduction (kgCO$_2$/m^2/year) [1] (target: >=4.6) *****	17.31	17.06
Self-consumption ratio [2]		87.40%	47.40%

[1] Carbon factor: electricity: 0.056 tn/Mwh; natural gas: 0.202 tn/Mwh; photovoltaic: 0 tn/Mwh; biomass: 0 tn/Mwh

[2] As AIH is not a licensed energy supplier, they are forbidden to supply the tenants with electricity. AIH will directly consume electricity only for lighting common areas and HVAC, which is far less than the required production. The presented numbers are the percentage of PV generated that is directly consumed by the common services of the building.

* Carbon emissions reduction target is relative to the French case study. It is based on the reduction targeted during the design phase of the project.

5.1.2 Italian case study

The energy values for the Actual performance are reported for the monitored period of August 2019 - July 2020.

Table 27 and Figure 42 show the energy breakdown for the two case study dwellings. Actual space heating is higher than the as-built estimates in one dwelling but lower in the other. This demand is sufficiently offset by renewable energy.

Table 27: Energy performance for all case study dwellings, IT

All values kWh/m^2/yr		IT1		IT2	
		As-built	Actual	As-built	Actual
ITALY	Space heating	22	16.5	17.3	28.4
	Cooling/ventilation	15.6	11.3	14.7	9
	Domestic hot water	9.8	6.5	15.5	1.6
	Lighting	10.1	N/A	12	N/A
	Appliances	9.9	7.7	19.5	2.9
	Regulated energy use[1]	47.4	34.3	47.5	39
	Renewable energy[2]	49.7	**39.9**	49.7	**56.3**
	Net regulated energy[3]	-2.3	**-5.6**	-2.2	**-17.3**

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[1]**Regulated energy use = heating, cooling, domestic hot water, fans, pumps and ventilation (otherwise known as the building load).**

[2]**Renewable energy: energy production from building integrated renewables and the energy produced by the community/settlement systems.**

[3]**Net regulated energy = (regulated energy use minus renewable energy)**

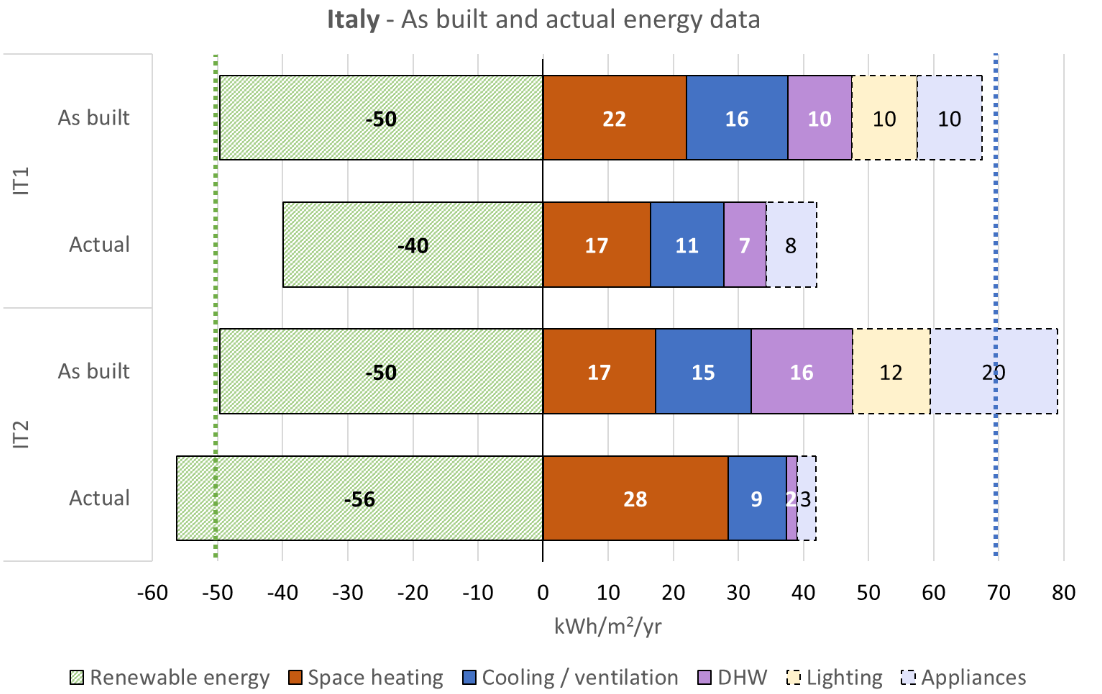

Figure 42: Energy data for all case study dwellings, IT

As shown in Table 27and Table 28, the net regulated energy target is sufficiently satisfied and even surpassed by a great deal. However, the renewable energy production target is not met, although by a small extent. Table 28 also shows that the cost reduction target is also achieved.

Table 28: KPI's for the IT case study

#	KPIs	As-built	Actual
1	Net Regulated energy usage (kWh/m^2/year) (target: < 20 kWh/m2/year)	-2.2	-11
2	Renewable production (kWh/m^2/year) (target: > 50 kWh/m2/year)	49.7	47.6
3	Cost reduction (%) (target: 16% reduction compared to the reference case)	24.8	24.8
4	Carbon emission reduction (kgCO_2/m^2/year) [1] (target: >=23)*	26.5	49.6 [1]
Self-consumption ratio [2]		0.48 [2]	0.55 [2]

[1] The actual energy consumption for lighting is not monitored in the Italian case study buildings. Therefore, the total energy consumption of the settlement (used to calculate the carbon emission reduction with respect to the Reference settlement) is calculated when considering the energy consumption for lighting of the calibrated buildings model.

[2] These values do not take into account the contribution of the battery, due to simulation limits and monitoring outputs, respectively.

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* Carbon emissions reduction target is relative to the Italian case study. It is based on the reduction targeted during the design phase of the project.

5.1.3 UK case study

Actual energy data were collected from October 2019 – August 2020 for UK1 and UK3. As UK2 was occupied from end of January 2020, the data for UK2 are available from February 2020 – August 2020. For this reason, about 33% of all data (October – January) for UK2 are extrapolated/simulated through the calibrated model. The space heating monitoring in UK1 did not log any data for the entirety of the project; therefore, the space heating value for UK1 is from the calibrated model.

Table 29 and Figure 43 show the energy breakdown for the case study dwellings. Actual space heating is much lower than the as-built estimates, leading to lower regulated energy consumption. The demand is sufficiently offset by renewable energy which also meets the target. Overall, the UK case study meets the renewable energy production target and the net regulated energy target. In two dwellings, the net regulated energy consumption is negative, significantly better than the target, the targets in these dwellings are also better than the as-built projections.

Table 29: Energy performance for all case study dwellings, UK

	All values kWh/m²/yr	UK1 (84.4 m²) As-built	UK1 (84.4 m²) Actual	UK2 (84.4 m²) As-built	UK2 (84.4 m²) Actual	UK3 (129.6 m²) As-built	UK3 (129.6 m²) Actual
UK	Space heating	43	37	43	12	46	26
UK	Cooling/ventilation	1	1	1	1	2	2
UK	Domestic hot water	25	29	25	33	20	14
UK	Lighting	1	1	1	0.3	1	1
UK	Appliances	18	22	18	24	25	27
UK	Regulated energy use[1]	68	67	68	45	69	43
UK	**Renewable energy[2]**	**52**	**51**	**52**	**51**	**52**	**52**
UK	**Net regulated energy[3]**	**16**	**16**	**16**	**-5**	**16**	**-9**

[1]Regulated energy use = heating, cooling, domestic hot water, fans, pumps and ventilation (otherwise known as the building load).

[2]Renewable energy: energy production from building integrated renewables and the energy produced by the community/settlement systems.

[3]Net regulated energy = (regulated energy use minus renewable energy)

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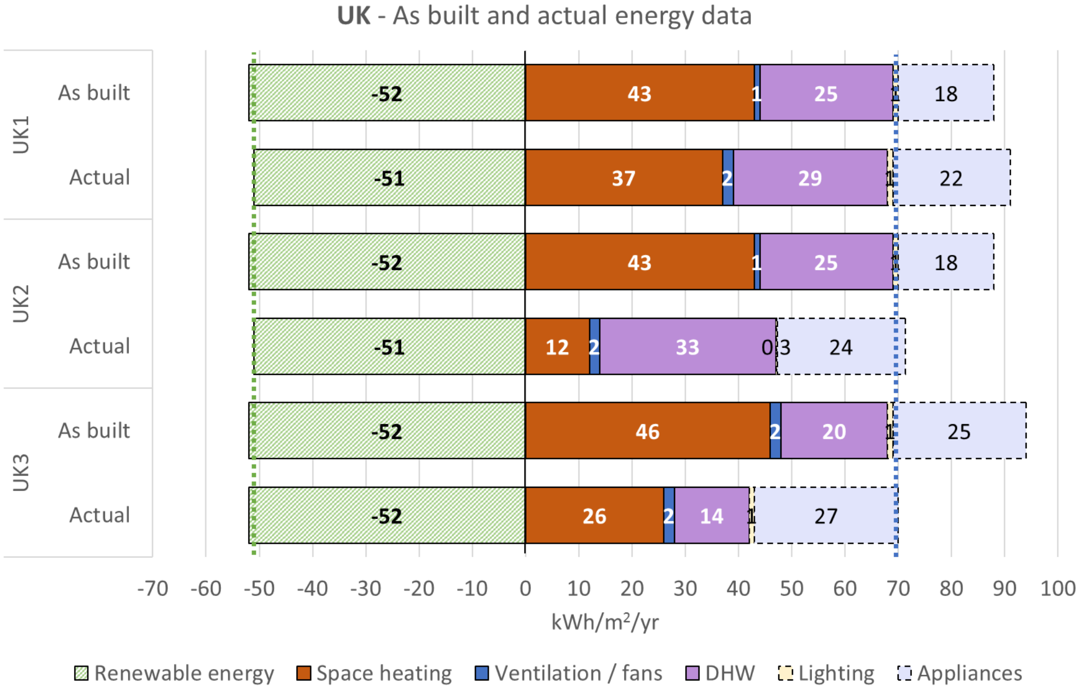

Figure 43: Energy data for all case study dwellings, UK

How the net regulated KPI was defined. In the UK, Building Regulations Part L: Conservation of fuel and power directs that TER/DER (Target CO_2 Emission Rate / Dwelling CO_2 Emission Rate) calculations be used to demonstrate compliance.

CO_2 emissions arising from:

- Provision of space heating and hot water, C_H
- Use of fans and pumps, C_{PF}
- Use of internal lighting, C_L

$$TER/DER = C_H \text{ X } FuelFactor + C_{PF} + C_L$$

The above are the regulated uses in a dwelling as per UK Building Regulations.

Regulated energy use is defined as energy use from heating, cooling, domestic hot water, fans, pumps and ventilation. Lighting appliances are considered unregulated as the owner has complete control over the number of bulbs and appliances and their efficiency in the dwelling from the initial occupation of the dwelling.

For the net regulated KPI generation from renewables is considered as 100% offset to energy consumed; therefore, net regulated equals the total settlement regulated energy minus the total renewable production. That is:

NREs = Net regulated energy of the settlement (kWh/m^2)

$$NREs = \frac{total\ regulated\ energy\ (kWh) - total\ renewable\ production\ (kWh)}{total\ area\ (m2)}$$

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Total amount of renewable energy provided for each dwelling is proportional to the area of the dwelling:

RPd = Renewable energy production for an individual dwelling (kWh)

$$RPd = total\ renewable\ production\ (kWh) \times \frac{area\ of\ dwelling}{area\ of\ settlement}$$

As described above, the KPI is met by simply using total annual estimated generation to offset total annual regulated consumption. In reality, the majority of the dwellings' consumption is space heating energy use. As is typical in the UK, this consumption is provided as hot water heated by natural gas and not by electricity. Another caveat is that the KPI is met from a 'settlement' perspective, i.e. total PV installed onsite (not just on the roof of each dwelling) are used in aggregate to offset the aggregate net-regulated consumption.

Table 30 also shows that the cost reduction target is also achieved.

Table 30: KPI's for the UK case study

#	KPIs	As-built	Actual
1	Net Regulated energy usage (kWh/m^2/year) (target: < 20 kWh/m2/year)	16	-1
2	Renewable production (kWh/m^2/year) (target: > 50 kWh/m2/year)	52.4	51.2
3	Cost reduction (%) (target: 16% reduction compared to the reference case)	17.8	17.8
4	Carbon emission reduction (kgCO$_2$/m^2/year) [1] (target: >=18)*	17.7	21.1
Self-consumption ratio [2]		N/A	True connected mean SCR (with battery) = 56% Settlement aggregate mean SCR (with battery = 40%

* Carbon emissions reduction target is relative to the UK case study. It is based on the reduction targeted during the design phase of the project.

Self-consumption

The self-consumption ratios are calculated only for the ZERO-PLUS dwellings. The following table (Table 31) shows the results.

Table 31: Monitored self-consumption ratios UK

Month	UK1		UK2		UK3	
	SC - PV	SC - PV+Batt	SC – PV	SC - PV+Batt	SC - PV	SC - PV+Batt
October 2019	20	50	-	-	37	89
November	27	75	-	-	55	90
December	23	79	-	-	43	82
January 2020	22	68	-	-	40	87
February	23	63	22	55	39	81
March	16	38	21	47	31	73
April	20	33	23	33	33	56

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Month	UK1		UK2		UK3	
	SC - PV	SC - PV+Batt	SC – PV	SC - PV+Batt	SC - PV	SC - PV+Batt
May	20	33	22	30	32	52
June	23	43	24	38	33	61
July	29	54	34	50	38	69
August	28	51	24	38	35	64
Average	**23**	**53**	**24**	**42**	**38**	**73**

Assessment of non-ZERO-PLUS dwellings in the same development

In the same development three Non ZERO-PLUS dwellings were assessed to be used as "control". This additional monitoring of non-ZERO-PLUS dwellings is necessary for the UK case study owner to show scalability of the ZERO-PLUS technologies, given that the UK case study is a development of 550 homes.

The assessment of three Non-ZERO-PLUS dwellings includes post-occupancy evaluation and indoor environmental monitoring. The findings provide a reference for comparing the indoor environmental conditions and occupant experiences of ZP dwellings with the non-ZERO-PLUS dwellings.

As the Non-ZERO-PLUS dwellings are similar in construction, they appear to have similar outcomes in occupant perception and environmental assessment. There is some variation; however, this is likely attributed to different orientations and forms of the dwellings and above all, occupant behavior. The occupants of the dwellings have opened windows in the winter and summer and have experienced hot temperatures in the summer. The complete assessment can be found in Annex E

5.1.4 Cypriot case study

The Cypriot case study involves the design of a theoretical prefabricated container system structure (named future "ZERO-PLUS demohouse" (Figure 44)) for residential use (student housing). The approach will be based on a modular system. The future ZERO-PLUS demohouse will be, in size, three times bigger than the existing demobox (see section 2.1.4 for the full description).

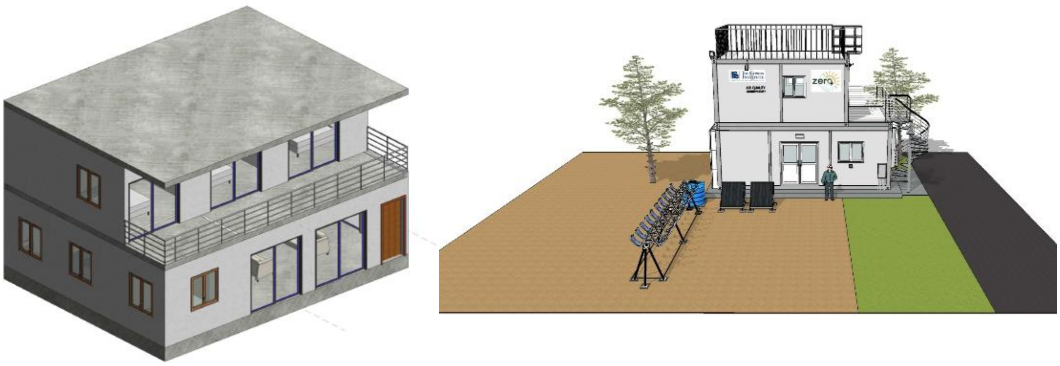

Figure 44: Sketches of the Future ZERO-PLUS demohouse (left) and the existing demobox (right)

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The technologies serving the two facilities are:

- **On the existing demobox**: 1 freescoo HVAC unit and FIBRAN insulation installed as a component of the fake wall of the demobox, not as an insulation element per se, to demonstrate the prefabrication and installation procedures for the technology;
- **On the ZERO-PLUS demohouse (theoretical application):** 1 freescoo HVAC unit and FIBRAN insulation on its walls;
- **At the settlement level:** FAE HCPV and inverter system.

Regarding the final energy of the ZERO-PLUS demohouse, the envelope components and building systems were identified after an optimization procedure aimed to meet the three KPIs established in the ZERO-PLUS project to express building performance requirements [11].

A description of the ZERO-PLUS building model can be found in Annex C.

Since the building has not been built before the ending of the ZERO-PLUS project, it was not possible to calculate the actual final energy consumption of the building. Table 32 shows the results of the energy simulation of the ZERO-PLUS demohouse.

Table 32: Energy performance the future ZERO-PLUS demohouse, CY

	All values kWh/m^2/yr	As-built	Actual
CYPRUS	Space heating	41.51	N/A
	Cooling/ ventilation	29.64	N/A
	Domestic hot water	2.05	N/A
	Lighting	19.72	N/A
	Appliances	45.11	N/A
	Regulated energy use[1]	73.2	N/A
	Renewable energy[2]	54.29	N/A
	Net regulated energy[3]	18.91	**N/A**

[1]Regulated energy use = heating, cooling, domestic hot water, fans, pumps and ventilation (otherwise known as the building load).

[2]Renewable energy: energy production from building integrated renewables and the energy produced by the community/settlement systems.

[3]Net regulated energy = (regulated energy use minus renewable energy)

The concept of the Cypriot case study is to create a zero-energy settlement formed by few ZERO-PLUS demohouses. For the purpose of this task, we assume that two ZERO-PLUS demohouse are built at the CyI premises and connected to 2 FAE HCPV/T modules with 20 mirrors each. The performance of this settlement will be indicated as-built although it is the result of dynamic simulation. Given the theoretical nature of the task it is not possible to compare the as-built performance with the “actual” performance of the settlement.

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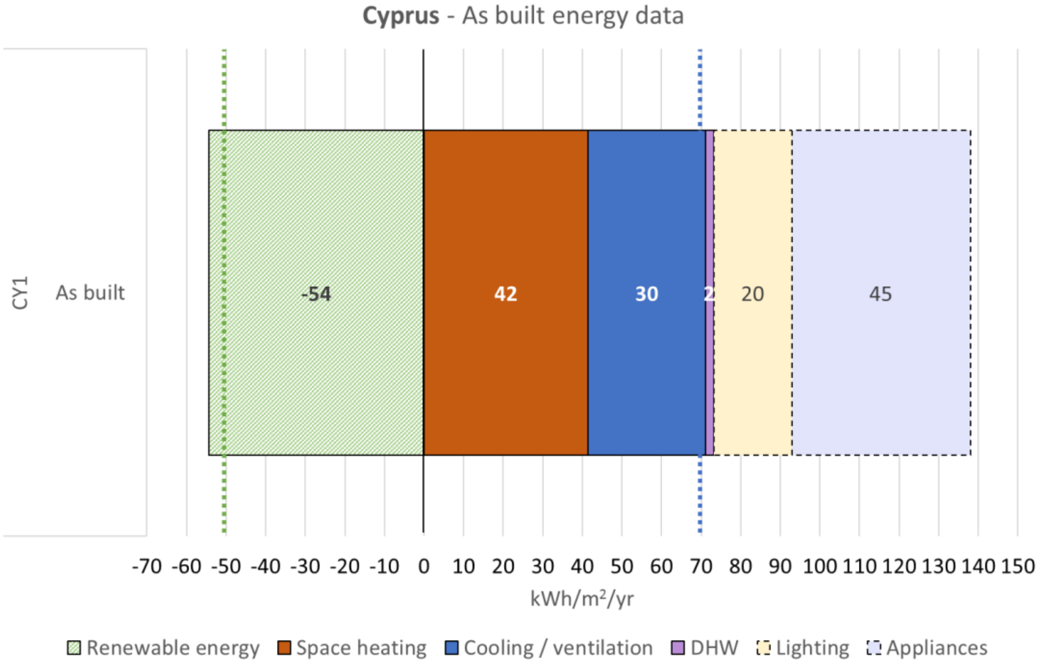

Figure 45: Energy data for the case study, CY

More information on the energy, emission and cost analyses can be found in Annex D.

Finally, based on the above energy, emission, and cost analyses, the results for the ZERO-PLUS settlement in Cyprus are shown in Table 33. All KPIs are met for the as-built scenario.

Table 33: KPI's for the CY case study

#	KPIs	As-built	Actual
1	Net Regulated energy usage (kWh/m^2/year) (target: < 20 kWh/m2/year)	14.8	N/A
2	Renewable production (kWh/m^2/year) (target: > 50 kWh/m2/year)	55.4	N/A
3	Cost reduction (%) (target: 16% reduction compared to the reference case)	17%	N/A
4	Carbon emission reduction (kgCO_2/m^2/year) [1] (target: >=34)*	33.6	N/A
Self-consumption ratio [2]		N/A	N/A

* Carbon emissions reduction target is relative to the Cypriot case study. It is based on the reduction targeted during the design phase of the project.

5.2 Impacts

In this section the "as-built" and "actual" impacts of the four ZERO-PLUS project settlements are presented.

- **Total Area of demonstration (m^2)**: this is the total area of all dwellings in which the ZERO-PLUS technologies and KPIs were applied.

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- **Energy Consumption for the Reference Settlement (kWh)**: Total energy consumption for standard construction reference case.

$$= ECref$$

- **Energy Consumption of the ZERO-PLUS NZ Settlement (kWh)**: Total energy consumption for ZERO-PLUS design.

$$= ECzp$$

- **Energy Conservation on yearly basis (kWh)**: The energy conservation is the difference between the reference case and ZERO-PLUS design above.

$$Annual\ energy\ conservation = ECref - ECzp$$

- **Carbon Emissions Reduction (tonnes)**: using regional or country specific emissions rate at '*x*' tn/MWh (tonnes) the unit of tn/MWh is used as it is proposed by the Covenant of Mayors.

$$CO^2\ emissions\ reduction = (ECref\ \times emissions\ rate\ \times 0.001) - (ECzp \times emissions\ rate \times 0.001)$$

- **Energy Cost Savings (€)**:

$$Eenergy\ costs\ saved = (ECref\ \times \frac{€}{kWh}) - (ECzp \times \frac{€}{kWh})$$

The following sections provide the Designed and Actual Impacts for each case study.

5.2.1 French case study

The following tables present the energy related impacts for the French case study. The actual energy conservation and cost savings are greater than the as-built condition. The carbon emissions reduction is slightly lower, likely due to the higher space heating in the actual case.

Table 34: Summary of energy conservation and cost savings from the ZERO-PLUS technologies in France

Total Area of demonstration (m2)	Energy Consumption for the Reference Settlement (kWh)	Energy Consumption of the ZERO-PLUS Settlement (kWh)	Energy Conservation on yearly basis (kWh)	Carbon Emissions Reduction using 0.056 tn/MWh (tonnes)[1]	Energy Cost Savings using €0.14/kWh[2]	Type
1,148	**101,238** [PE: 104,310]	**-11,330** [PE: -7,829]	**112,568** [PE: 112,139]	**19.9**	**15,699**	**As-built**
		-12,926 [PE: 11,548]	**114,164** [PE: 115,858]	**19.6**	**16,220**	**Actual**

[1]Emission factors: Guidelines of the Covenant of Mayors (2016)

Electricity	0.056 tn/MWh
Natural Gas	0.202 tn/MWh
Photovoltaic	0 tn/MWh
Biomass	0 tn/MWh

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[2]Electricity price: https://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_price_statistics#Electricity_prices_for_household_consumers

The following tables present the cost breakdown difference between the ZERO-PLUS technologies and the typical Net Zero Energy Building. These figures were used to calculate the cost reductionreported in section 5.1.

Table 35: The investment cost for the ZERO-PLUS technologies in France

Technology*	Provider	Unit	Number of Units	Cost per Unit (€)	Total Investment Cost (€)
MRE C05	Anerdgy	modules	6	6 103.47	36 620.83
HCPV	Arca	modules	5	2 236.2	44 724.00
Biomass district heating system connection	City Council of Voreppe	whole	1	15 000.00	15 000.00
Total Cost (€)					**100 081.83**

Table 36: The investment cost for a typical NZEB in France

Technology	Unit	Number of Units	Cost per Unit (€)	Total Investment Cost (€)
Thermal Panels	sqm	36	1 111.11	40 000.00
PV (120 modules of 250kWc each)	modules	120	500	60 000.00
Supporting frame	whole	1	36 500.00	36 500.00
Total Cost (€)				**136 500.00**

5.2.2 Italian case study

The following tables present the energy related impacts for the Italian case study. The actual energy conservation, carbon emissions reduction, and cost savings are greater than the as-built condition.

Table 37: Summary of energy conservation and cost savings from the ZERO-PLUS technologies in Italy

Total Area of demonstration (m2)	Energy Consumption for the Reference Settlement (kWh)	Energy Consumption of the ZERO-PLUS Settlement (kWh)	Energy Conservation on yearly basis (kWh)	Carbon Emissions Reduction using '0.483' tn/MWh (tonnes)	Energy Cost Savings using €'0.23' /kWh	Type
500	**26,745** [PE: 58,036][1]	**6,146** [PE: 13,337][1]	**20,598** [PE: 44,698][1]	**9.95**	**€ 4,737.60**	**As-built**
		516[2] [PE:1,119][1]	**26,229** [PE: 56,917][1]	**12.67**	**€ 6,032.70**	**Actual**

[1]Primary Energy (PE) factor for grid electricity: 2.17 (UNI/TS 11300)

[2]The actual energy consumption for lighting is not monitored in the Italian case study buildings. Therefore, the total energy consumption of the settlement is calculated when considering the energy consumption for lighting of the calibrated buildings model.

[3]Emission factors: Covenant of Mayors https://www.eumayors.eu/IMG/pdf/technical_annex_en.pdf

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[4]Electricity price updated for 2017: https://www.statista.com/statistics/881421/household-electricity-price-in-italy/

The following tables present the cost breakdown difference between the ZERO-PLUS technologies and the typical Net Zero Energy Building. These figures were used to calculate the cost reductionreported in section 5.1.

Table 38: The investment cost for the ZERO-PLUS technologies in Italy

Technology*	Provider	Unit	Number of Units	Cost per Unit (€)	Total Investment Cost (€)
Advanced Envelope Components	FIBRAN	Surface area of pitched roof (m^2)	375	24.48	9180
	FIBRAN	Surface area of external walls (m^2)	236.03	56.67	13,384.14
	FIBRAN	Surface area of floor (m^2)	258.91	22	5696.02
	Stiferite	Surface area (m^2)	930	9.68	9000
	Thermo-bonder polyester fiber	Surface area (m^2)	1860	12.9	24,000.00
	Cool plaster	Surface area of external walls (m^2)	173.55	27	4685.85
BEMS	ABB HEMS and Load Control	Module	2	1850	3700
Advanced HVAC	Heat Pump and mechanical ventilation	Module	2	21,800.00	43,600.00
	Underfloor heating	Module	2	20,000.00	40,000.00
Energy Production Technologies	PV panels	kWp	12	2000	24,000.00
	ABB React	Module	2	8500	17,000.00
Total Cost (€)					**194246.01**

Table 39: The investment cost for a typical NZEB in Italy

Technology	Unit	Number of Units	Cost per Unit (€)	Total Investment Cost (€)
Thermal insulation	Surface area of pitched roof (m^2)	418.38	76,74	32,106.48
Wall system finishing + insulation panel	Surface area of external walls (m^2)	413.03	63.96	26,417.40
Advanced HVAC	Module	2	22,000.00	44,000.00
PV	kWp	25	2,000.00	50,000.00
Thermal panels	m2	8	750	6000
Storage	Module	2	7245	14,490.00
Electrical plant	Module	2	28,500.00	67,000.00
Total Cost (€)				**240,013.88**

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5.2.3 UK case study

The following tables present the energy related impacts for the UK case study. The actual energy conservation, carbon emissions reduction and cost savings are greater than the as-built condition.

Table 40: Summary of energy conservation and cost savings from the ZERO-PLUS technologies in the UK

<table>
<tr><th>Total Area of demonstration (m2)</th><th>Energy Consumption for the Reference Settlement [1] (kWh)</th><th>Energy Consumption of the ZERO-PLUS Settlement (kWh)</th><th>Energy Conservation on yearly basis (kWh)</th><th>Carbon Emissions[3] Reduction (tonnes)</th><th>Energy Cost[4] Savings using</th><th>Type</th></tr>
<tr><td rowspan="2">298.4</td><td rowspan="2">43,602
PE: 53,504][2]</td><td>11,300
[PE: 17,372]</td><td>32,302
[PE: 36,132]</td><td>8.9</td><td>€ 2,274.68</td><td>As-built</td></tr>
<tr><td>7,250
[PE: 11,510]</td><td>36,352
[PE: 41,994]</td><td>9.7</td><td>€ 2,455.91</td><td>Actual</td></tr>
</table>

[1]Reference building energy: The reference buildings are the three ZP dwellings modelled in form but simulated to the basic standards of what would be required for a dwelling to pass UK Building Regulations.

https://www.gov.uk/government/publications/conservation-of-fuel-and-power-approved-document-l

[2]Primary Energy (PE) factors: mains gas / gas from heat network: 1.13; grid electricity (also PV consumed): 1.5; PV exported 0.5 (https://www.bregroup.com/wp-content/uploads/2019/11/SAP-10.1-08-11-2019_1.pdf)

[3]Carbon factors: gas: 0.21 tn/MWh; electricity: 0.316 tn/MWh (https://www.bregroup.com/wp-content/uploads/2019/11/SAP-10.1-08-11-2019_1.pdf)

[4]Cost factors: gas: €0.04; electricity: €0.17; median PV export discount: €0.04 (https://www.uswitch.com/gas-electricity/); exchange rate £1 = €1.12

The following tables present the cost breakdown difference between the ZERO-PLUS technologies and the typical Net Zero Energy Building. These figures were used to calculate the cost reductionreported in section 5.1.

Table 41: The investment cost for the ZERO-PLUS technologies in the UK

Technology*	Provider	Unit	Number of Units	Cost per Unit (€)	Total Investment Cost (€)
Photovoltaics	Carbon Legacy	kWp	16	1,442.84	23,085.44
Batteries	Carbon Legacy	Tesla PowerWall II 13.5kWh Battery Storage System	3	7332.26	21,996.78
Hive home energy management	British Gas	Hive smart home system	3	763.45	2,290.34
Total Cost (€)					**47,372.56**

Table 42: The investment cost for a typical NZEB in UK

Technology	Unit	Number of Units	Cost per Unit (€)	Total Investment Cost (€)
Photovoltaics	kWp	5.79	1,375.67	7,965.15
Batteries	Tesla PowerWall II 13.5kWh Battery Storage System	1	7332.26	7,332.26
Hive home energy management	Hive smart home system	1	763.45	763.45
Total Cost (€)				**16,060.86**

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5.2.4 Cypriot case study

Based on the energy, emission and cost analyses reported in section 5.1.1, the overall performance metrics regarding the entire (theoretical) Cypriot case study constituted by two ZERO-PLUS demohouses and two FAE HCPV/T is summarized (Table 43).

Table 43: Summary of energy conservation and cost savings from the ZERO-PLUS technologies in Cyprus

Total Area of demonstration (m2)	Energy Consumption for the Reference Settlement(kWh)	Energy Consumption of the ZERO-PLUS Settlement (kWh)	Energy Conservation on yearly basis (kWh)	Carbon Emissions Reduction using 0.874tn/GWh for CY (tonnes)	Energy Cost Savings using €0.3/kWh for CY	Type
260	19,698 [PE: 36,422]	13,976 [PE: 21,500]	5,720 [PE: 14,920]	4.36	1,681.40	**As-built**
N/A	N/A	N/A	N/A	N/A	N/A	**Actual**

The following tables present the cost breakdown difference between the ZERO-PLUS technologies and the typical Net Zero Energy Building. These figures were used to calculate the cost reduction reported in section 5.1.

Table 44: The investment cost for the ZERO-PLUS technologies in Cyprus

Technology	Provider	Unit	Number of Units	Total Investment Cost (€)
Advanced Envelope Components	FIBRAN	XPS (8cm thickness for external roof)	96.4 m2 of external roof	994.89
	FIBRAN	XPS (4cm thickness for external walls)	75 m2 of external walls	426.75
	FIBRAN	Cool plaster system without XPS	75 m2 of external walls	2,091.28
HVAC	ARCA	HVAC freescoo	1 module	7,500.00 (+7,500.00 for 5 HVAC units)
Energy Production Technologies	ARCA	FAE HCPV/T	2 modules	11,000.00
Total Cost (€)				**29,512.92**

* installation costs excluded

Table 45: The investment cost for a typical NZEB in Cyprus

Technology	Unit	Number of Units	Total Investment Cost (€)
Insulation	m2	171.4	4,555
Total Solution VRV System, hydromodule / hydrobox	Modules	6 built-in unitary split ac units, heat pump version for heating and cooling	31,155
PV	kWp	43223,00	8,235
Solar panels	m2	4	3,6
Total Cost (€)			**47,545**

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5.3 Energy consumption patterns during the lockdown for COVID-19 pandemic

The monitoring period of ZERO-PLUS included the first COVID-19 outbreak. Despite the challenges, the monitoring activities continued to run, to the extent possible, namely continuous monitoring data (objective data) and Post Occupancy Evaluation (POE) surveys and interviews (subjective data).

Due to the rapid spread of the COVID-19 pandemic, a series of unprecedented measures were defined at the national level to limit people's infection. Country-specific lockdown measures were put in place affecting the economy, social interaction, people's mobility, among other aspects of people’s life.

This section analyzes the energy consumption patterns of the demonstration buildings located within the four ZERO-PLUS settlements before, during, and after the COVID-19 pandemic lockdown. The analysis aims to interpret the energy consumption patterns (i.e. regulated energy usage as defined in section 5.1) in each demonstration building taking into account the reality of the lockdown. Differences in the energy consumption patterns may be expected between the pre-lockdown monitored period and the period where the movement of people was limited for the first time in each country in response to the increasing COVID-19 spread.

The following subsections present, for each case study, a brief description of the main characteristics and duration of the lockdown imposed in each respective country and the regulated energy patterns of each demonstration building during the entire monitoring period (ending on the 15/08/2020 in each settlement). The comparison of the energy consumption patterns before, during, and after the imposed lockdown has to take into account also the existing dependency of the regulated energy consumptions on the outside air temperature, to avoid misleading conclusions where a higher/lower energy consumption during the lockdown is attributed exclusively to the fact that the occupants were spending more time at home. This is because the cooler/warmer the outside air temperature, the more energy it is required to heat/cool a building to comfortable indoor air temperatures.

To take into account the regulated energy consumption dependency on the weather conditions, monitored data of energy consumption, indoor air temperature, and outdoor air temperature (recorded by the local weather stations) were plotted and analyzed together. These data were also cross-analyzed with the results of the POE surveys performed along the entire monitoring period (from summer 2019 to summer 2020) to assess the link between the energy consumption patterns and user behavior in the four net-zero energy settlements. In this section, all the final observations and discussion of the results refer to the period before, during, and after the official lockdown in each country.

5.3.1 French case study

The main characteristics of the COVID-19 pandemic lockdown in France are presented as follows:

- **Start date:** 17th of March 2020.

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- **Measures:** national quarantine with restriction in the movement of the population except for necessity, work, and health circumstances. Temporary closure of non-essential shops, schools, universities, and businesses.
- **Duration:** 1 month, 3 weeks, and 3 days [12]
- **End date:** 11th of May 2020 with advice on limiting the movement of the population.

The regulated energy patterns of the demonstration apartments are not available because the smart meters did not work during the lockdown. Their communication cards were defective and it was not possible to replace or repair them before July 2020 because of the limitation imposed by the national lockdown (impossible to send staff to the building because this intervention was not considered urgent and significant). Consequently, only the total consumption of the buildings is available, but without details on the energy profile over time.

Therefore, the present analysis cannot be performed for the French case study.

The POE votes for thermal comfort in the French apartments were observed, even if not in combination with the monitored data to collect information that may inform on changes in the occupant's habits related to the lockdown. The POE surveys were performed in the periods reported in Table 46.

Table 46: Date of the France Case study POE surveys and summary of the observations

Summer 2019	Winter 2020	Spring 2020	Summer 2020
Unoccupied yet. Before COVID-19 lockdown.	11/02/2020 - 20/02/2020 Before COVID-19 lockdown.	07/05/2020 - 15/05/2020 During the lockdown and post-lockdown period	30/06/2020 - 08/07/2020 During the less stringent phase of the COVID-19 lockdown (post-lockdown)
POE Observations associated with the lockdown			
N/A	N/A	N/A The occupants did not make any observations or changes in habits related to the lockdown.	N/A The occupants did not make any observations or changes in habits related to the less stringent phase of the COVID-19 lockdown.

5.3.2 Italian case study

The main characteristics of the COVID-19 pandemic lockdown in Italy are presented as follows:

- **Start date:** 9th of March 2020 (from the 24th of February 2020 the schools were closed and other restrictions were applied in Emilia-Romagna, which is among the most affected regions in Italy).
- **Measures:** national quarantine with restriction in the movement of the population outside the residence municipality, except for necessity, work, and health circumstances. Temporary closure of non-essential shops, schools, universities, and businesses.
- **Duration:** 2 months, 1 week, and 2 days [13]

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- **End date:** 3rd of May 2020 with advice on limiting the movement of the population. From the 18th of May 2020 non-essential shops were re-opened and from the 3rd of June 2020 was allowed the free movement throughout the national territory with movement limits only in and out to certain foreign countries.

The period after the lockdown is characterized by a general slow return to normality since still limited cases of COVID-19 exist and people do not feel totally safe.

The period of investigation for the regulated energy use patterns started on the 9th of June 2019 and terminated on the 15th of August 2020, including the COVID-19 pandemic lockdown. However, the hourly DHW monitoring is available only for the months of July and August 2020, while it is available monthly for the rest of the monitoring period. Therefore, for consistency in the whole analyzed period, only HVAC consumption is considered in this analysis (i.e. energy consumption of heating, cooling, fans, pumps, and ventilation).

The HVAC energy use (i.e. Regulated Energy consumption - DHW) patterns for the two Italian demonstration buildings, i.e. IT1 and IT2, and the outdoor and indoor air temperature profiles for the entire monitoring period (from the 9th of June 2019 to the 15th of August 2020) are shown in Figure 46 and Figure 47, respectively. The two graphs show the absolute values with a frequency of 15 minutes as recorded by the monitoring system. The black profile is associated with data collected before the lockdown period (pre-lockdown), while the red profile and the green profiles refer to the period during and after the lockdown (post-lockdown), respectively.

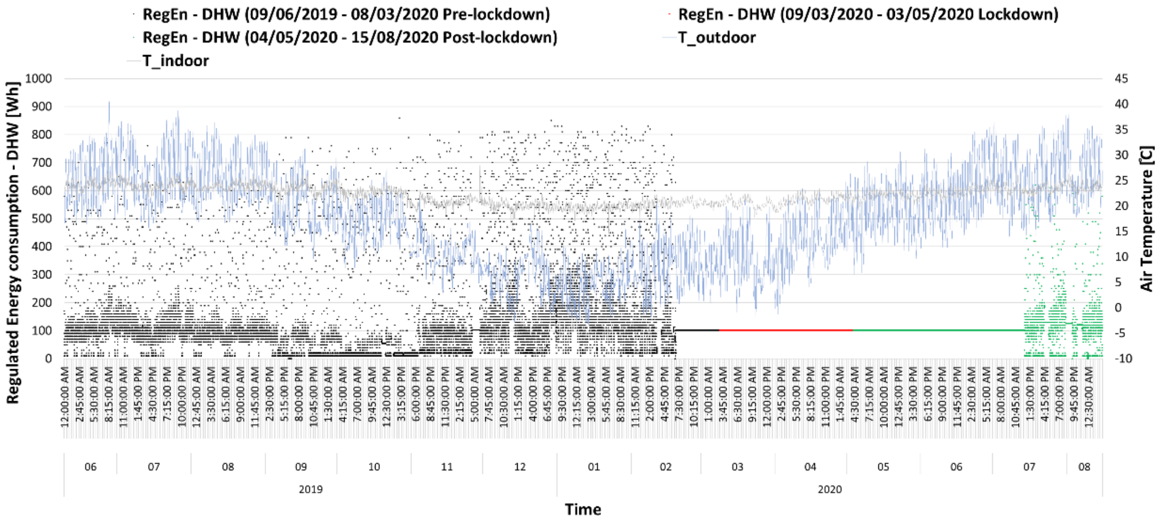

Figure 46: HVAC energy use (Regulated Energy consumption – DHW) vs outdoor (blue) and indoor (grey) air temperature profiles for IT1 (09/06/2019 - 15/08/2020) before (black), during (red), and after (green) the national lockdown

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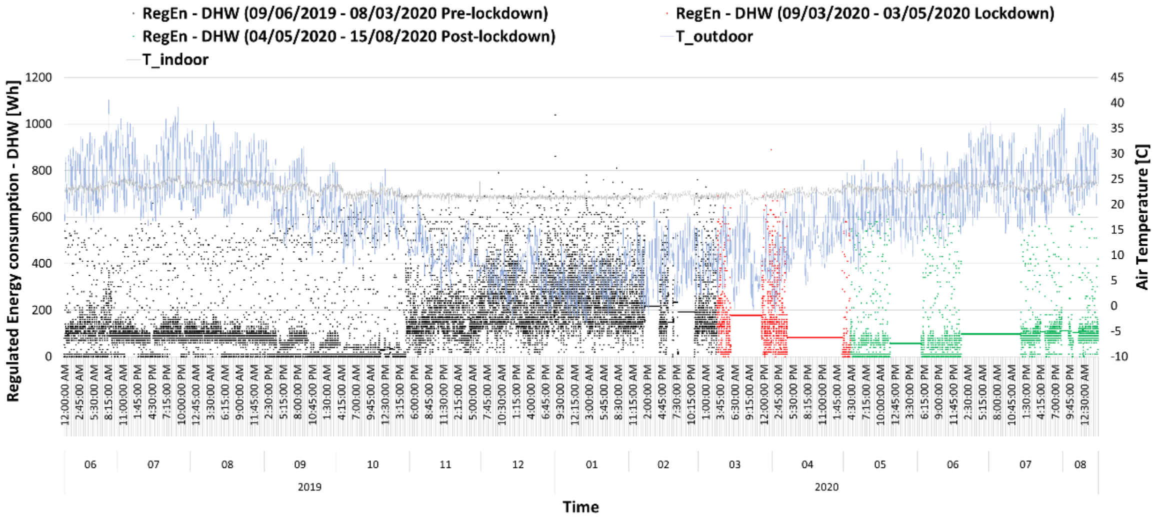

Figure 47: HVAC energy use (Regulated Energy consumption – DHW) vs outdoor (blue) and indoor (grey) air temperature profiles for IT2 (09/06/2019 - 15/08/2020) before (black), during (red), and after (green) the national lockdown

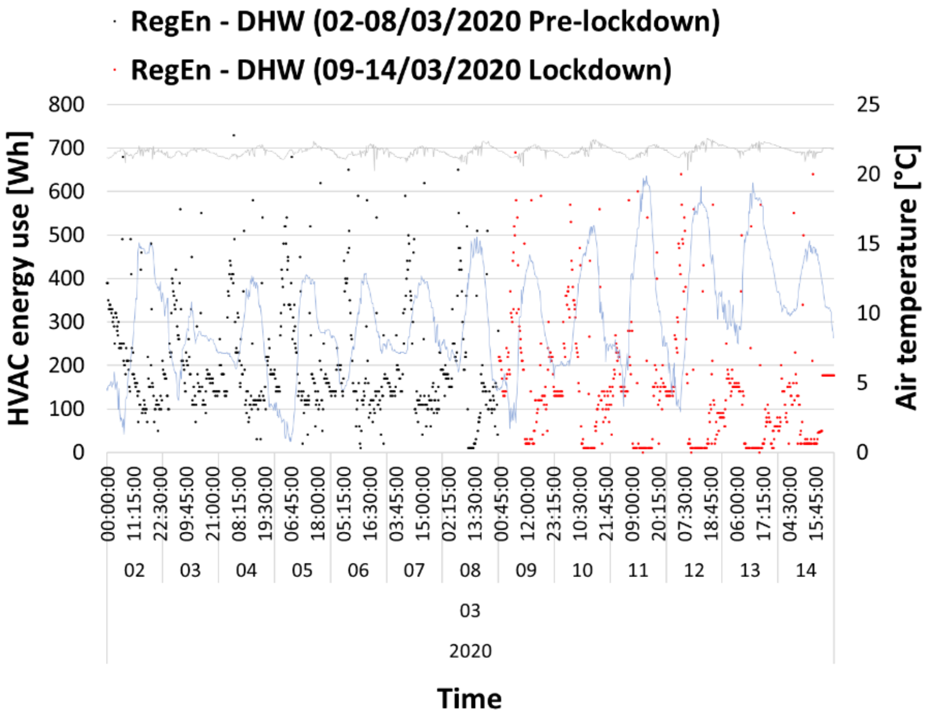

Figure 48: HVAC energy use vs outdoor (blue) and indoor (grey) air temperature profiles for IT2 for two consecutive weeks (02-14/03/2020) before (black) and during (red) the national lockdown

Due to monitoring equipment complications and the impossibility to solve them during the most stringent phase of the COVID-19 lockdown, continuously monitored data of energy use for IT1 are not available during the lockdown period, as depicted in Figure 46. Therefore, this analysis cannot be performed for building IT1. On the other hand, the trend of HVAC energy consumption in IT2 (Figure 47) shows that within similar external thermal boundary conditions the HVAC energy use is negligibly increased during the lockdown period. On the contrary, the energy need is significantly reduced after the lockdown. However, this reduction seems to be

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associated with the improvement of the weather conditions in the mid-season month after the lockdown, i.e. May. More in detail, Figure 48 reports selected days before and during the lockdown period, i.e. from March 2nd to 14th, 2020, characterized by similar outdoor thermal boundaries. This insight analysis confirms what previously observed: the HVAC energy use during the lockdown, i.e. when occupants were obliged to be all day long at home, is similar to the trend before the lockdown. The energy consumption appears to be even lower in the selected lockdown week. Nevertheless, this small reduction is most probably associated with a slight increase in outdoor dry-bulb temperature during the second analysed week. It has to be noted that, this result may also be attributed to the fact that in Emilia-Romagna some restrictions started already at the end of February 2020 and that IT2 hosts a 2-person family that used to spend most of their time at home even before the two analysed consecutive weeks.

The POE votes for thermal comfort in the two Italian buildings were observed in combination with the above discussed monitored data. The POE surveys were performed in the periods reported in Table 47 that summarizes some observations associated with the lockdown period.

Table 47: Date of the Italian Case study POE surveys and summary of the observations

Summer 2019	Winter 2020	Spring 2020	Summer 2020
23/07/2019 Before COVID-19 lockdown.	15/02/2020 Before COVID-19 lockdown.	N/A – Postponed due to monitoring equipment complications and the impossibility to solve them during the most stringent phase of the COVID-19 lockdown.	15/07/2020 After the most stringent phase of the COVID-19 lockdown, but still under after-lockdown restrictions.
POE Observations associated with the lockdown			
The first POE was carried out in person in the two buildings: IT1 hosts a 4-person family. However, only the two adults took part in the POE survey; IT2 hosts a 2-person family and both took part in the POE survey.	Similarly, the second POE was carried out in person in the two buildings. Again, in IT1 only two persons of four took part in the POE survey, and in IT2 both the occupants took part in the POE survey.	N/A	Although this POE was carried out after the lockdown, it was decided to perform an online survey in order to limit travels and contacts with a non-familiar person, as requested by the occupants and according to the guidelines post-lockdown.

According to what was observed during the POE, it is expected that the Regulated energy use was affected by the pandemic lockdown restrictions for what concerns especially IT1. In fact, most of the IT1 occupants were usually out of the house during daytime which has changed during quarantine. On the contrary, little changes for the occupants of IT2 were recorded.

5.3.3 UK case study

The main characteristics of the COVID-19 pandemic lockdown in the UK are presented as follows:

- **Start date:** 23rd of March 2020.

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- **Measures:** National quarantine with restriction in the movement of the population except for necessity, work in essential establishments (e.g. supermarkets, hardware stores, launderettes, post office, bank, etc.), and health circumstances. Ordered not to visit friends and family in their homes; allowed to take one form of exercise per day. Temporary closure of non-essential shops, schools, universities, and businesses.
- **Duration:** 1 month, 2 weeks, and 6 days for the more stringent lockdown, even if the country was operating in a form of lockdown for the entire investigated period (e.g., until the 15th of August 2020) [14].
- **End date:** Complete end to be determined. On the 13th of May 2020, some restrictions on who could go to work were eased, as well as the ability to meet someone else from a different household outside. On the 15th of June 2020, "non-essential retail" businesses started to re-open, while on the 4th of July 2020 it was the turn to reopen some of the hospitality industry and other public places. Re-opening of non-essential businesses involved with close contact (e.g., nail, hair salons) began on the 13th of July 2020. It is not illegal for larger gatherings of up to 30 people to take place – although it is still advised that a maximum of six people meet outdoors and only two households indoors. There are legal exemptions for pubs and restaurants where the number of people may rise above 30.

In September, the country and local measures started to tighten up again in light of the expected increases in cases in autumn and winter.

The period of investigation for the regulated energy use patterns started on the 1st of November 2019 and terminated on the 15th of August 2020, including the COVID-19 pandemic lockdown. However, in UK1, the space heating data were unavailable, and therefore only the energy consumption associated with fans, pump, ventilation, and DHW is considered in this analysis (e.g., Regulated Energy consumption – Heating) for UK1. UK2 and UK3 include instead the space heating data. UK2 was not occupied until the end of January 2020 and for this reason, the regulated energy consumption was analyzed starting on the 1st of February 2020.

The Regulated energy use patterns for the three English demonstration ZERO-PLUS buildings, i.e. UK1, UK2, and UK3, and the outdoor and indoor air temperature profiles for the respective entire monitoring periods are shown in Figure 49, Figure 50 and Figure 51, respectively. The three graphs show the absolute values with a frequency of 1 hour as recorded by the monitoring system. The black profile is associated with data collected before the lockdown period (pre-lockdown), while the red profile and the green profiles refer to the period during and after the most stringent period of lockdown (post-lockdown), respectively. In this analysis, the 31st of May 2020 was considered as the end date of the more stringent phase of the lockdown.

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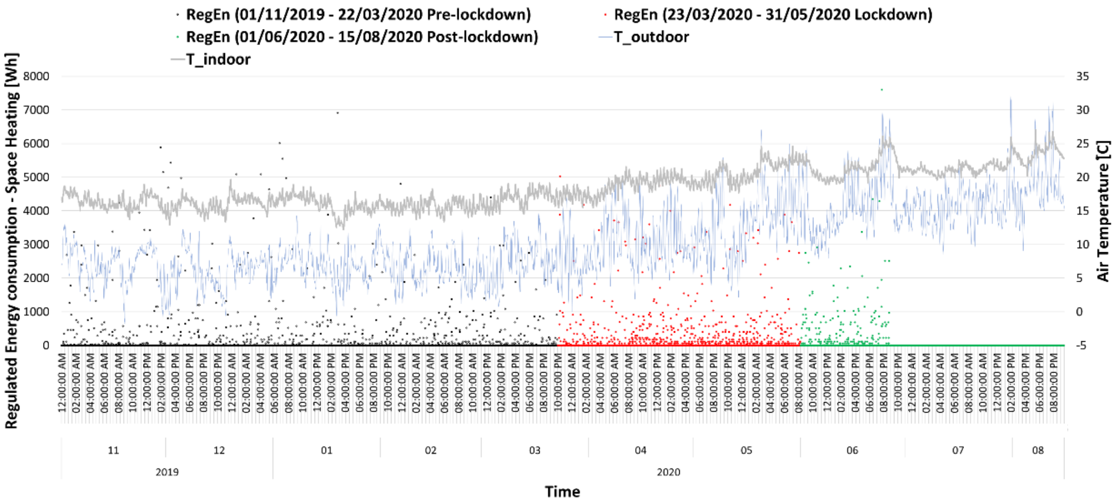

Figure 49: Regulated Energy consumption – space heating vs outdoor (blue) and indoor (grey) air temperature profiles for UK1 dwelling (01/11/2019 - 15/08/2020) before (black), during (red), after (green) the national lockdown

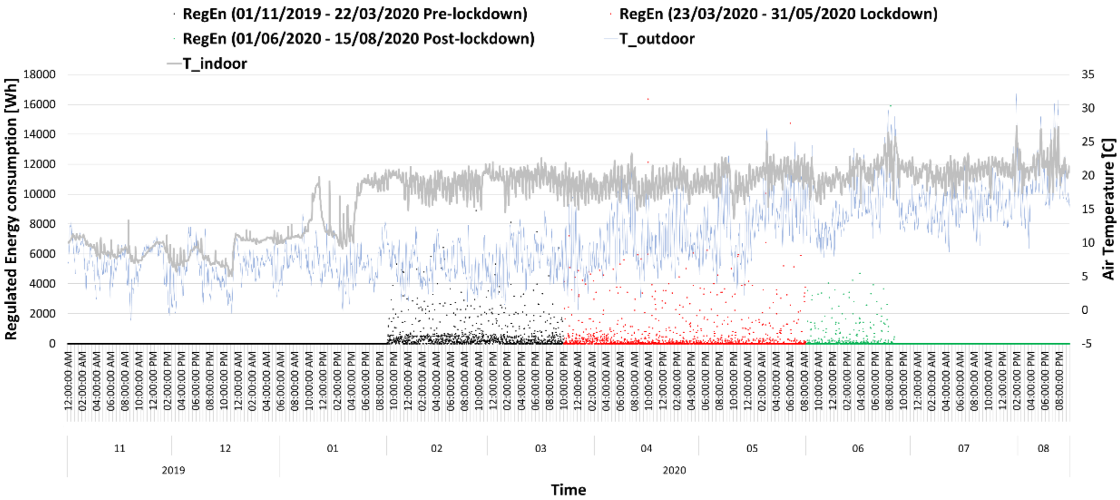

Figure 50: Regulated Energy consumption vs outdoor (blue) and indoor (grey) air temperature profiles for UK2 dwelling (01/11/2019 - 15/08/2020) before (black), during (red), after (green) the national lockdown

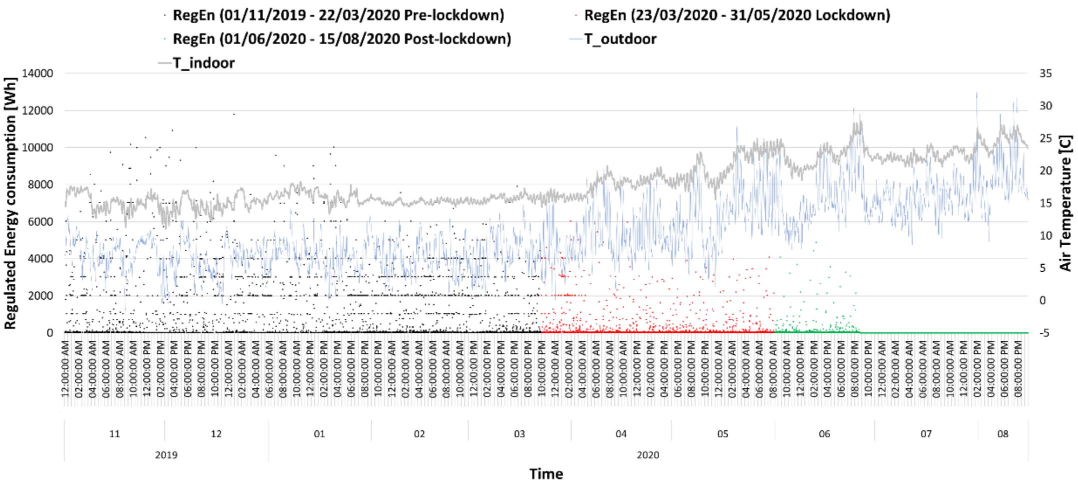

Figure 51: Regulated Energy consumption vs outdoor (blue) and indoor (grey) air temperature profiles for UK3 dwelling (01/11/2019 - 15/08/2020) before (black), during (red), after (green) the national lockdown

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In UK1 it appears that there is a slight shift upwards during the lockdown for what concerns the energy consumed for fans, pump, ventilation, and DHW. UK2 and UK3 appear to show a small jump during lockdown but appear to level out as seasonal temperatures get warmer.

Overall, looking at the total house electricity consumption (HEC), there is an increase in electricity consumption across all dwellings from the COVID-19 pre-lockdown (01/02/2020 – 22/03/2020) to during lockdown (23/03/2020 – 31/05/2020).

The following paragraphs present the investigation of the overall daily electricity use, changes to peak demand, detailing of end-uses to investigate the above changes further, and finally space heating.

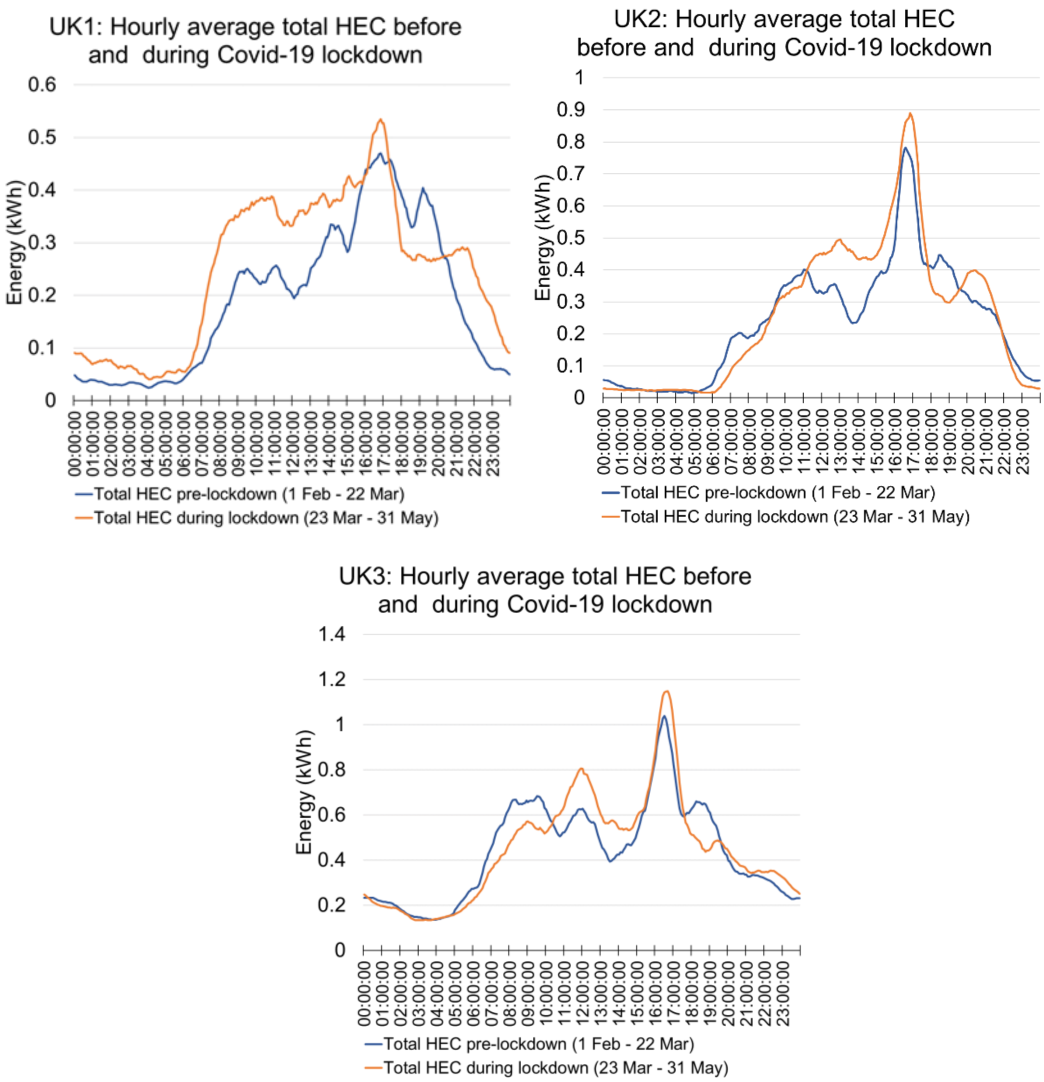

Figure 52: Hourly electricity consumption (HEC) contrast before (blue) and during (orange) COVID-19 lockdown for the three dwellings UK1, UK2, and UK3

UK1 increased total daily HEC by 30%, UK2 increased by 9%, and UK3 increased by only 2%. Figure 52 contrasts the shift in average hourly total HEC for each period in the dwellings. In UK1 the increase is notable, where there is more energy consumption in the morning to afternoon and a sharper peak at peak demand times.

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ZP2 also had a higher late morning/noon peak consumption and a higher peak demand. ZP3 also had a sharper peak during peak demand but no other significant change overall. Though during the initial questionnaire assessment, both UK1 and UK3 stated that they are 'home all the time' it is expected that the occupants in UK1, in reality, before the lockdown left the house more often to visit friends or relatives albeit possibly not on a regular schedule.

Looking deeper at electricity use in the dwellings, electricity consumption for fans and lighting (sub-metered) were removed from the total electricity use to isolate all remaining uses, called 'appliances' here. The hypothesis is that this 'appliance' consumption should increase as occupants are stuck at home in lockdown; however, this increase is not expected to be overly large, but noticeable. This is because most of the extra use is expected to be in low power devices like televisions, computers, and potentially more significant cooking. Though lighting consumption could also increase, it is best removed as the lockdown period progressed through days which are increasing in daylight hours.Figure 53, Figure 54 and Figure 55 show the fan, lighting, and appliance energy consumption pre-lockdown and during lockdown for UK1, UK2, and UK3, respectively. The only dwelling showing a notable impact of lockdown in appliance use is UK1, where a slight downward trend before lockdown becomes a significant upward trend. UK2 and UK3 demonstrated downward trends in consumption during lockdown; however, in UK2 this is barely noticeable and is a little higher than pre-lockdown, and in UK3 the downward trend also appeared to be slowing during the lockdown.

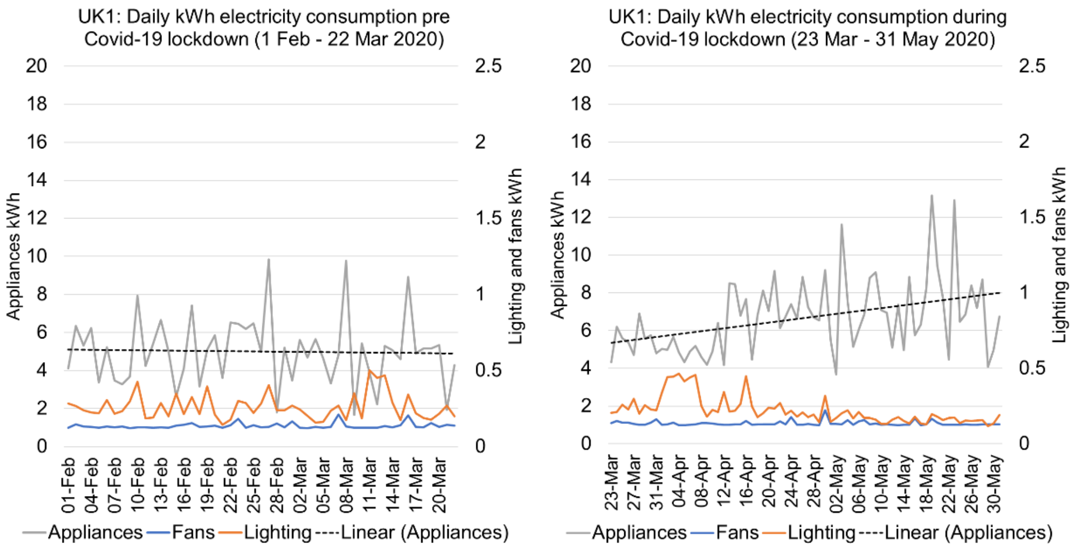

Figure 53: Sub-metered electricity use (pre- left, during lockdown right) for UK1 dwelling

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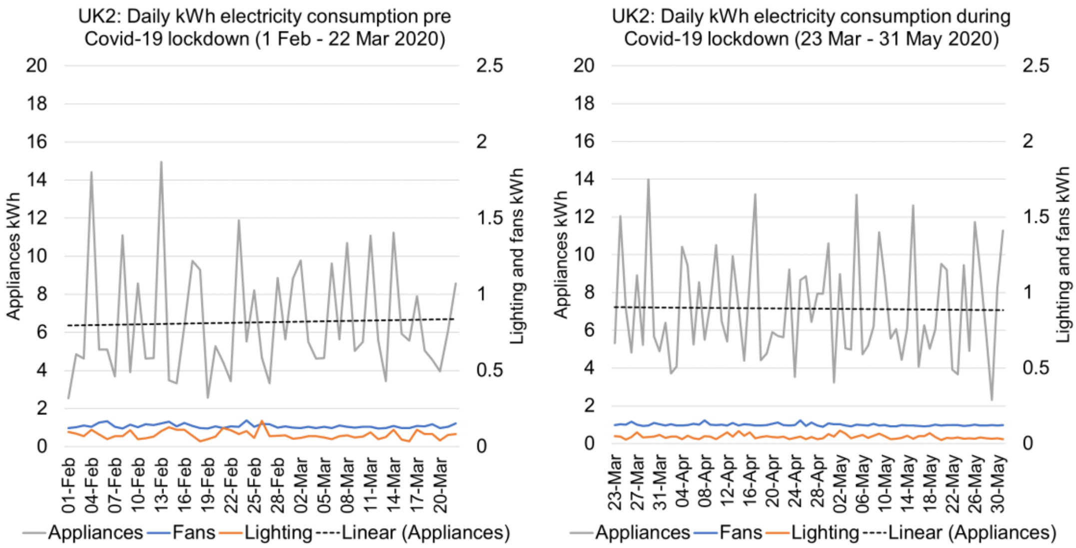

Figure 54: Sub-metered electricity use (pre- left, during lockdown right) for UK2 dwelling

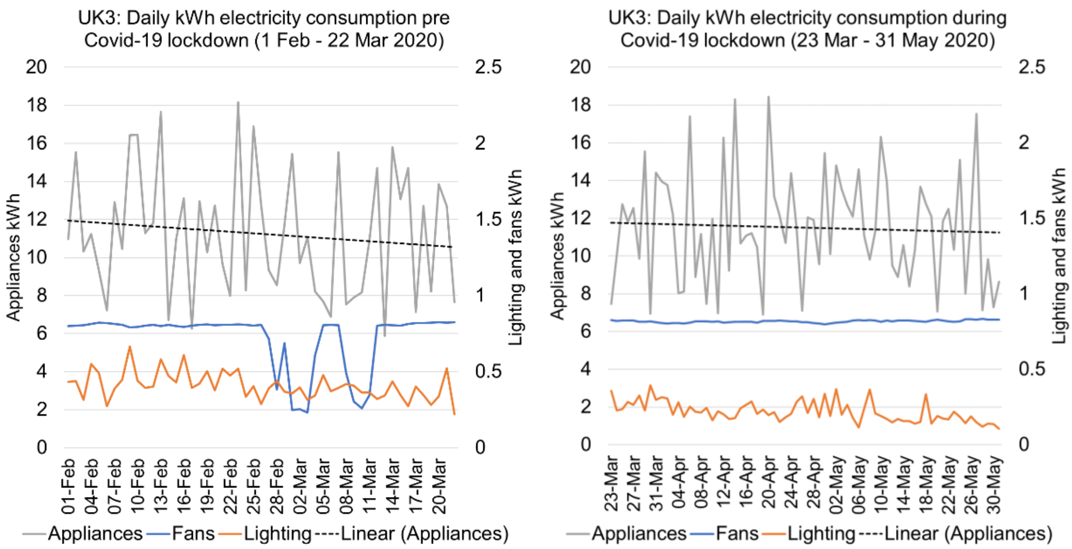

Figure 55: Sub-metered electricity use (pre- left, during lockdown right) for UK3 dwelling

The normalisation of space heating is another way to observe the impact of lockdown on energy consumption; however, a limitation of this method is that lockdown has occurred as the heating season was ending. For this reason, correlation with heating degree days (HDD) is used to assess impact. Figure 56 shows UK2 and UK3 daily total space heating as it correlates to the daily HDD for the same period. One aspect to note immediately is that the correlation between space heating and HDD is much weaker during lockdown as opposed to before. This, however, could just be an aspect of the end of the heating season and not necessarily an increase of user heating.

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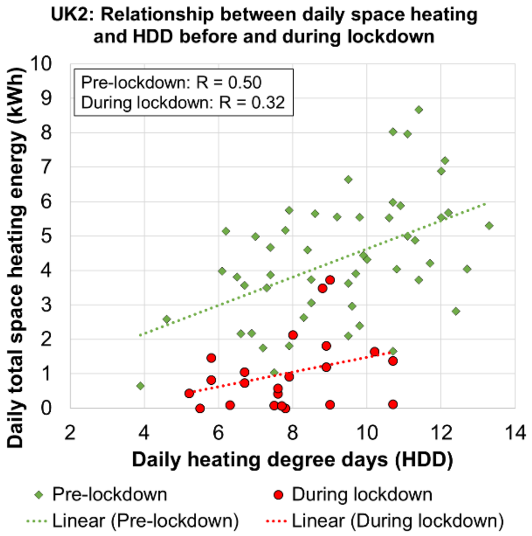

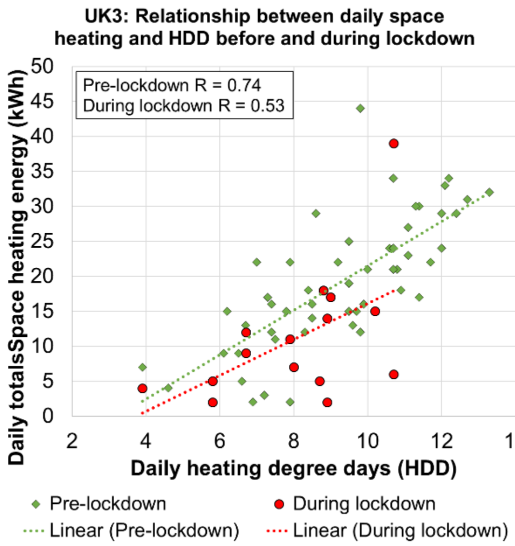

Figure 56: Correlation between space heating and HDD pre- (green) and during (red) COVID-19 lockdown for UK2 (left) and UK3 (right)

In theory, if there is more use of heating as a result of being at home more, the proportion of total heating consumption above the best fit line will be higher during the lockdown. Both dwellings are showing a small increase in the proportion of total heating above the best fit line during lockdown (from 63% to 65% in UK2 and from 61% to 62% in UK3). This slight increase is, however, not considered high enough to suggest that there is a significant increase in heating in these dwellings as a result of lockdown. As it is the end of the heating season the number of instances assessed was limited.

Furthermore, the POE votes for thermal comfort in the UK buildings were observed in combination with the discussed monitored data. The POE surveys were performed in the periods reported in Table 48.

Table 48: Date of the UK Case study POE surveys and summary of the observations

Summer 2019	Winter 2020	Spring 2020	Summer 2020
Unoccupied yet. Before COVID-19 lockdown.	18/02/2020 Before COVID-19 lockdown.	29/05/2020 – 05/06/2020 After the first phase of relaxing COVID-19 lockdown.	30/07/2020 During the less stringent phase of the COVID-19 lockdown.
POE Observations associated with the lockdown			
N/A	The first POE was carried out in the three dwellings and 4 responses were obtained. - Temperature: "good" - Noise/lighting: "good–very good" - Ventilation: "very good" Most occupying the dwellings 24 hours a day.	Only 2 responses were obtained. - Temperature: "good" - Noise/lighting: "good – very good" - Ventilation: "no response" Most occupying the dwellings 24 hours a day (no behavioural change during and after the lockdown).	4 responses were obtained. - Temperature: "good – very good" - Noise / lighting: "very good" - Ventilation: "no response" Most occupying the dwellings 24 hours a day (no behavioural change during and after the lockdown).

According to what was observed during the POE, it is expected that the regulated energy use was limitedly affected by the pandemic lockdown restrictions given the

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fact that most occupants in the three dwellings use to stay at home most of the time, regardless of the occurrence of the lockdown.

5.3.4 Cypriot case study

As a consequence of the COVID-19 pandemic, the Cypriot Ministry of Health issued first some preventive measures in March, while a strict lockdown, including a work-from-home policy, was effectuated on March 16, 2020 [15].

The implemented measures were similar to other European countries: quarantine with restriction in the movement of the population except for necessity, work, and health circumstances. Temporary closure of non-essential shops, schools, universities, and businesses, personal protective devices. Accordingly, nobody could access the Air Quality Observatory after the 16th of March 2020 until the 21st of May 2020, when slowly some measures were released.

Therefore, no energy consumption due to user presence was recorded during the lockdown period and the present analysis cannot be performed for the Cypriot case study.

The POE votes for thermal comfort in the Cyprus building were observed in combination with the monitored data. The POE surveys were performed in the periods reported in Table 49.

Table 49: Date of the Cypriot Case study POE surveys and summary of the observations

Summer 2019	Winter 2020	Spring 2020	Summer 2020
Unoccupied yet. Before COVID-19 lockdown.	28/02 Before COVID-19 lockdown.	29/04/2020 – 04/05/2020 – 11-19/05/2020 – 06/06/2020 – 12-18/06/2020 During the stringent and less stringent phase of the COVID-19 lockdown.	07-15/07/2020 During the less stringent phase of the COVID-19 lockdown.
POE Observations associated with the lockdown			
N/A	N/A	N/A No occupants were continuously using the building and therefore no changes in habits related to the lockdown could be recorded.	N/A No occupants were continuously using the building and therefore no changes in habits related to the post-lockdown could be recorded.

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6. Transition from building level to settlement level

"*Greater energy efficiency can only be achieved through a transition from single NZE buildings to NZE settlements, in which the energy loads and resources are optimally managed*." – Objective 3 of the ZERO-PLUS project

Transition from building level to settlement level is modelled to observe the energy balance that could be achieved through such an arrangement.

6.1 Methodology

The demand for energy in households can fluctuate over the course of the day with peaks at different times of the day determined by household activities. When aggregated over a community, the peaks can smoothen out indicating the true energy demand for a community. This aggregation assessment can be done for the year and or seasonally to identify which season has higher demand.

In reality, no case study implemented an aggregation of energy consumption which was met directly by aggregated renewable generation and optimized storage. For this reason, calculations / simulations were used by each case study to observe an optimally managed system. The transition from building level to settlement was simulated by modelling an energy management system that in each case will take full advantage of the renewable energy production of the installed technologies against the existing energy consumption patterns of the dwellings.

6.2 French Case study

6.2.1 Current design conditions

As Alpes Isère Habitat is not a licensed energy supplier, they are forbidden to supply the tenants with electricity. The electricity produced by the PV is exported to the grid, sold in full, and the income generated is pooled with all the electricity production of AIH's real estate assets. Then these revenues are used to improve all buildings in AIH's real estate assets, whether they are equipped with photovoltaic panels or not. This is the principle of equity between social tenants, whether their home is efficient and recent or not.

6.2.2 Modeling of self-consumption at the building level

We modelled the consumption of electricity produced at the building level. Consumption in the individual flats was not monitored during the project; therefore, the theoretical case of using the generated electricity to meet the needs of the flats could not be projected.

Unable to sell this energy to the occupants, only common uses were considered (lighting of common areas, elevator, automatic doors, pumps, ventilation, etc.).

The month of April was considered, as it represents an average between summer and winter.

During the day, energy production is much greater than needs. In a single day, only 13% of the energy produced is consumed for self-consumption (8.2kWh) and 87% is

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sold on the national grid (53kWh). However, over a day, PV energy only meets 44% of needs, requiring the injection of 10.4kWh from the grid.

Thus, the installation of batteries allowing to store approximately this capacity would allow the autonomy of the building for common uses over half of the year.

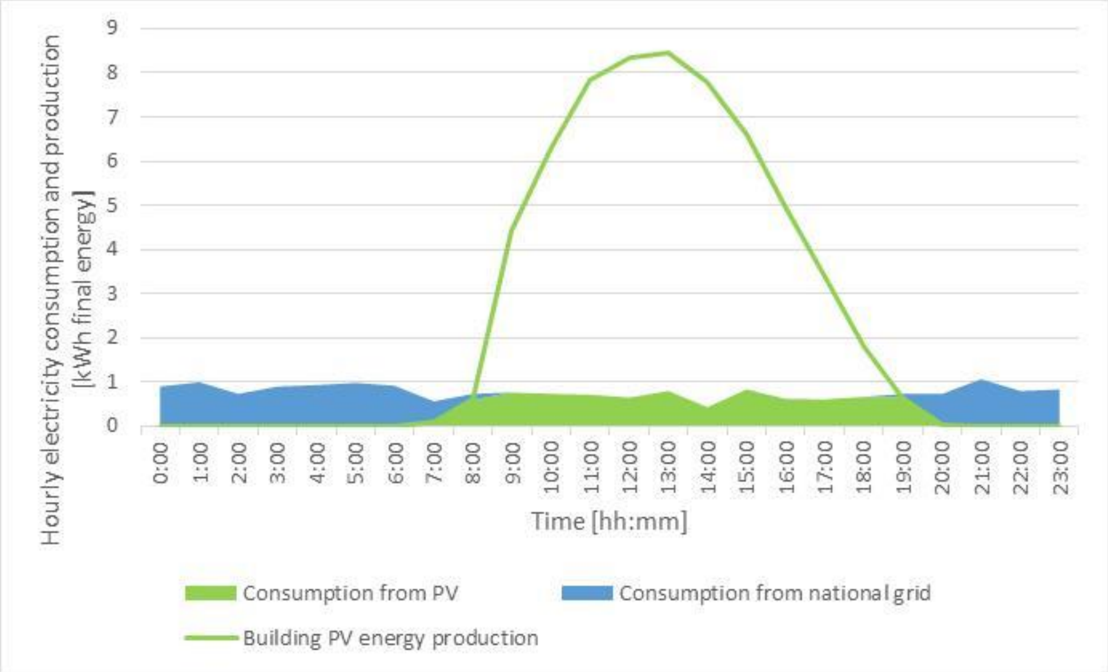

Figure 57: Total hourly consumption of common equipment in the building averaged over the month of April 2020 (kWh Final Energy) in France

6.3 Italian Case study

6.3.1 Current design conditions

PV panels are installed at settlement level in equal size for both villas and energy storage to be used for common use in the outdoor areas. The energy produced by the PV at settlement level is used for common purpose, stored in the batteries, and sent to the national grid when produced in excess.

6.3.2 Transition to settlement level

The monitored actual energy performance of the two buildings in the settlement for the months of August 2019 (Figure 58) and January 2020 (Figure 59), i.e. representative of summer and winter, respectively, is considered for this analysis. Since the actual energy consumption for lighting is not monitored in the Italian case study buildings, the total energy consumption of the settlement is calculated when considering the energy consumption for lighting of the calibrated buildings model.

The total hourly energy consumption and production of the two dwellings in the settlement averaged over the summer representative month, i.e. August 2019, show that a large amount of renewable energy is generated during the central hours of the day but only partially directly self-consumed by the two buildings. A shared energy storage battery would allow increasing the settlement self-consumption. On the other hand, the total hourly energy consumption and production of the two dwellings in the

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settlement averaged over the winter representative month, i.e. January 2020, show that renewable energy produced by the PV panels in winter is much lower than in summer and mostly used for direct self-consumption. Accordingly, a settlement shared seasonal energy storage system could further allow using part of the solar energy produced during the warm season, when solar potential is mostly available, in the cold season, when energy is still mostly needed.

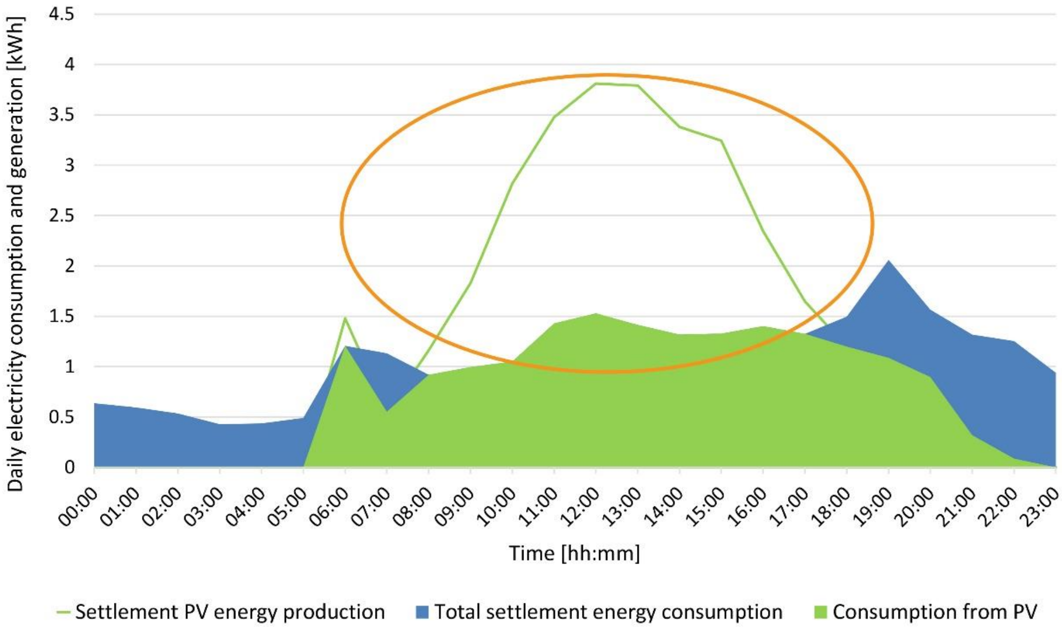

Figure 58: Total hourly energy consumption of dwellings in the settlement averaged over the month of August 2019 in Italy

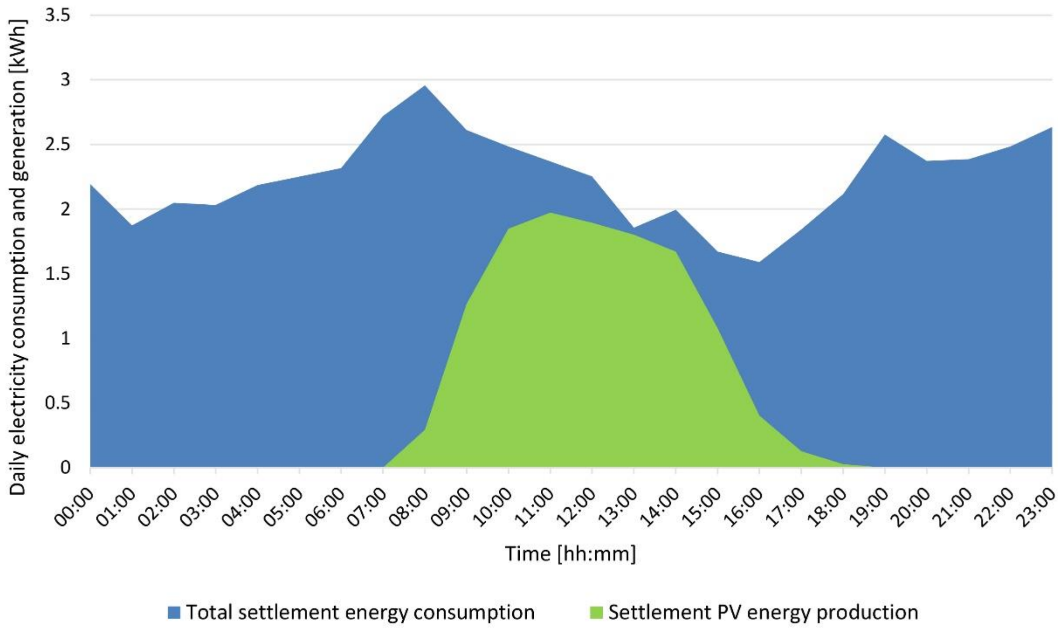

Figure 59: Total hourly energy consumption of dwellings in the settlement averaged over the month of January 2020 in Italy

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6.4 UK case study

6.4.1 Current arrangement and explored options

When photovoltaics as a generation solution were selected, the first settlement level solution was to install these on the roof of the energy centre of the development and feed into the dwellings directly. Batteries would also be installed in the energy centre and serve the dwellings on aggregate. The greatest weakness in this design, which ultimately caused the solution to be impracticable, was that the roof of the energy centre could not structurally hold the 56 panels that were required to meet the ZERO-PLUS KPI. Altering the structure of the roof to support the array would have caused the ZERO-PLUS settlement cost-savings KPI to fail.

Problem two was with the energy storage solution: As part of the design feasibility, the option of energy management and storage at a settlement level was explored. To enable this, it would require a private wire connection from the settlement generation to the dwelling level storage. This was neither technically nor financially feasible.

Problem three was with micro grid control: The electricity Distribution Network Operator (DNO) and governing body OFGEM have strict regulations about the operation and management of the electricity grid. With the separation of electricity generation at settlement level and energy storage/consumption at dwelling level the implications of energy management and load control were not feasible in the UK case study. As part of OFGEM requirements for large scale energy generation grid approval was required from the DNO to enable electricity to be exported to the grid. The cost of this was the standard 250GBP.

In contrast, the typical non-ZERO-PLUS, low-energy solution would be to install an equivalent capacity, i.e., enough to generate about 17 kWh of electricity per year per dwelling on the roof of each of the three dwellings.

To achieve a ZERO-PLUS settlement and more efficient solution, the PV was installed across four dwellings (the ZERO-PLUS dwellings and one neighbouring dwelling). This was done so that no PV had to be installed on northeast facing roofs of the dwellings (an inefficient solution). The PV generation is supplied to the dwellings individually, but total generation is netted to the three ZERO-PLUS dwellings to achieve the ZERO-PLUS KPIs. The three ZP dwellings also have batteries to store and displace solar peak energy to peak consumption times. The resulting design allows for separated generation and storage, with a “net” calculation between generation and storage to theoretically balance the system.

6.4.2 Theoretical settlement level solution

To meet the objective to assess the ideal settlement solution, for the UK case, a theoretical case is modelled where the total PV generation is stored in the three batteries and used to offset dwelling peak demand in the three ZP dwellings referred to as the *settlement*. This will help to answer what is the optimal size of the system in the current configuration and demand of the ‘settlement’?

The demand for energy in households can fluctuate over the course of the day, with peaks at different times of the day determined by household activities. When

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aggregated over a community, the peaks can smoothen out indicating the true energy demand for a community. Figure 60 shows the current home electricity consumption (HEC) for the three dwellings. The three dwellings have a peak load between 16:00 – 18:00 which coincides with typical UK peak load. Figure 61 shows the aggregate hourly mean for the settlement. Settlement peak is also between 16:00 – 18:00.

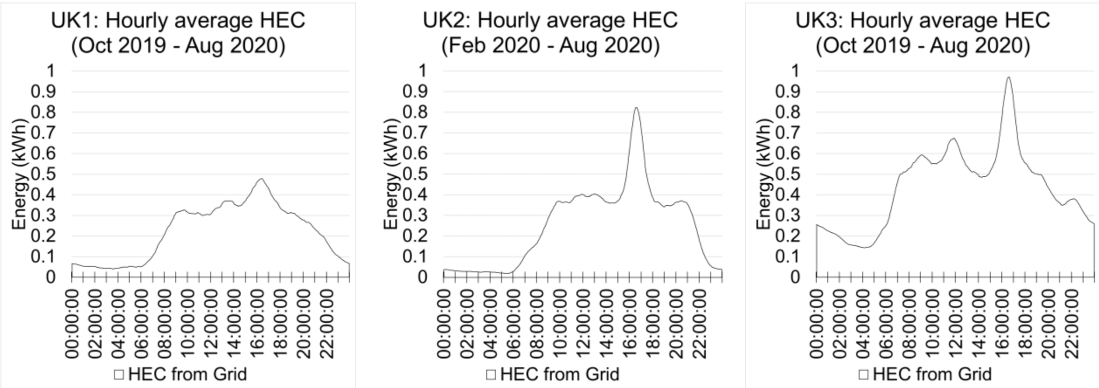

Figure 60: Hourly average electricity consumption for the ZP dwellings from left to right: UK1, UK2 and UK3

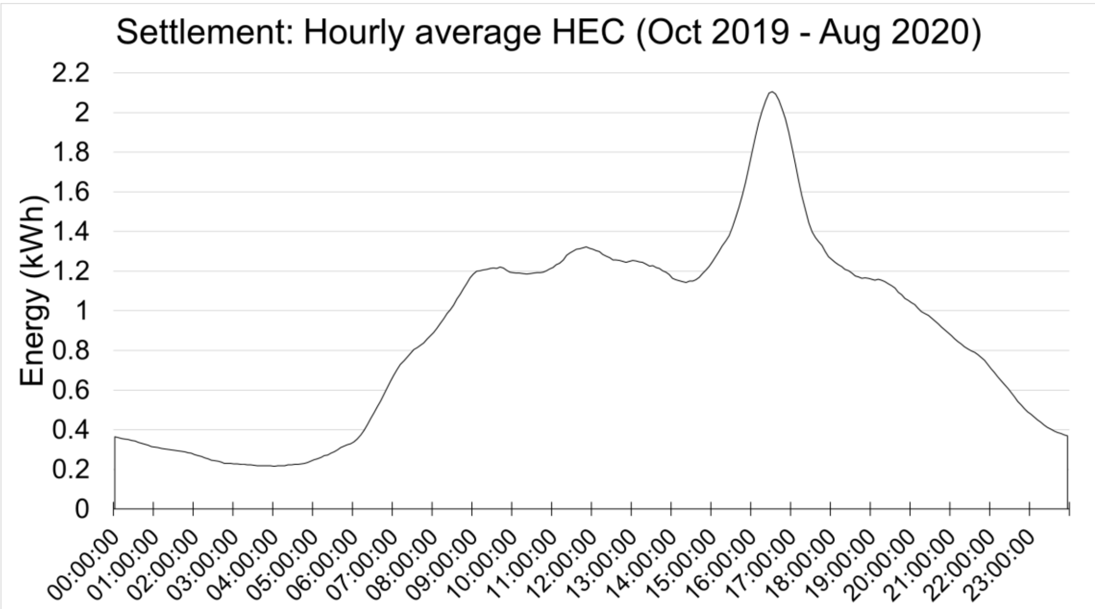

Figure 61: Hourly average electricity consumption for the ZP settlement for the UK

The installed PV array has the capacity to entirely cover the average hourly electricity consumption load in the dwellings during PV generation time. It is important to point out; however, that space heating in the dwellings is from district heating, not electricity. Figure 62 shows the self-consumption potential for the monitoring period. As UK2 was occupied in January 2020 (analysis data available from Feb 2020), missing consumption and generation data for UK2 from October 2019 – end of January 2020 are filled in with consumption and generation data from UK1 for the exercise.

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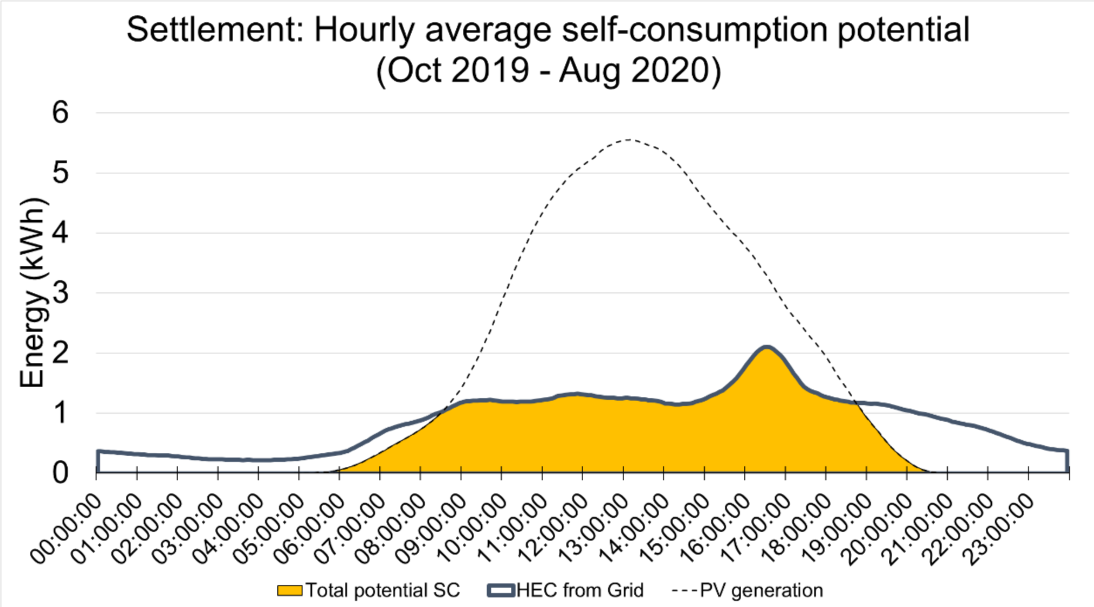

Figure 62: Hourly average self-consumption potential for the settlement for the UK

The model for charging and discharging is such that the battery charges when there is excess PV electricity generation and discharged when the household's demand exceeds generation. Figure 63 shows the self-consumption potential with battery for the monitoring period. The battery discharge, as measured can cover all HEC not covered by PV instantaneous use. From this figure, on an hourly mean, self-consumption of PV is 40% of total PV generation and the remaining PV, either exported to battery or the grid is 60%. The remaining HEC covered by the battery is 88% of this remaining PV generation.

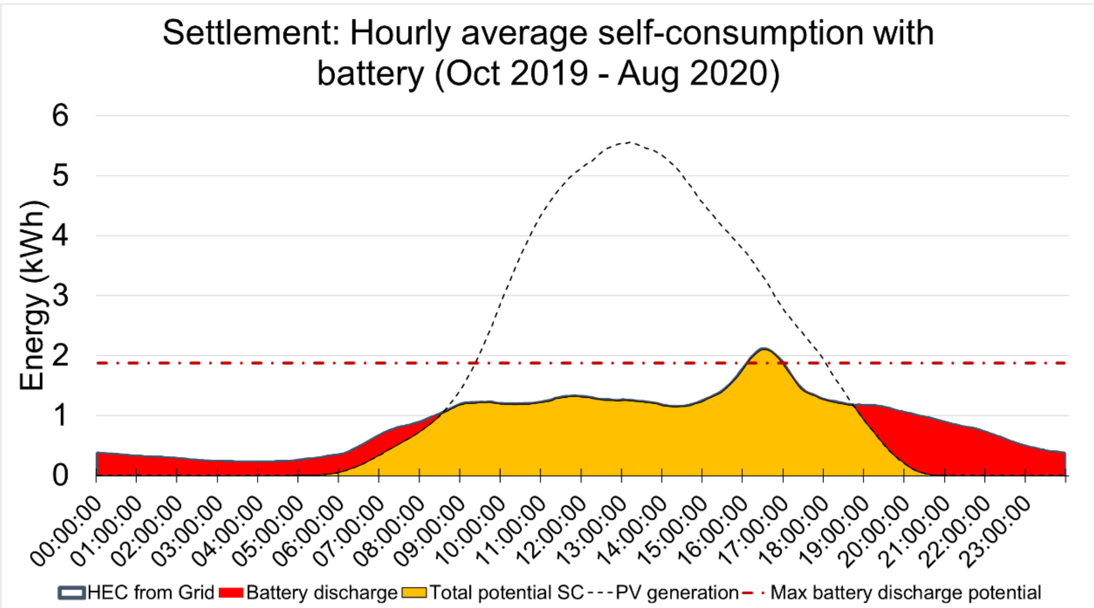

Figure 63: Hourly average energy balance between consumption, generation and storage for the UK

Figure 64 and Figure 65 show the same analysis split into winter and summer. In summer, though the dwellings do not employ cooling technology, there is a sharper peak during evening peak time and during morning. This may be a lasting effect of

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COVID- 19 lockdowns. The occupants, in general, for the most part stay at home. Though the lockdowns were relaxed through summer there is possibly more time spent at home overall.

Over winter, the figure shows that there is not enough remaining PV generation to cover all HEC as it would only cover 66% of HEC outside of PV self-consumption. This, however, will significantly reduce peak load for the dwellings.

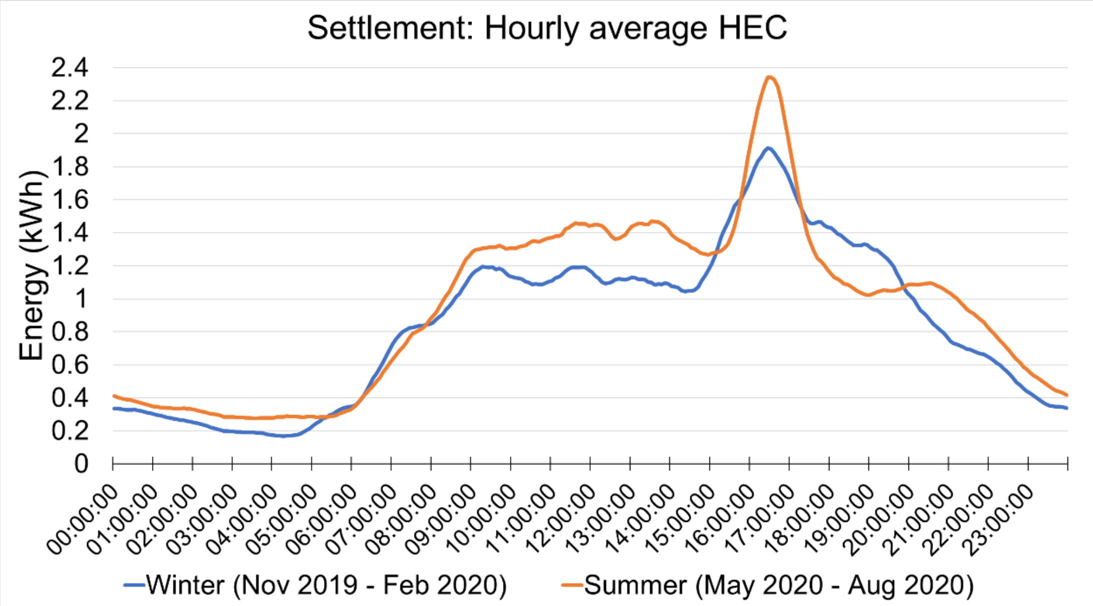

Figure 64: Hourly average HEC split into winter and summer

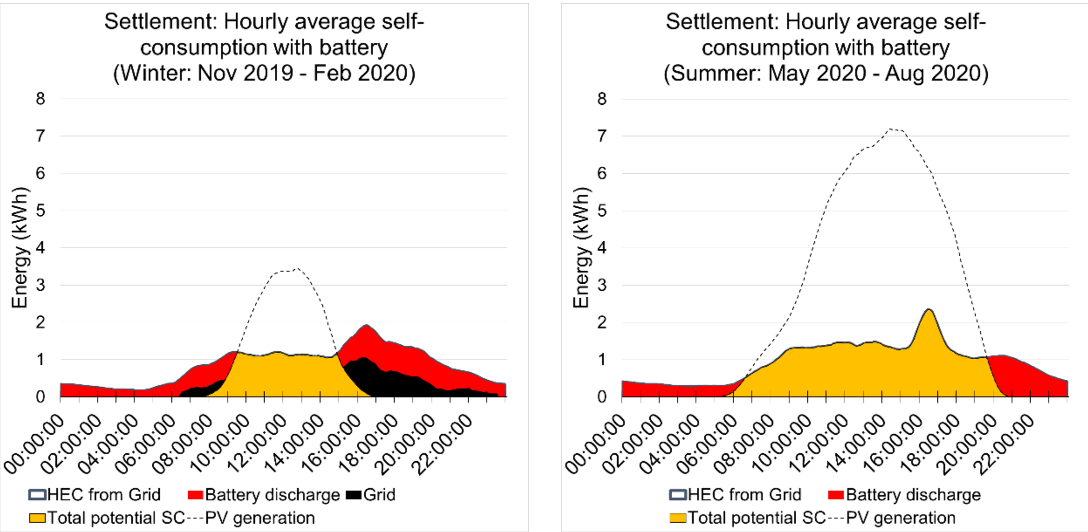

Figure 65: Hourly average energy balance: left winter, right summer for the UK

6.4.3 Self-consumption

Based on actual data, Table 50 shows total consumption, generation and self-consumption related data (see section 5 for more detail) for the settlement. Note that October – January data are extrapolated for UK2 and all data for September are extrapolated. The overall annual mean self-consumption ratio (SCR) for PV alone is 28% with a maximum of 48% (November). Batteries increase this to 41% with a

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maximum of 70% (November). The concept of self-consumption depends on both consumption and size of PV. The larger the PV area and/or smaller the total consumption (during generation hours), the smaller SCR will be.

6.4.4 Optimization

Based on the annual mean, an optimized size for the PV system (in same azimuth and tilt) would be 8.6 kWp, slightly larger than half the currently installed system. This assumes three batteries are installed (one per dwelling). Figure 66 shows the results for the optimized model. In this case, annual SCR of PV alone would be 64%, as close to 100% of the remaining unused generation would be distributed through the battery. In this case, as the peak load is not covered by the PV, batteries would be essential in order to relieve local peak demand.

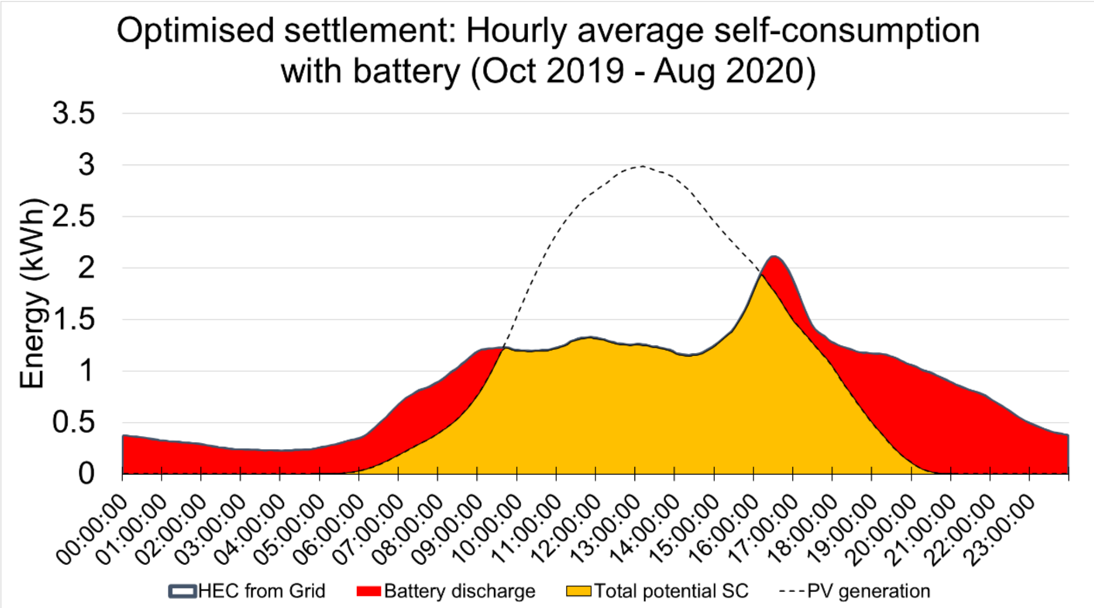

Figure 66: Hourly average energy balance – optimized settlement model for the UK

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Table 50: Consumption, generation and self-consumption statistics for the UK

UK settlement	Daily average electricity	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PV size: 16 kWp Battery size: 13.5 kWh (x3) 7kW peak / 5 kW continuous Efficiency: 90%	Total consumption (kWh)	646	618	648	690	720	676	703	676	663	595	628	649
	Total generation (kWh)	487	732	1480	2087	2380	1792	1480	1490	1302	612	356	368
	PV electricity consumed instantly	92	154	253	397	440	364	376	324	260	114	78	70
	Self-consumption from PV alone (percentage of PV electricity consumed instantly)	29%	29%	23%	23%	23%	26%	33%	28%	28%	26%	41%	31%
	PV electricity discharged from the battery (kWh)	237	252	204	152	134	165	184	188	120	117	109	262
	Percentage increase in self-consumption attributed to battery	33%	26%	18%	8%	7%	10%	11%	12%	16%	26%	29%	35%
	Total final self-consumption (battery and PV)	62%	55%	41%	32%	30%	36%	44%	40%	44%	52%	70%	66%

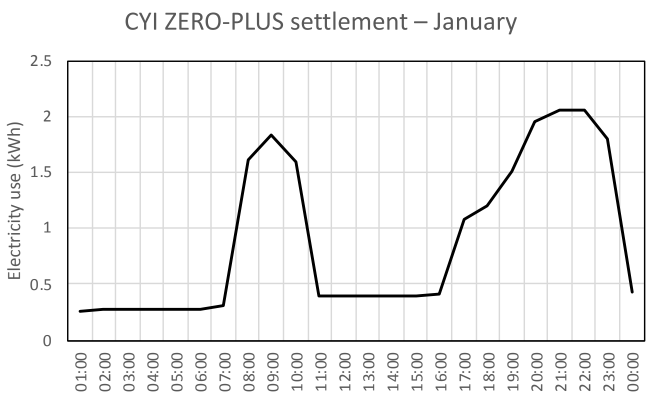
6.5 Cypriot case study

The settlement hereby considered is a theoretical case made of two ZERO-PLUS demohouses located close to the existing demobox (Figure 7). The two buildings are student houses that are mostly used during the lunch break and after the course time in the afternoon and evening. At the settlement level, two FAE HCPV/T units with 20 mirrors each are considered to generate electricity and waste heat for the settlement. In the current analysis, only the electrical yield is considered and not the thermal contribution of the FAE HCPV/T units.

In the numerical model the FAE HCPV/T units were modelled with PV arrays set in order to be characterized by a nominal power generation capacity of 1 kW_{el} each and a nominal electrical efficiency of 28.5% (average between 27 and 30%).

The electricity produced by the FAE HCPV/T at settlement level, will be firstly self-consumed and in case of production surplus it will be stored in batteries, and used to offset dwellings peak demand.

To characterize the electricity generation and the electricity demand the average days for the months of January and July are presented in Figure 67. January is chosen because it is the coldest month and July is chosen because it is a hot month and August is the month when students typically leave the Institute for their summer holidays.



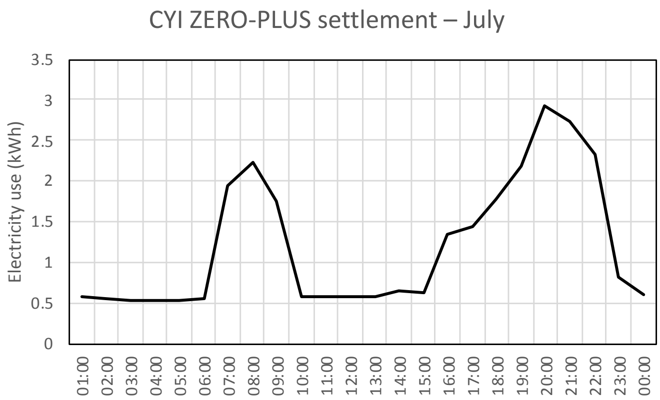


Figure 67: Total hourly energy consumption of the ZERO-PLUS demohouses in the CYI settlement averaged over the months of January (left) and August (right)

The electricity demand of the two student-houses fluctuate over the course of the day, with peaks in the morning (between 8:00 and 10:00 in winter and 7:00 and 9:00 in summer) and in the evening (between 20:00 and 23:00).

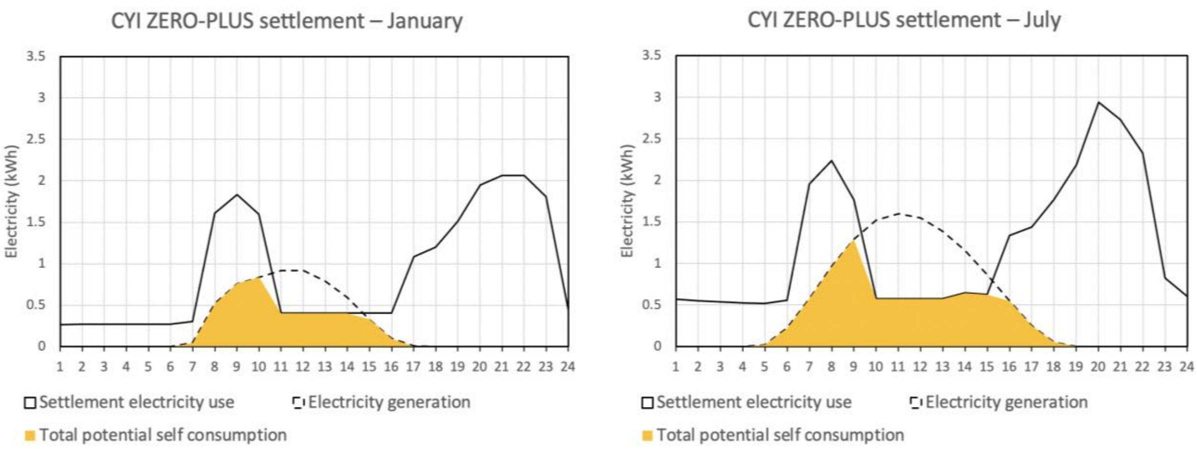


Figure 68: Total hourly energy consumption of the ZERO-PLUS demohouses in the CYI settlement averaged over the months of January (left) and August (right)

The total hourly electricity consumption and production of the settlement, averaged over January and July (Figure 68), show that most of the renewable energy is generated during the central hours of the day but only partially it is directly self-consumed by the two buildings. Furthermore, only two modules of FAE HCPV/T are not sufficient to cover the daily electricity demand of the settlement.

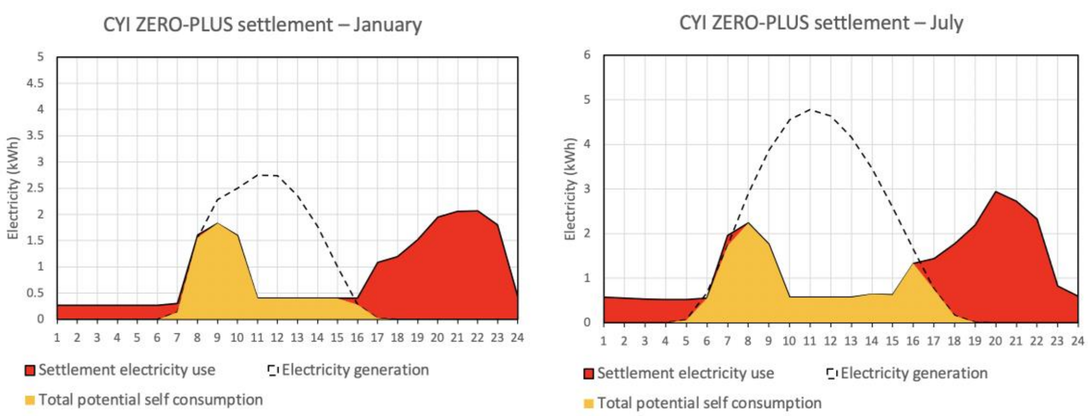


Figure 69: Hourly average energy balance between consumption, generation and storage in Cyprus. Left, January; Right, July.

6.5.1 Optimization

Assuming to install 6 FAE HCPV/T units and a storage with a max battery discharge potential of 3.5 kW (Table 51), it is possible to fully cover the electricity demand of the settlement during the summer months but a limited contribution is required from the grid in the winter months (4.10 kWh/day).

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Table 51: Consumption, generation and self-consumption statistics for Cyprus

Cy settlement	Daily average electricity	Jan	Jul
FAE HCPV/T units: 6 kWp Battery size: 12 kWh (x2) 7 kW peak / 3.5 kW continuous Efficiency: 90%	Total consumption (kWh)	666.5	895.9
	Total generation (kWh)	539.4	1116
	PV electricity consumed instantly	230.6	377,6
	Self-consumption from PV alone (percentage of PV electricity consumed instantly)	42.7%	33.8%
	PV electricity discharged from the battery (kWh)	181.4	738.4

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7. Conclusions

Monitoring activities and the Web-GIS platform were at the core of the ZERO-PLUS project as they were used for the fine-tuning of the simulation models, for checking real-time performance of the settlements to ensure timely interventions and troubleshooting of the installed systems and technologies where needed, and finally for evaluating the total energy performance of the settlements. A major output of the monitoring activities and the Web-GIS platform are the high quality data sets that were produced for all the ZERO-PLUS case studies [5] and were utilized for the verification of the case studies performance, the POE and the demonstration of the transition from the building to settlement level. The post occupancy monitoring for all case studies lasted for over 10 months with the exception of the Cypriot case study where the post occupancy monitoring period was 4.5 months long.

The four ZERO-PLUS case studies were successfully realized despite many challenges both technical and regulatory, with the latter more demanding to tackle. Several obstacles with more important the time-consuming procedure of obtaining a construction permit for the Cypriot case study led us to implement the ZERO-PLUS technologies in an existing structure in the CyI campus that helped us assess the prefabricated container system structure (ZERO-PLUS demohouse), that will be built in the near future according to the ZERO-PLUS approach. The other three case studies (Italy, France and the UK) are real-life residential settlements.

For each case study appropriate modelling and simulation software was selected. The models were updated in different phases of the project to ensure that that the KPIs were met. The as-built simulation results were produced by taking into account the as-built designs and the technologies installed. The models were calibrated by using, to the extent possible, the monitored data from the pre-occupancy checks and pre-occupancy monitoring. The purpose of the as-built calibration was dual. Firstly, to evaluate the simulation models and tools that were used and secondly, to assess the expected energy performance of the 4 case studies which were tested against the actual performance that derives from the monitoring. Both energy consumption and energy production targets were acceptably achieved. For the Italian, UK and Cypriot case study the calibration error is within accepted limits set by the ASHRAE Guideline-14 [8]. For the French case study since the as-built scenario included only updated air permeability values no validation indices were calculated.

Another calibration was performed at the end of the project. The purpose of this final calibration was the evaluation of the simulation models and tools that supported the approach's repeatability and reliability as they were used for the development of the methodology for the transition from building level to settlement level. The data collected from the ZERO-PLUS case studies during the measurement and verification period were used to perform the final calibrated simulations of the developed simulation models. Overall, **the final calibration of the simulation models is acceptable in all case studies.** Specifically:

- The French case study presents the greater deviation between the final calibrated simulations and the monitored performance. The deviations in the French case study were mainly due to changes in construction that could not be foreseen or incorporated in the simulation model.
- The Italian case study was calibrated to an acceptable accuracy with a small tendency to overestimate both the regulated energy consumption and renewable energy production.
- In the UK case study an acceptable final calibration was achieved as well. Small deviations were attributed to the weather file as well as to occupant behavior profiles. Simulating occupant behavior with varying heating patterns and profiles in one of the houses has contributed to reduced deviation between monthly simulated and actual space heating consumption. This approach, however, is not efficient from the calibration effort point of view.
- In the case study of Cyprus, similarly to the UK case study, the weather file calibration and lack of information about occupancy patterns in some periods were related to the deviations observed. However, the final calibration error was within acceptable limits.

It is safe to say that the ZERO-PLUS modelling approach for simulating the expected building and settlement performance at the design phase has produced reliable performance results. Moreover, keeping a record of the changes that might occur during construction is useful in understanding possible performance deviations, such as those observed in the French case study.

The renewable generation targets and the net regulated targets were calculated using the as-built models but also the actual monitored data. **All case studies were able to meet the renewable generation targets and the net regulated consumption targets**. In fact, **in many cases the in-use performance of dwellings was better than the as-built projections.** However, it is noted that the Cypriot case studies results are still theoretical. This better than design or as-built projection is most likely attributed to occupant behavior, which is difficult to predict accurately in relation to energy consumption. In the UK case, for example, the pre-occupancy evaluation of the building fabric thermal performance showed less than desirable results; however, this drawback was compensated by far less than expected heating demand from the occupants.

In the same development of the UK case study, three older non-ZERO-PLUS dwellings were used as “control” for observation of newer homes within the same development and the impact of the Zero Plus technologies. The findings provide a reference for comparing the indoor environmental conditions and occupant experiences of the ZERO-PLUS dwellings with the non-ZERO-PLUS dwellings. As the non-ZERO-PLUS dwellings are similar in construction, they have shown similar outcomes in occupant perception and environmental assessment. There was some variation; however, this is likely attributed to different orientations and forms of the dwellings and above all, occupant behavior.

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Another important element is whether the case studies meet the Key Performance Indicators (KPIs) of the project set from the beginning. **Most dwellings hit all KPIs except for a few cases.** In Italy the renewable energy production target was just short of the target, i.e. by 4.8% which may be the result of a seasonal variation such as cloud cover or dust[11]. However, **many dwellings, including those in Italy have exceeded net regulated consumption expectations by performing as net-zero dwellings.** Again, this shift can be attributed to modelling assumptions, construction variation, and occupant behaviour.

In line with reduced net regulated consumption, most case studies have increased total energy conservation and CO_2 emission reductions in the in-use stage based on actual data against the as-built projections enhancing their impact. All, but France, reduced their carbon emissions; however, the difference in France was minimal, i.e., actual carbon emissions reduction was 1.5% less than the as-built projection. As their energy conservation was improved in the actual case overall, this unimproved CO_2 emissions reduction is attributed to the higher than projected space heating consumption and the change in fuel proportions.

The monitoring period of ZERO-PLUS included the first COVID-19 outbreak. Despite the challenges, the monitoring activities, both the monitoring and the Post Occupancy Evaluation (POE) surveys and interviews, continued to run, to the extent possible. The energy consumption patterns of the demonstration buildings located within the four ZERO-PLUS settlements before, during, and after the COVID-19 pandemic lockdown were examined. **It has not been possible to draw any conclusion for the French and the Cypriot case studies due to monitoring limitations.** In the first case due to lack of monitored data, as it was not possible to analyze the regulated energy pattern for the entire period of investigation. In the case of Cyprus no occupants had been continuously using the building and therefore no changes in habits related to the post-lockdown could be recorded. So, it hasn't been possible to observe any variation on the regulated energy consumption pattern that may be associated with the measures imposed during the lockdown period in these two case studies. **In the Italian and the UK case studies the lockdown conditions did not cause significant changes in the energy patterns compared to the situation before the national lockdown.** However, the HVAC energy use was reduced (significantly in the case of the Italian case study) after the lockdown with respect to the pre-lockdown period probably due to the improvement of the weather conditions.

It is a fact that greater energy efficiency can be achieved through a transition from single NZE buildings to NZE settlements, in which the energy loads and resources are optimally managed. Due to technical, cost and/or legislative restrictions that did not allow for energy load management at settlement level in any case study it was decided to model the transition from building level to settlement level to observe the energy balance that can be achieved through such an arrangement.

[11] As examples, one study [16] found PV yield uncertainties were estimated to be about 3.9% for year-to-year climate variability, 5% for long-term average horizontal insolation, 3% for estimation of radiation in the plane of the array, 3% for power rating of modules, 2% for losses due to dirt and soiling, 1.5% for losses due to snow and 5% for other sources of error. Another study [17] found variability in interannual global horizontal irradiation (GHI) to be 3.4% and 6% to account for error in the modelling of GHI.

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The four case studies demonstrate that storage for supplemental renewable energy generation is essential for increasing self-consumption of renewable energy in all locations and for shifting the load to meet peak demand. In the French case study, it is clear that the PV system would cover all dwellings in the development if it were able to be used in that way. However, as it can only be used to cover communal building loads, battery would be needed if the energy company did not financially support export to the grid. In the Italian case study, a storage system like a battery would only be useful in the summer; however, if a seasonal storage system would be used greater levels of self-consumption could be achieved. In the UK case study, an optimal PV size was found to meet the dwelling's demand load and battery sizes. This PV system would be slightly smaller than the one currently installed. As some of the individual dwellings have lower self-consumption compared to others, aggregating the supply and consumption of PV creates a more efficient use of the energy. In the Cypriot case study, there was a significant need to shift the load to meet evening and less so morning peak demand but in the optimised scenario it was found to be possible to fully cover the electricity demand of the settlement during the summer months with a limited contribution from the grid in the winter months.

The **feasibility of the ZERO-PLUS approach in the different climatic regions** is fully supported by the results and the developed methodology based on four major axes.

1. The actual monitored performance results. As demonstrated in Table 2 the KPIs are met in all but one cases. In the Italian case study, the renewable energy production is 47.6 kWh/m^2/year instead of 50kWh/m^{2}k/year and is attributed to extraordinary weather conditions. Moreover, in all case studies the added-value of the ZERO-PLUS approach is proven, namely the cost-effectiveness of the construction process, thanks to the application of an integrated approach to building design, and to the optimisation of the energy load for each building by designing the energy generation system at the settlement level.
2. The developed methodology. Mostly the Post-Construction/Installation- Pre-occupation Phase and Post-occupation Phase procedures of the Measurement and Verification (M&V) plan are relevant here, The M&V plan [6] (including monitoring, the Web-GIS platform and simulations) tailored specifically to the needs of a settlement rather than of a building has supported the realization of the case studies as it provided guidelines, fail-safes and mitigation measures all the way guarantying the quality of the results.
3. The as-built simulation results. The as-built estimation of the energy performance of the settlements could be relied upon for decision making. In all case studies the Net regulated energy use has actually been underestimated whereas the Renewable production was estimated to be within 4-5% of the actual value with the exception of the French case study where it was also underestimated (Table 52). Deviations are mostly attributed

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to the actual occupancy patterns that cannot be accurately predicted in the as-built phase and also due to the actual weather data.

4. The methodology developed for demonstration of the transition from building level to settlement level showed how greater energy efficiency can be achieved in each climatic region if it isn't hindered by regulatory and legislative constraints.

Table 52: As-built and Actual KPIs for the French, Italian and UK ZERO-PLUS case studies and as-built KPIs for the Cypriot case study

#	KPIs	French case study		Italian case study		UK case study		Cypriot case study
		As-built	Actual	As-built	Actual	As-built	Actual	As-built
1	Net Regulated energy usage (kWh/m^2/year) (target: < 20 kWh/m2/year)	-6.82	-10.06	-2.2	-11	16	-1	18.9
2	Renewable production (kWh/m^2/year) (target: > 50 kWh/m2/year)	74.99	122.97	49.7	47.6	52.4	51.2	54.3
3	Cost reduction (%) (target: 16% reduction compared to the reference case)	26.70%		24.8		17.8		17
4	Carbon emission reduction (kgCO_2/m^2/year) (target varies per case study; FR >=4.6; IT>=23; UK>=18; CY>=34)	17.31	17.06	26.5	49.6 [1]	17.7	21.1	16.8

Conclusively, it can be said that beside the successful implementation of the ZERO-PLUS approach supported by the actual monitored performance results (1st axis), the legacy of the ZERO-PLUS approach is reinforced by axes 2, 3 and 4. **The developed M&V plan tailored to the settlement level, the acceptable as-built results and the methodology for the transition from building to settlement level can be used to successfully support the transferability and replicability of the ZERO-PLUS approach**.

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Annex A - Monitoring Timeline and monitored data

In the tables below (Table 53 to Table 60) you can find the monitoring timeline and durations as well as the monitored data for each case study.

The specifications for the monitoring equipment were set by the project's technical committee to ensure the correct measurement of the Net regulated energy (one of the KPIs of the project), and thermal comfort of the residents of the settlement.

Table 53: Monitoring timeline and duration for the French Case study

Actions	Type	Duration	Comments
Preoccupancy checks	Air permeability (a) & u-value tests (b)	(a)23/07/2019 and 23/09/2019- 2 day (b) 05-15/09/2019- 10 days	(a)7 dwellings over 18 were tested (b) 1 dwelling was tested
Pre occupancy monitoring	Space CO2 Space temperature Space relative humidity Space occupancy Window open/close Building equipment electric power Building equipment electric consumption Building light electric power (just for common areas) Building light electric consumption (just for common areas) Building DHW & Heating electric power Building DHW & Heating electric consumption Building ventilation electric power Building ventilation electric consumption PV electric power PV electric energy production Heating Energy consumption DHW energy and volume consumptions	From August 1st to September 25th 8 weeks	
Post- Occupancy monitoring		From September 26th 2019 to 15th of August 2020	
Weather station	Outdoor air temperature Outdoor relative humidity Wind Speed	From September 26th 2019 to 15th of August 2020	

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Actions	Type	Duration	Comments
	Wind direction Global radiation		

Table 54: Measurements for the case study of Voreppe, FR

No	Measurement name	Units	Range	Resolution	Accuracy (±)
1	Space temperature	°C	0 -40	0.1	0.5°C
2	Space relative humidity	%	10-90	1	10.00%
3	Space CO2 level	ppm	0-2000	20	40 ppm
4	Space occupancy	0/1	0-1		
5	Space Illumination	Lux	0-500	0.2	0.5lux
6	Window open/close	On/Off	0-1	-	-
7	Door open/close	On/Off	0-1	-	-
8	Building ventilation electric power	W	0-25000	0.1	0.10%
9	Building ventilation electric consumption	Wh	0 -99,999,999 MWh	1	0.1Wh
10	Building fans,pumps electric power	W	0-25000	0.1	0.10%
11	Building fans,pumps electric consumption	Wh	0 -99,999,999 MWh	1	0.1Wh
12	Building heating power	W	0-25000	0.1	0.10%
13	Building heating energy consumption	Wh	0 -99,999,999 MWh	1	0.1Wh
14	Building domestic hot water	Wh	0-25000	0.1	0.10%
15	Building electric power (consumption)	W	0 -99,999,999 MWh	1	0.1Wh
16	Building electric energy consumption	Wh	0 -99,999,999 MWh	1	0.1Wh
17	Settlement PV electric power production	W	0-25000	0.1	0.10%
18	Settlement PV electric energy production	Wh	0 -99,999,999 MWh	1	0.1Wh
19	Outdoor air temperature	°C	-40 - 64	0.1	1
20	Relative humidity	%	1-100	1	4.00%
21	Wind Speed	m/s	1-50	0.4	5.00%
22	Wind direction	deg	0 – 360	1	3deg
23	Rain	mm	0 -950	0.2	5.00%
24	Global radiation	W/m2	0-2000	50	10.00%

Table 55: Monitoring timeline and duration for the Italian Case study

Actions	Type	Duration	Comments
Pre-occupancy checks	In field U-value measurement (external walls)	1/2/2019-5/3/2019; more than 1 month	In both IT1 and IT2, the U-value for external walls is slightly higher than that one declared at the design stage

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Actions	Type	Duration	Comments
Pre-occupancy checks	Air permeability (blower door test)	5/3/2019; 1 day	IT2 was not completed (including all finishes) when the test was performed, thus the results for this building cannot be considered reliable
Pre-occupancy checks	Thermal imaging	5/3/2019; 1 day	In both IT1 and IT2, the infrared analysis on the external facades show a non-homogeneous surface temperature distribution
Pre-occupancy monitoring	Indoor microclimate monitoring in one room (air temperature and relative humidity, mean radiant temperature, air speed, radiant asymmetry, CO_2 concentration, VOCs), only air temperature and relative humidity monitoring in a second room, outdoor air temperature and relative humidity monitoring	IT1: 18/6/2018-6/7/2018; about 3 weeks IT2: 1/2/2019-5/3/2019; more than 1 month	The pre-occupancy monitoring in IT1 was shorter than 1 month due to construction delays and the need of owners to move in
Post-Occupancy monitoring	Space air temperature and relative humidity, CO_2 concentration, occupancy presence, illuminance, window and door opening/closing, building equipment and HVAC electricity consumption, PVs electricity production	starting from 19/06/2019 to 15/08/2020	All sensors for IEQ were connected to the WebGIS platform in June 2019, but there was a delay with the data transmission due to the Rotex G1 connection problems.
Weather station	Outdoor air temperature and relative humidity, wind speed and direction, rain, pressure, global solar radiation	starting from 07/05/2019 to 15/8/2020	Installed on the rooftop of IT2

Table 56: Measurements for the case study of Granarolo dell'Emilia, IT

No	Measurement name	Units	Range	Resolution	Accuracy (±)
1	Space temperature	°C	0 -40	0.1	0.5°C
2	Space relative humidity	%	10-90	1	10.00%
3	Space CO2 level	ppm	0-2000	20	40 ppm
4	Space occupancy	0/1	0-1		
5	Space Illumination	Lux	0-500	0.2	0.5lux
6	Window open/close	On/Off	0-1	-	-
7	Door open/close	On/Off	0-1	-	-

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No	Measurement name	Units	Range	Resolution	Accuracy (±)
8	Space Setpoint temperature	°C	0 -40	0.1	0.5°C
9	Building HVAC electric power	W	0-25000	0.1	0.10%
10	Building HVAC electric consumption	Wh	0 -99,999,999 MWh	1	0.1Wh
11	Building electric power (consumption)	W	0-25000	0.1	0.10%
12	Building electric energy consumption	Wh	0 -99,999,999 MWh	1	0.1Wh
13	Building Domestic hot water	Wh	0 -99,999,999 MWh	1	0.1Wh
14	Building PV electric power	W	0-25000	0.1	0.10%
15	Building PV electric energy production	Wh	0 -99,999,999 MWh	1	0.1Wh
16	Building Battery Stored Energy	Wh	0 -99,999,999 MWh	1	0.1Wh
17	Outdoor air temperature	°C	-40 - 64	0.1	1
18	Relative humidity	%	1-100	1	4.00%
19	Wind Speed	m/s	1-50	0.4	5.00%
20	Wind direction	deg	0 – 360	1	3deg
21	Rain	mm	0 -950	0.2	5.00%
22	Global radiation	W/m^2	0-2000	50	10.00%

Table 57: Monitoring timeline and duration for the UK Case study

Actions	Type	Duration	Comments
Preoccupancy checks	Air permeability, U-value tests, thermography	3/4/2019 - 24/3/2019; 1 month	
Pre-occupancy monitoring	Analysis of early electricity consumption and temperature data	All dwellings: 20/7/2019 - 18/8/2019; 1 month UK2: 20/7/2019 - 12/9/2019; ~1 month	(early occupancy data used to calibrate as-built model
Post- Occupancy monitoring	Temperature, RH, CO_2, electricity consumption (various), electricity generation (consumption / export), battery charge / discharge, space heating, DHW, occupant survey	UK1: 22/7/2019 - 22/7/2020; 1 year UK2: Nov 2019 – Aug 2020; 10 months UK3: 5/8/2019 - 5/8/2020; 1 year	
Weather station	Temperature, RH, solar radiation	24/10/2019 - 30/9/2020	

Table 58: Measurements for the case study of Derwenthorpe, UK

No	Measurement name	Units	Range	Resolution	Accuracy (±)
1	Space temperature	°C	0 -40	0.1	0.5°C
2	Space relative humidity	%	10-90	1	10.00%

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No	Measurement name	Units	Range	Resolution	Accuracy (±)
3	Space CO2 level	ppm	0-2000	20	40 ppm
4	Space occupancy	0/1	0-1		
5	Space Illumination	Lux	0-500	0.2	0.5lux
6	Window open/close	On/Off	0-1	-	-
7	Door open/close	On/Off	0-1	-	-
8	Space Setpoint temperature	°C	0 -40	0.1	0.5°C
9	Building fans, pumps electric power	W	0-25000	0.1	0.10%
10	Building fans, pumps electric energy consumption	Wh	0 -99,999,999 MWh	1	0.1Wh
11	Building electric power (consumption)	W	0-25000	0.1	0.10%
12	Building electric energy consumption	Wh	0 -99,999,999 MWh	1	0.1Wh
13	Domestic hot water	Wh	0 -99,999,999 MWh	1	0.1Wh
14	Building thermal energy consumption	Wh	0 -99,999,999 MWh	1	0.1Wh
15	Building PV electric power	W	0-25000	0.1	0.10%
16	Building PV electric energy produced	Wh	0 -99,999,999 MWh	1	0.1Wh
17	Building Battery Stored Energy	Wh	0 -99,999,999 MWh	1	0.1Wh
18	Outdoor air temperature	°C	-40 - 64	0.1	1
19	Relative humidity	%	1-100	1	4.00%
20	Wind Speed	m/s	1-50	0.4	5.00%
21	Wind direction	deg	0 – 360	1	3deg
22	Rain	mm	0 -950	0.2	5.00%
23	Global radiation	W/m2	0-2000	50	10.00%

Table 59: Monitoring timeline and duration for the Cy Case study

Actions	Type	Duration	Comments
Preoccupancy checks	Thermal imaging	17/02/2020	Air permeability cannot be measured in the Cyprus case-study with a typical blower door test, because the facility is not airtight and it would be not possible to pressurize it up to 50 Pa difference with respect to ambient pressure
	U-value tests	16/07/2020 (to have a proper temperature difference between indoor and outdoor	

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Actions	Type	Duration	Comments
		air temperatures during the most critical period).	
Pre-occupancy monitoring	• Space air temperature and relative humidity, CO_2 concentration, occupancy presence, window and door opening/closing, building equipment and HVAC electricity consumption, PVs electricity production	For environmental measures: starting from 16/07/2019 For building technical systems: 03/03/2020 To 15th of August 2020	All sensors for IEQ were connected to the WebGIS platform in July 2020, and the building technical systems in March 2020. But we experienced some connection issues during the first days given by firewalls and windows updates that restarted the PC connected to the freescoo
Post-occupancy monitoring	• Indoor air temperature, • Indoor relative humidity, • CO_2 concentration, • Occupancy, • windows/door operations	28/02/2020 to 15/7/2019; 4,5 months	
Weather station	• Outdoor air temperature, • Outdoor relative humidity, • Wind speed • Wind direction, • Global solar irradiance on a horizontal plan	Continuous	The weather station is available at the CyI campus

Table 60: Measurements for the case study of Cy Case study

No	Measurement name	Units	Range	Resolution	Accuracy (±)
1	Space air temperature	°C	0-40	0.1	0.5°C
2	Space relative humidity	%	10-90	1	10.00%
3	Space CO_2 level	ppm	0-2000	20	40 ppm
4	Space occupancy	0/1	0-1		
5	Window open/close	On/Off	0-1	-	-
6	Door open/close	On/Off	0-1	-	-
7	Setpoint Space temperature	°C	0 -40	0.1	0.5°C
8	Building HVAC (freescoo) electric power	W	0-25000	0.1	0.10%
9	Building HVAC (freescoo) electric consumption	Wh	0 -99,999,999 MWh	1	0.1Wh
10	Building electric power (consumption)	W	0-25000	0.1	0.10%
11	Building electric energy consumption	Wh	0 -99,999,999 MWh	1	0.1Wh

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No	Measurement name	Units	Range	Resolution	Accuracy (±)
12	Building FAE electric power production	W	0-25000	0.1	0.10%
13	Building FAE electric energy production	Wh	0 -99,999,999 MWh	1	0.1Wh
14	Building FAE thermal energy production	Wh	0 -99,999,999 MWh	1	0.1Wh
15	Outdoor air temperature	°C	-40 - 64	0.1	1
16	Relative humidity	%	1-100	1	4.00%
17	Wind Speed	m/s	1-50	0.4	5.00%
18	Wind direction	deg	0 – 360	1	3deg
19	Rain	mm	0 -950	0.2	5.00%
20	Global radiation	W/m2	0-2000	50	10.00%

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Annex B - List of data for calibrated simulations

Table 61: List of data for calibrated simulations in the case study of France

No	Measurement name	Units	Collection phase	Time interval	Location
1	Space temperature	°C	Pre-occupancy monitoring	Sub-hourly values (every 15 minutes)	Living room (in the 4 flats monitored)
			Post-occupancy evaluation	Sub-hourly values (every 15 minutes)	
2	Space relative humidity	%	Pre-occupancy monitoring (free-floating conditions)	Sub-hourly values (every 15 minutes)	Living room (in the 4 flats monitored)
			Post-occupancy evaluation	Sub-hourly values (every 15 minutes)	
3	Space occupancy	0/1	Post-occupancy evaluation	Sub-hourly values (every 15 minutes)	1 per flat monitored
4	Window open/close	On/Off	Post-occupancy evaluation	Sub-hourly values (every 15 minutes)	1 per flat monitored
5	Building equipment electric power	W	Post-occupancy evaluation	-	4 flats monitored in the building
6	Building equipment electric consumption	kWh	Post-occupancy evaluation	Average monthly values	4 flats monitored in the building
7	Building light electric power (just for common areas)	W	Post-occupancy evaluation	-	Building (common areas)
8	Building light electric consumption (just for common areas)	kWh	Post-occupancy evaluation	Annual values	Building (common areas)
9	Building HVAC electric power (Ventilation & Heating)	W	Post-occupancy evaluation	-	Building (common areas)
10	Building HVAC electric consumption	kWh	Post-occupancy evaluation	Annual values	Building (common areas)
11	Building ventilation electric power	W	Post-occupancy evaluation	-	Building (common areas)
12	Building ventilation electric consumption	kWh	Post-occupancy evaluation	Annual values	Building (common areas)
13	PV electric power	W	Post-occupancy evaluation	-	-
14	PV electric energy production	kWh	Post-occupancy evaluation	Undefined	Building (common areas)
15	Outdoor air temperature	°C	Pre-occupancy monitoring	Sub-hourly values (every 15 minutes)	Weather station (top of the building)
			Post-occupancy evaluation	Sub-hourly values (every 15 minutes)	
16	Outdoor relative humidity	%	Pre-occupancy monitoring	Sub-hourly values (every 15 minutes)	-

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No	Measurement name	Units	Collection phase	Time interval	Location
			Post-occupancy evaluation	Average hourly values	
17	Wind Speed	m/s	Post-occupancy evaluation	Undefined	-
18	Wind direction	deg	Post-occupancy evaluation	Average hourly values	-
19	Global radiation	W/m^2	Post-occupancy evaluation	Average hourly values	-
20	External wall U-value	W/m^2K	Pre-occupancy checks	Average value	
21	Building air permeability	m3/h/m²	Pre-occupancy checks	Average value	Building
22	Spaces occupancy schedules	0/1	POE surveys and questionnaires	Typical weekly schedule	
23	Window open/close habits	On/Off	POE surveys and questionnaires	-	
24	Windows solar shading systems open/close habits and schedules	On/Off	POE surveys and questionnaires	Typical daily schedule	
25	Heating set-point temperature	°C	POE surveys and questionnaires	-	
26	Heating set-back temperature	°C	POE surveys and questionnaires	-	
27	Heating system switch-on/off schedules	On/Off	POE surveys and questionnaires	Typical weekly schedule	Every room
28	Desired Temperature	°C	Post-occupancy evaluation		
29	Building Heating Consumption	kWh	Post-occupancy evaluation		
30	Building Domestic Hot Water	kWh	Post-occupancy evaluation		

Table 62: List of data for calibrated simulations in the case study of Italy

No	Measurement name	Units	Collection phase	Time interval	Location
1	Space temperature	°C	Pre-occupancy monitoring (free-floating conditions)	Sub-hourly values (every 10 minutes)	At least in one room per floor
			Post-occupancy evaluation	Average hourly values	
2	Space relative humidity	%	Pre-occupancy monitoring (free-floating conditions)	Sub-hourly values (every 10 minutes)	At least in one room per floor
			Post-occupancy evaluation	Average hourly values	

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No	Measurement name	Units	Collection phase	Time interval	Location
3	Space occupancy	0/1	Post-occupancy evaluation	Sub-hourly values (every minute)	Every room
4	Window open/close	On/Off	Post-occupancy evaluation	Sub-hourly values (every minute)	Every room
5	Building equipment electric power	W	Post-occupancy evaluation	-	Every room
6	Building equipment electric consumption	kWh	Post-occupancy evaluation	Average monthly values	Building
7	Building light electric power	W	Post-occupancy evaluation	-	Every room
8	Building light electric consumption	kWh	Post-occupancy evaluation	Average monthly values	Building
9	Building HVAC electric power	W	Post-occupancy evaluation	-	Every room
10	Building HVAC electric consumption	kWh	Post-occupancy evaluation	Average monthly values	Building
11	Building ventilation electric power	W	Post-occupancy evaluation	-	Every room
12	Building ventilation electric consumption	kWh	Post-occupancy evaluation	Average monthly values	Building
13	Building DHW heating consumption	kWh	Post-occupancy evaluation	Average monthly values	Building
14	Building gas consumption	m^3	Post-occupancy evaluation	Average monthly values	Building
15	PV electric power	W	Post-occupancy evaluation	-	-
16	PV electric energy production	kWh	Post-occupancy evaluation	Average hourly values	-
17	Outdoor air temperature	°C	Pre-occupancy monitoring	Sub-hourly values (every 10 minutes)	-
			Post-occupancy evaluation	Average hourly values	
18	Outdoor relative humidity	%	Pre-occupancy monitoring	Sub-hourly values (every 10 minutes)	-
			Post-occupancy evaluation	Average hourly values	
19	Wind Speed	m/s	Post-occupancy evaluation	Average hourly values	-
20	Wind direction	deg	Post-occupancy evaluation	Average hourly values	-
21	Global radiation	W/m^2	Post-occupancy evaluation	Average hourly values	-
	Construction document and system specification review	-	Pre-occupancy review	-	Building

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No	Measurement name	Units	Collection phase	Time interval	Location
22	External wall U-value	W/m^2K	Pre-occupancy checks	Average value	North-facing wall
23	Building air permeability	h^{-1}	Pre-occupancy checks	Average value	Building
24	Spaces occupancy schedules	0/1	POE surveys and questionnaires	Typical weekly schedule	Every room
25	Window open/close habits	On/Off	POE surveys and questionnaires	-	Every room
26	Windows solar shading systems open/close habits and schedules	On/Off	POE surveys and questionnaires	Typical daily schedule	Every room
27	Heating set-point temperature	°C	POE surveys and questionnaires	-	Every room
28	Heating set-back temperature	°C	POE surveys and questionnaires	-	Every room
29	Cooling set-point temperature	°C	POE surveys and questionnaires	-	Every room
30	Cooling set-back temperature	°C	POE surveys and questionnaires	-	Every room
31	Heating system switch-on/off schedules	On/Off	POE surveys and questionnaires	Typical weekly schedule	Every room
32	Cooling system switch-on/off schedules	On/Off	POE surveys and questionnaires	Typical weekly schedule	Every room
33	Mechanical ventilation system switch-on/off schedules	On/Off	POE surveys and questionnaires	Typical weekly schedule	Every room
34	Lighting system switch-on/off schedules	On/Off	POE surveys and questionnaires	Typical weekly schedule	Every room
35	Number and type of lamps	-	Pre-occupancy checks	-	Every room
36	Equipment and appliances switch-on/off schedules	On/Off	POE surveys and questionnaires	Typical weekly schedule	Every room
37	Number, type, and technical characteristics of equipment and appliances	-	Pre-occupancy checks	-	Every room

Table 63: List of data for calibrated simulations in the case study of UK

No	Measurement name	Unit for calibration	Phase	Time interval
1	Air Permeability testing	0.01 ACH	Pre-occupancy fabric evaluation	N/A
2	Thermal imaging	N/A	Pre-occupancy fabric evaluation	N/A
3	In-situ U-value tests (North walls and roof)	0.01 $W/m^2 \cdot K$	Pre-occupancy fabric evaluation	N/A
4	Outdoor air temperature via onsite weather station	0.1°C	Post-occupancy evaluation	15 min.
5	Outdoor relative humidity via onsite weather station	1%	Post-occupancy evaluation	15 min.

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6	Outdoor wind speed and direction via onsite weather station	0.1 km/h	Post-occupancy evaluation	15 min.
7	Global solar radiation via onsite weather station	1 W/m^2	Post-occupancy evaluation	15 min.
8	Building space heating consumption via ORSIS	1 kWh	Post-occupancy evaluation	30 min.
9	Indoor air temperature via ORSIS	0.1^{o}C	Post-occupancy evaluation	30 min.
10	Space occupancy via HIVE	0/1	Post-occupancy evaluation	15 min.
11	Building ventilation and lighting electric consumption / pattern	0.1 kWh	Post-occupancy evaluation	30 min.
12	Heating set-point via HIVE / ORSIS	1^{o}C	Post-occupancy evaluation	30 min.
13	Heating pattern via HIVE	0 / 1	Post-occupancy evaluation	15 min.

Table 64: List of data for calibrated simulations in the Cypriot case study

No	Measurement name	Unit* for calibration	Phase	Time interval
1	Space occupancy	0/1	Post-occupancy evaluation	The model uses hourly data
2	Door/Window opening	0/1	Post-occupancy evaluation	
3	Building electric power	1 W	Post-occupancy evaluation	
4	Building electric consumption	1 kWh	Post-occupancy evaluation	
5	FAE electric energy power	1 W	Post-occupancy evaluation	
6	FAE electric energy production	1 kWh	Post-occupancy evaluation	
7	Indoor air temperature	1^{o}C	Post-occupancy evaluation	
8	Outdoor air temperature	1^{o}C	Post-occupancy evaluation	
9	Global radiation	1 W/m^2	Post-occupancy evaluation	
10	Construction document and system specification review	N/A	Pre-occupancy review	
11	Thermal imaging	N/A	Pre-occupancy fabric evaluation	
12	In-situ U-value tests (North wall)	0.01 W/(m^2·K)	Pre-occupancy fabric evaluation	
13	Heating set-point (occupant survey)	1^{o}C	Post-occupancy evaluation	

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Annex C - Cypriot demohouse – building model

The building model of the ZERO-PLUS demohouse was built in DesignBuilder. Figure 70 shows the geometrical layout, type of use of the rooms and orientation of the building.

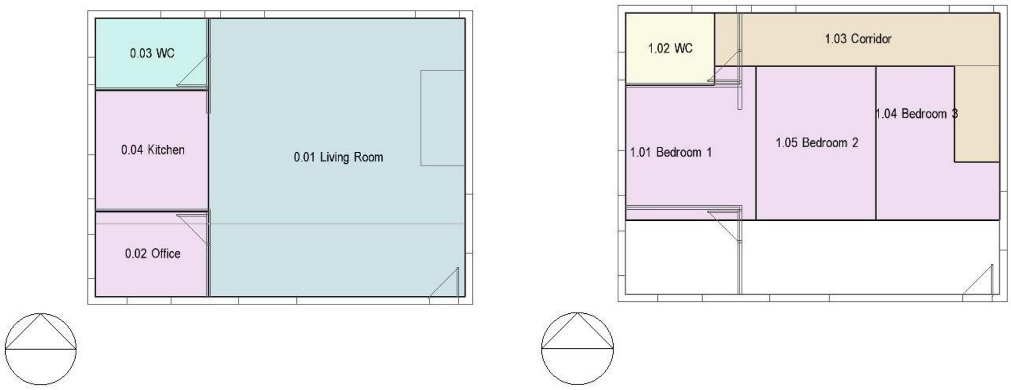

Figure 70: Geometrical layout and type of use of the rooms. Ground Floor on the left and First Floor on the right.

Schedules used to model occupancy and occupant related input data (Figure 71) and occupation density (Table 65) are reported.

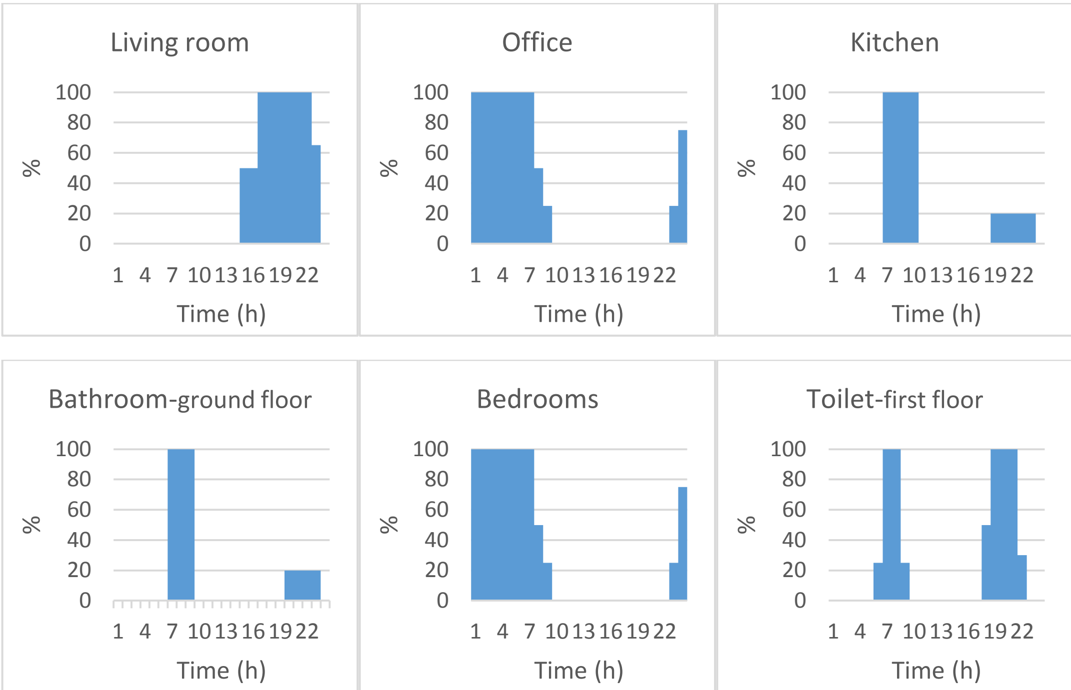

Figure 71: Schedules used to model occupancy and occupant- related input data

Table 65: Occupation density per thermal zone used in the numerical model of the ZERO-PLUS demohouse

	Living Room	Office	WC	Kitchen	Bedroom 1	Bedroom 3	Bedroom 2	WC

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Occupation density (People/m^2)	0.11	0.0229	0.102	0.0229	0.068	0.068	0.068	0.0243

Table 66 presents the building characteristics used in the numerical model of the ZERO-PLUS demohouse

Table 66: Building characteristics used in the numerical model of the ZERO-PLUS demohouse

General information	**Future ZERO-PLUS demohouse**
Gross floor area in m^2	390
Thermal transmission coefficients	
U-Values of walls in W/(m^2 K)	0.21
U-Values of roof in W/(m^2 K)	0.21
U-Values of floor in W/(m^2 K)	0.644
Other specific parameters	
Shading	Overhanging slab extension / External shading in bedrooms
Type of glazing (U-value in W/(m^2 K); g-value is adimentional)	Common Low-Emissivity double glazing (U = 2.40; g = 0.56)

Regarding the active systems, given the novelty of freescoo HVAC and FAE HCPV, the most similar components available in the software were used: a water-source heat pump with mechanical ventilation system for the freescoo HVAC and the PV module for the FAE HCPV. Those components were tailored to meet the nominal performance of the active systems.

Since the building has not been built before the ending of the ZERO-PLUS project, it is not possible to calculate the actual final energy consumption of the building.

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Annex D - KPIs for the Cypriot Case study

The ZERO-PLUS settlement in Cyprus is a theoretical cluster made of two demohouses located into the plot of the Cyprus Institute along the east-west axis (therefore not generating solar obstructions among them) and two FAE HCPV/T modules located in front of the demohouses (and not obstructed along the operating angles ±60º). The result of energy simulation for one of the ZERO-PLUS demohouses is reported in the internal document Impacts calculation and Methodology for simulations and performance verifications for the ZERO-PLUS demohouse in Cyprus [11].

To compute the **carbon emission reduction** from the energy calculation reported in [11], the following carbon emission conversion factors are adopted:

1. 0.794 $kgCO_2/kWh_{electricity}$.
2. 0.266 $kgCO_2/kWh_{diesel}$.

Given an electricity savings of 2696.26 kWh and a diesel saving of 164 kWh (both delivered energy per energy carrier) for each ZERO-PLUS demohouse, the corresponding carbon emission reduction of the settlement implementing the ZERO-PLUS demohouse concept is:

((2696.26 x 2) x 0.794) + ((164 x 2) x 0.266) = 4281.66 + 84.25 =

= 4368.9 $kgCO_2$/year = 33.60 $kgCO_2/m^2$/year =

= **4.37 $tnCO_2$/year = 0.034 $tonCO_2/m^2$/year**.

Moreover, the **overall yearly energy cost saving** for the ZERO-PLUS settlement can be computed assuming a specific energy cost saving of:

1. 0.3 €/kWh for electricity[12],
2. 0.638 €/litre for (heating) diesel[13].

Assuming, in average, a calorific content of diesel of 10.96 kWh/litre (whose only 30% is directly used for water heating[14]), the specific energy cost saving is:

((2696.26 x 2) x 0.30) + ((164 x 2) / (10.96 x 0,3) x 0.638) = 1617,76 + 63.64 =

= **1681,40 €/year**

Table 67: Summary of energy conservation and cost savings for the future ZERO-PLUS demohouse

Total Area of demonstration (m2)	Energy Consumption for the Reference	Energy Consumption of the ZERO-PLUS demohouse and	Energy Conservation on yearly basis (kWh)	Carbon Emissions Reduction ($tonCO_2$/year)	Energy Cost Savings (€/year)

[12] https://in-cyprus.philenews.com/cyprus-had-the-highest-increase-in-electricity-prices-in-the-eu/#:~:text=According%20to%20Eurostat%2C%20electricity%20prices,%E2%82%AC18.3%20per%20100%20kWh.

[13] https://www.globalpetrolprices.com/Cyprus/heating_oil_prices/

[14] https://www.sustainabilityexchange.ac.uk/files/cambridge_regional_college_sus_how_much_energy_do_you_use_pdf.pdf

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	demohouse + Districts (kWh)	Settlements (kWh)			
2 x 130	19,369 **(35,813)**	13,976 **(21,500)**	5,393 **(14,066)**	4.37	1681,40

The numbers in parentheses are the primary energy consumption based on the fuel mix used.

The cost reduction is calculated as the yearly energy cost saving of the ZERO-PLUS settlement and similar settlement made of conventional demohouse [11].

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Annex E - Assessment of non-ZERO-PLUS dwellings in the same development

The assessment of three non-ZERO-PLUS dwellings included post-occupancy evaluation and indoor environmental monitoring. The findings provide a reference for comparing the indoor environmental conditions and occupant experiences of ZERO-PLUS dwellings with the non-ZERO-PLUS dwellings. Note that for this analysis, UK1 – 3 are referred to as ZP1 – 3.

Findings from Post-occupancy evaluation:

The POE surveys which were used for the ZERO-PLUS dwellings were used to evaluate the non-ZERO-PLUS (NZP) dwellings. These were sent out to occupants at the same time as the ZERO-PLUS dwellings for the Winter period (February 2020) and Summer period (August 2020). In the winter period four responses were returned (two in NZP1, one in NZP2, and one in NZP3). In the summer period three responses were returned (two in NZP1 and one in NZP3; NZP2 reported an illness in the family and was unable to return a response).

As opposed to the ZP dwellings, the NZP dwellings were more diverse in origin, age, and household make-up. NZP1 was occupied by a family originally from Portugal; the others were from England. Whereas, in the ZP dwellings the households were mostly young individuals (almost all 25-34 years old), the NZP dwellings were older with two in the 35-44-year range, and two in the 45-64 year range. All NZP households were in their houses longer than the ZP households at the time of survey (Table 68).

Table 68: non-ZERO-PLUS dwelling details

	NZP1	NZP2	NZP3
Form	Left side semi-detached	Detached	Semi-detached
Total Floor area (m^2)	Not available	Not available	Not available
No. of bedrooms	3	3	2
Time in dwelling	3 years 5 months	3 years	8 Months
Number of occupants	4	4	2
Household	2 adults / 2 children	3 adults / 1 child	1 adult / 1 child
Renewables	12x – 300 Wp PV panels	None	None

In the winter period only one person (NZP2) reported fatigue among all sick building syndrome symptoms questioned. In the summer one person (NZP3; different NZP3 occupant from winter survey) reported fatigue, sleepiness and headache. It is notable that this person also reported a chronic condition from a brain injury. Fatigue and sleepiness were also reported among the ZERO-PLUS dwellings.

In the winter period perception of temperature, ventilation, noise, lighting, and odors were 'good' and mostly 'very good'; with no negative responses. In the summer period, the responses were the same for NZP1 but NZP3 reported a 'poor' opinion of temperature and a 'very poor' opinion of odors. In contrast, there were no 'very poor'

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opinions in the ZERO-PLUS dwellings; however, one ZERO-PLUS dwelling respondent considered temperature ‘poor’ and in another noise to be ‘poor’.

In winter period all occupants reported that they open windows to control the thermal environment. In the summer, this response was the same; however, all NZP dwellings noted that the houses are difficult to cool down when they get too hot and opening windows is only ‘slightly effective’. Like the ZERO-PLUS dwellings, the NZP occupants all open windows during the day and at night, open doors to secure areas (e.g. garden), drink cold drinks and use a stand or desk fan to cool down when it is too hot.

The overall satisfaction was ‘very good’ in all dwellings except NZP3 (noted in summer only). The reason for this was that the house is “very hot in summer cold in winter”. Positive comments noted good Indoor Air Quality (IAQ), well-built and tight house, heating is responsive, and good sound proofing.

Assessment of indoor environment:

From the assessment of indoor environment through data loggers in the living room of all dwellings for the winter, the temperature patterns for the NZP dwellings appear to not be significantly different from the pattern for the ZERO-PLUS dwellings (Figure 72). However, ZP3 and ZP2 stand out somewhat from the others. In ZP3 it was a pattern of low heating; in ZP2 it was a pattern of high heating. NZP2 also had high temperatures but they weren’t maintained as steadily as ZP2. NZP3 and ZP1 had very similar temperature patterns.

Table 69 shows the correlations between interior and exterior temperature, interior and exterior relative humidity (RH), and window opening count on an hourly basis. The NZP dwellings have a stronger relationship between inside and outside temperature; however, the RH relationship is low over all dwellings. ZP3, the dwelling with the lowest temperatures, had the window open for over 50% of the hours during the winter period assessed. Table 70 shows the mean and standard deviation for the temperature and RH in winter and summer. For the winter period, the mean temperature in the NZP dwellings ranged between 18 and 22^{o}C. The standard deviation in temperature was smaller in the dwellings that opened windows more. High frequency of window opening likely corresponded to lower heating setpoints. Between the ZP and NZP dwellings, the variability in temperature appears to be most related to occupant behavior.

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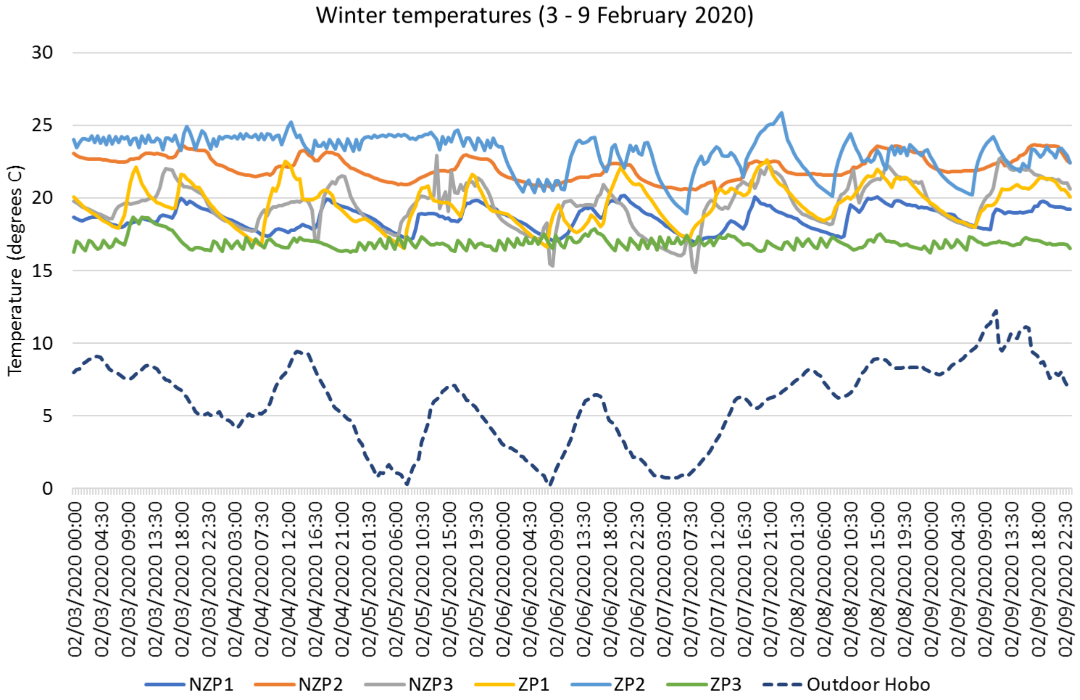

Figure 72: Winter temperature data for the living room in all dwellings

Table 69: Winter and summer temperature and RH indoor / outdoor correlations and window opening count (hourly)

	Winter (3-9 February 2020)			**Summer (27 July – 2 August 2020)**		
	Temperature (r)	**RH (r)**	**Window**	**Temperature (r)**	**RH (r)**	**Window**
NZP1	0.33	0.36	14	0.58	0.19	46
NZP2	0.70	0.07	2	0.76	0.56	81
NZP3	0.61	0.11	5	0.81	0.54	8
ZP1	0.45	0.01	0	0.83	0.71	0
ZP2	0.18	0.16	0	0.82	0.66	43
ZP3	0.10	0.19	91	0.79	0.58	68

Table 70: Winter and summer temperature and RH mean and standard deviations

	Winter (3-9 February 2020)				**Summer (27 July – 2 August 2020)**			
	Temperature		**RH**		**Temperature**		**RH**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
NZP1	18.6	0.79	55.8	2.2	24.1	0.9	54.4	4.2
NZP2	22.1	0.82	36.2	1.9	22.2	1.6	53.1	3.8
NZP3	19.6	1.55	41.9	3.1	23.3	1.6	48.2	4.3
ZP1	19.6	1.37	40.9	3.0	24.5	1.7	48.5	5.3
ZP2	23.1	1.29	36.8	2.9	24.0	1.6	48.5	5.5
ZP3	17.0	0.42	46.9	5.4	24.0	2.0	47.8	5.9

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From the assessment of environmental loggers in the living room of all dwellings for the summer, the temperature patterns for the NZP dwellings are more in line with the patterns of the ZP dwellings (Figure 73). Interestingly, however, when the external temperature peaked during the period (30°C), the NZP dwellings remained cooler than the ZP dwellings. Though orientation, size, form, shading, and occupancy can all affect this, the use of windows (Table 68, above) could be a notable influence as, for example NZP2, the coolest dwelling, opened the window almost 50% of the time. The summer mean temperature in the NZP ranged from 22 to 24°C. Overall ZP1 remained the warmest with no window opening. It should, however, be noted that though the most used window in a room was requested from the occupant during placement of the loggers, not all windows were monitored in the room. Internal and external temperature correlation was much stronger in the summer as windows were opened more in most dwellings. With respect to overheating thresholds, following the temperature peak on 31 July 2020, the remaining days are expected to were uncomfortably warm if not hot for all dwellings except for NZP2. It can be seen here why all NZP dwellings noted that the houses are difficult to cool down when they get too hot and opening windows is only 'slightly effective', though NZP2 appears to be managing the heat better than the other dwellings.

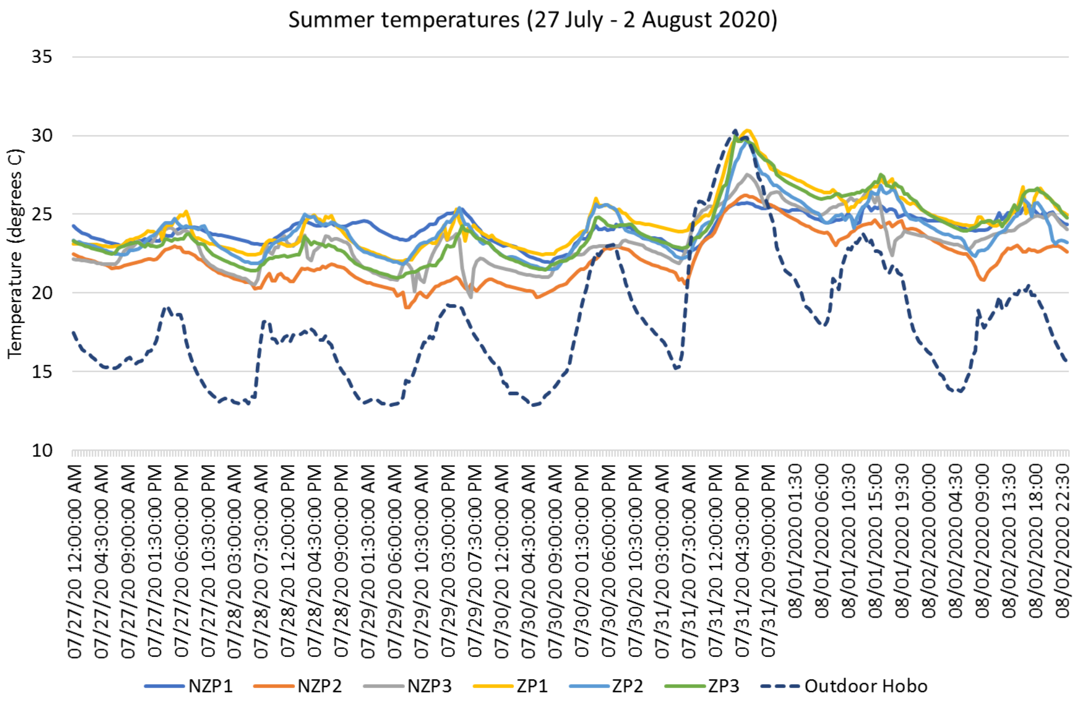

Figure 73: Summer temperature data for the living room in all dwellings

Winter RH mean ranged between 36 and 55%. Winter RH for all dwellings was fairly close in percentage and pattern with the exception of NZP1 (Figure 74). It is theorized that they may have a humidifier as their mean RH was 10% points above the second highest value. As NZP1 and ZP3 both opened windows more frequently in the summer they also have different and sometimes higher RH patterns than the other dwellings. In most dwellings the mean RH was too low (<~40%) but the higher RH

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was likely more acceptable in the dwellings that opened windows. Summer RH, like summer temperature showed a much tighter match in pattern as the dwellings are all free-running (Figure 75). In the summer the NZP RH ranged from 48 to 54% with very high standard deviation, corresponding with changes in the external RH. Though the relationship between internal and external RH in the summer was relatively strong in most dwellings, in all cases, the relationship was stronger for temperature.

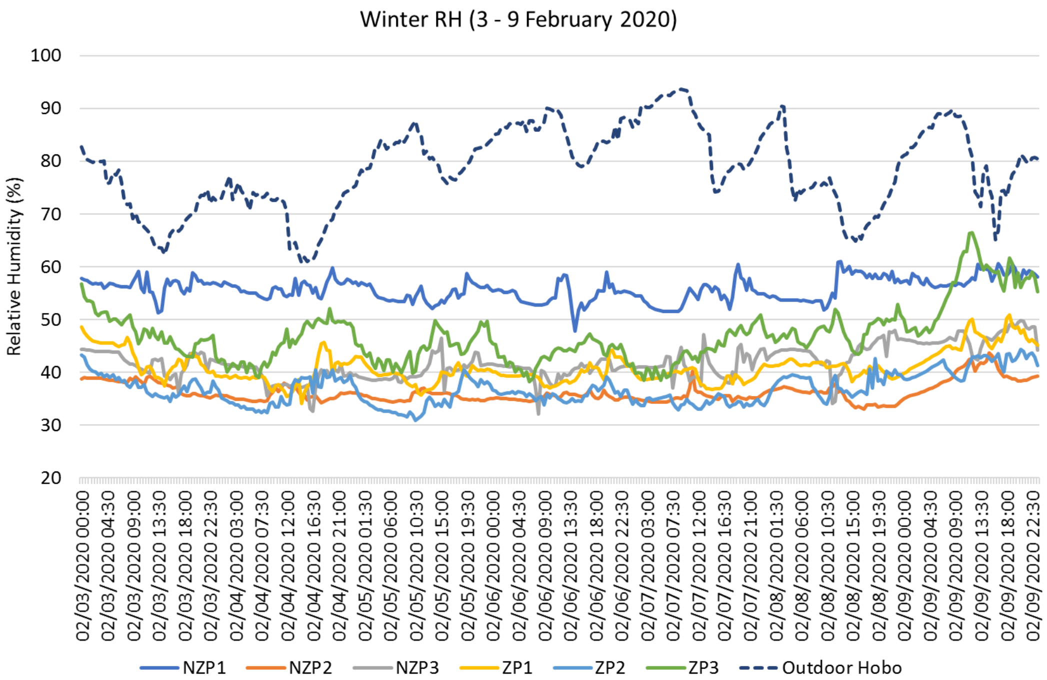

Figure 74: Summer RH data for the living room in all dwellings

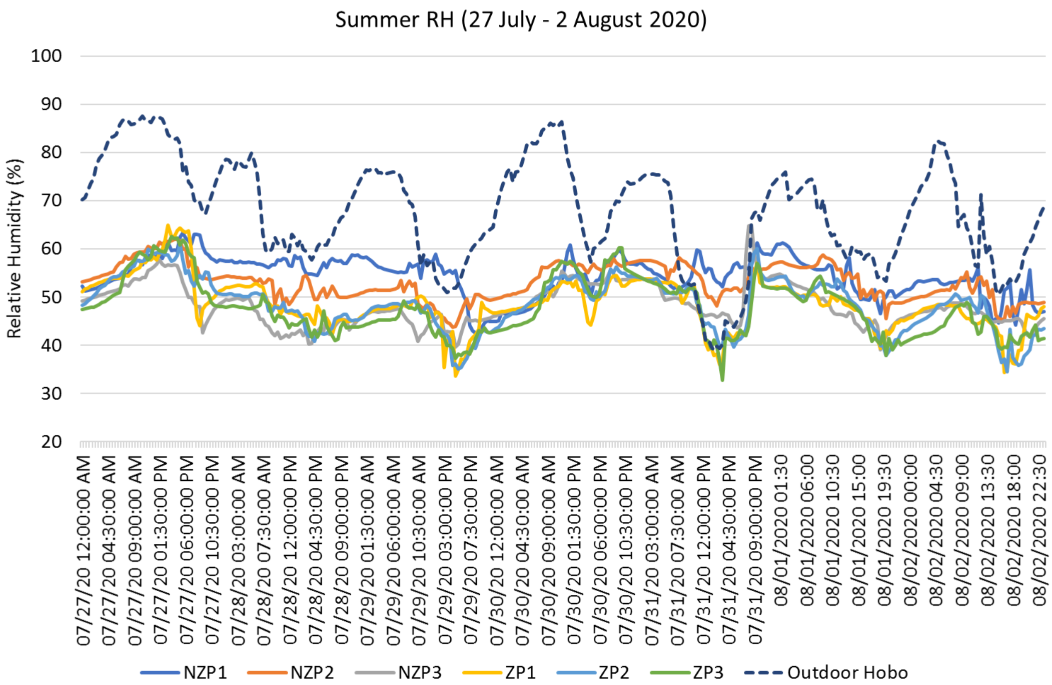

Figure 75: Summer RH data for the living room in all dwellings

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Annex F- Problem Identification Procedure

The present Problem Identification Procedure is a protocol of steps that are suggested to be followed and implemented by each case study support group (Rescue team) supported by the case study owners and technology providers as needed. The steps of the protocol should be implemented one after the other as follows:

- Step 1: weather check
- Step 2: fabric check
- Step 3: technologies check
- Step 4: occupant check
- Step 5: monitoring system check

Initiation of procedure

The reason for initiation of a Problem Identification Procedure will be the non-satisfactory performance of the ZERO-PLUS settlements.

The ZERO-PLUS project has set targets for energy production and energy consumption per year:

- Operational energy usage in residential buildings ≤ 0-20 kWh/m² per year
- Renewable energy generation ≥ 50 kWh/m² per year

Considering that the horizon of a year is long and in order to avoid accumulation of problems, a period of 1 month will be defined for checking the performance. Every 1 month a performance report will be generated and sent to the "Rescue Person". The performance report can be generated automatically by the Web-GIS platform. Simulation models, in order to have the projected performance for comparison, are already available per case study.

If the performance report reveals that performance was not as expected for that 1 month period, the "Rescue Person" will initiate the problem identification procedure in order to identify the cause and if possible take corrective actions. The Rescue Team, the case study owners and the technology providers will be requested to participate in relevant phases.

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First step

Firstly exogenous causes will be sought, specifically incidences of extreme weather.

Purpose of this step is to check whether extreme phenomena have occurred that could compromise performance by reducing energy production of the innovative technologies or intriguing energy consumption.

The Rescue Person, assisted, by re the Rescue Team if needed, will go through the data for that period and will identify whether extreme weather phenomena might have compromised performance. If unusual weather data have been recorded simulations using the recorded weather data of that period will verify if poor performance is related to extreme weather. The case study modeling teams will participate in this step for preparing the weather files and running the simulations.

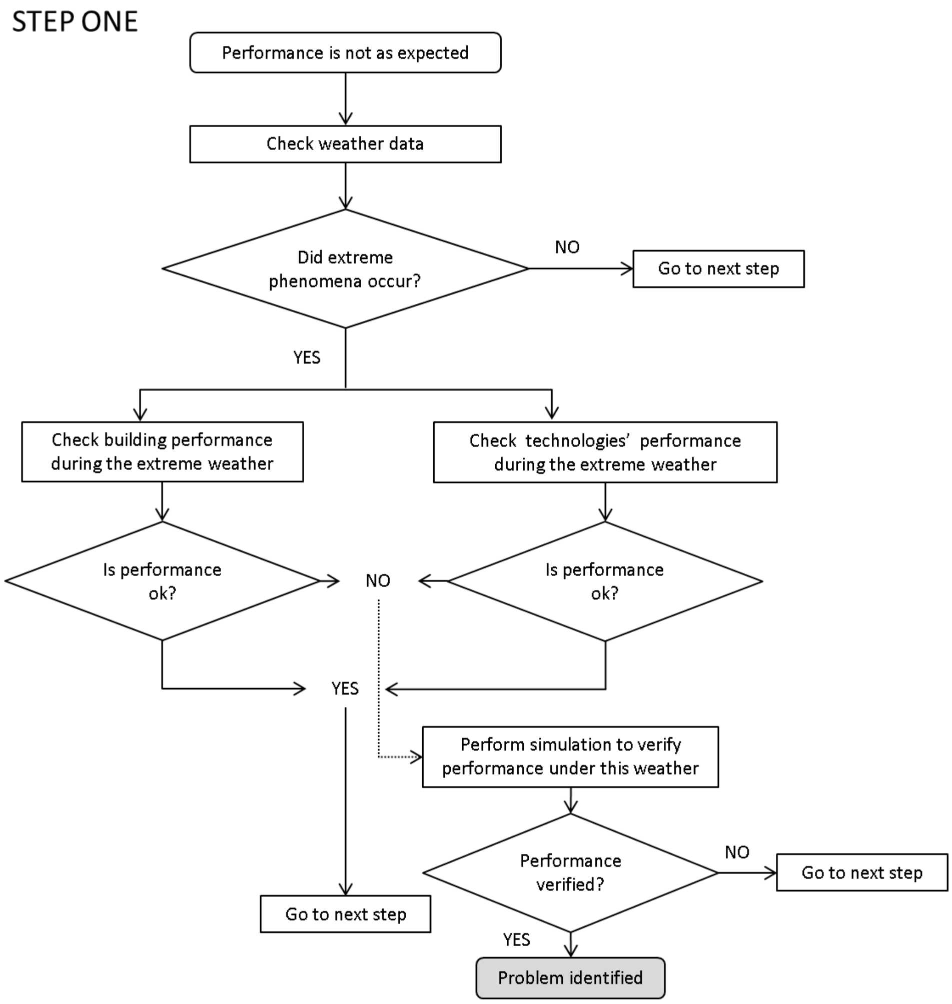

Figure 76: Flowchart of step 1 for problem identification

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Second step

After excluding weather as a cause of poor performance, the next step should be to check the building fabric. According to D6.7 Building Commissioning Plan, building diagnostics tests will be performed after construction and pre-occupation. Performance of the fabric should be verified prior to handover and the results will be recorded in the Commissioning Report.

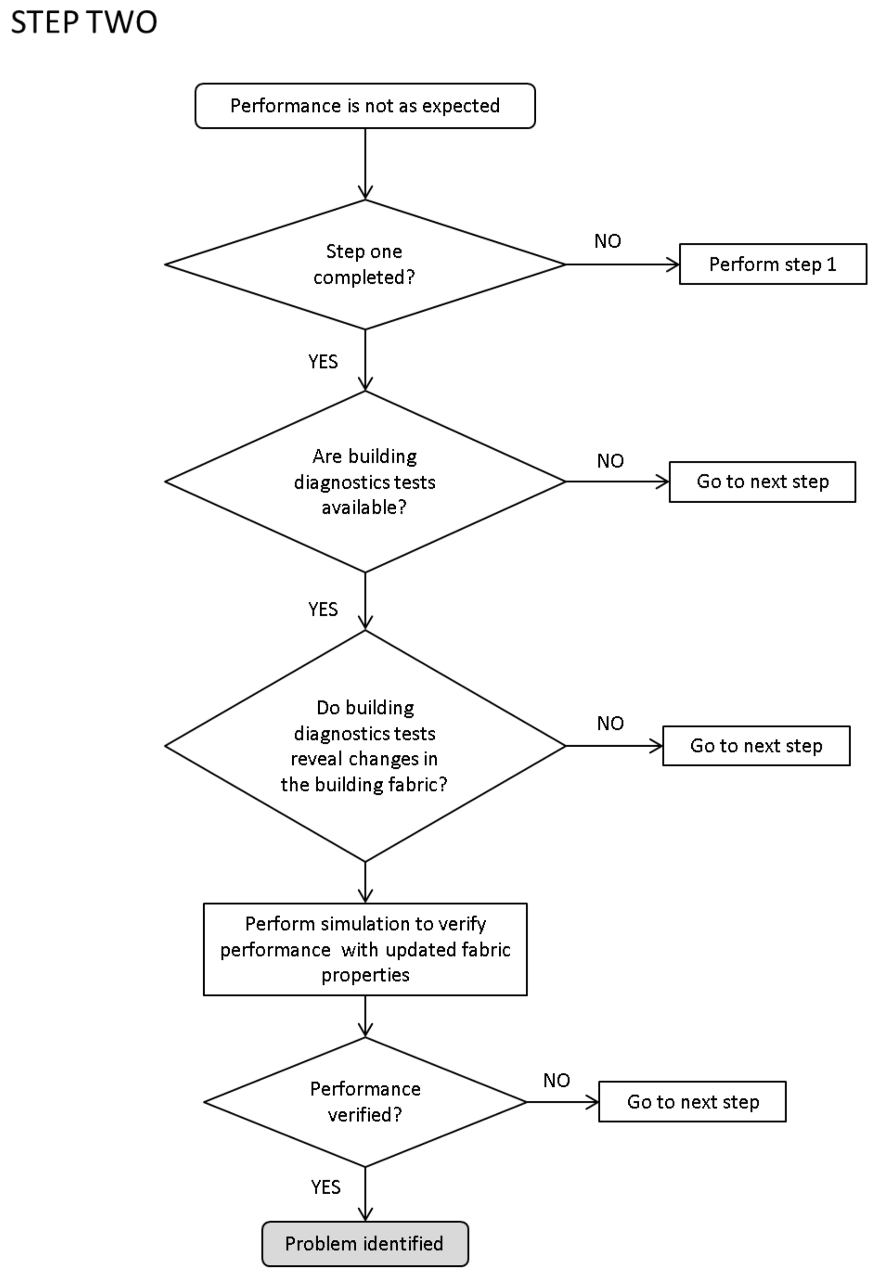

Figure 77 Flowchart of step 2 for problem identification

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It is unlikely that a new building will show fabric deterioration within a month or a few months, so this step could be omitted during the first year and be used after the first year of the building's life.

For the implementation of step two, portable instruments will be needed for the performance of the tests. The case study support teams might be able to provide such instruments. Furthermore, the case study support teams might have to run simulations with updated fabric properties.

Third step

The performance of the technologies is being monitored and performance data (of each technology separately as well as simultaneous performance) are collected and stored in the Web-GIS platform.

Installation and functional tests will be performed as part of commissioning of the technologies. Approximately 1-2 months post-installation/pre-occupancy the technologies will be monitored and any abnormal performance will be identified and corrected. Installation, functional and post-installation/pre-occupancy tests are described in D6.7 Building Commissioning Plan; hence initial performance should be as expected and required. After that, if expected performance is not achieved, and having completed the first two steps, the technologies will also be checked.

For the third step, the "Rescue Person" will have to coordinate the audit of the commissioning report, of the maintenance schedule and of the fault notifications for each technology. The commissioning report will provide information about installation and initial performance. The maintenance schedule will show whether the technology has been maintained as expected. The fault notifications will show history of faults and whether they have been corrected.

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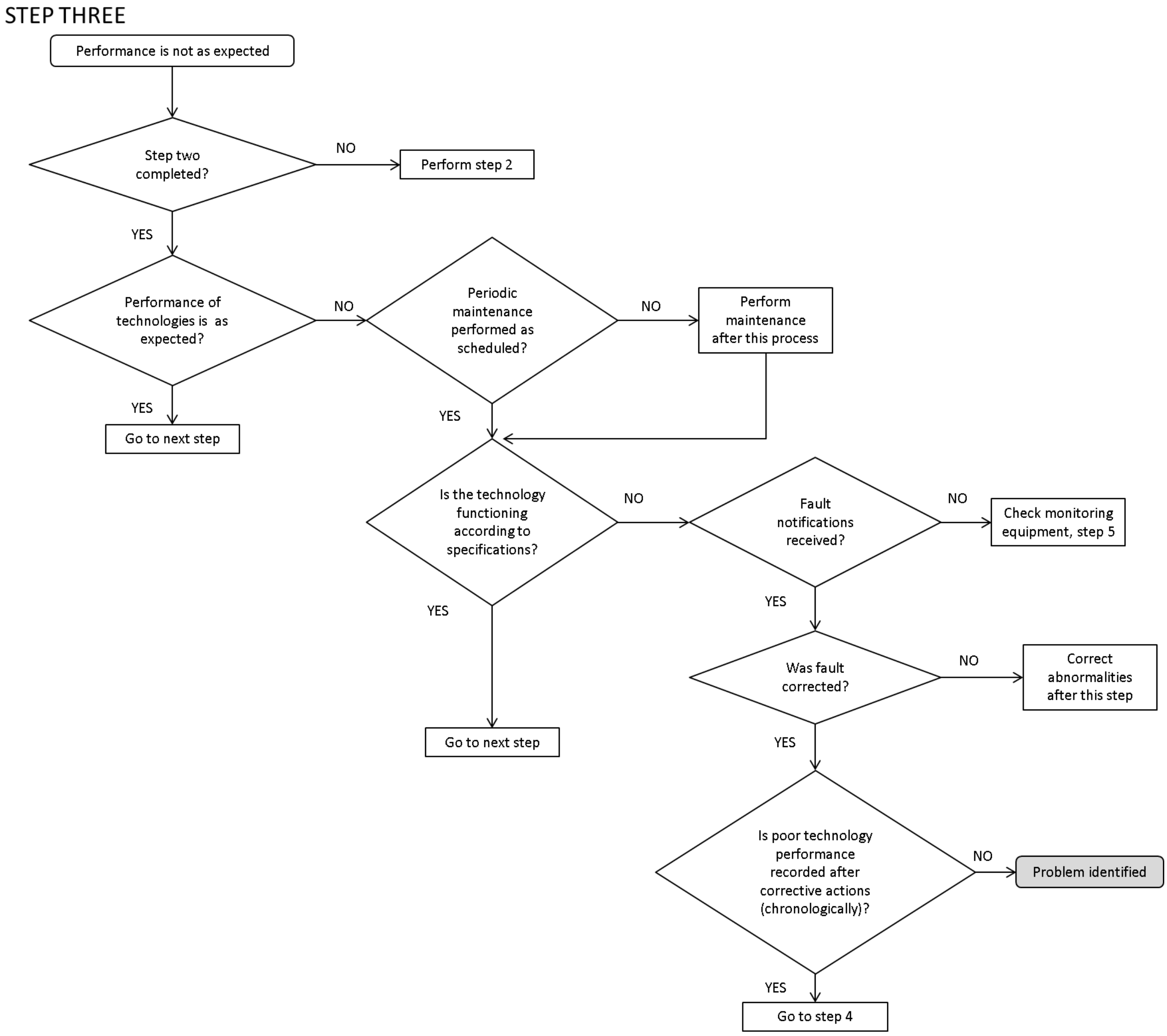

Figure 78: Flowchart of step 3 for problem identification

Fourth step

Interaction of the building users with the technologies and the buildings can affect performance. WindRail, FAE and SBskin are energy production technologies that will not be handled by occupants.

However, building users will interact directly with thermostats. Data from the HIVE thermostat (UK case study) can be captured and recorded thus identify if users' settings can have an impact on performance. The thermostat settings in the other three case studies will also be monitored. In this context, changes in Freescoo settings by occupants will also be captured.

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For this step the case study support teams might have to run simulations with the updated set-points.

STEP FOUR

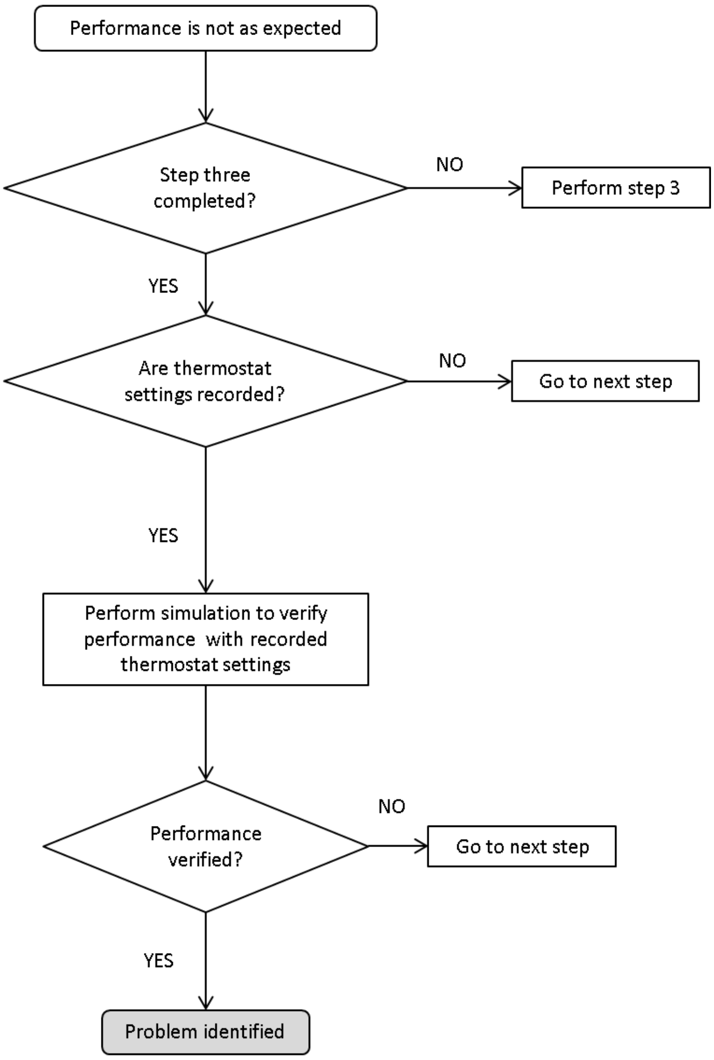

Figure 79 Flowchart of step 4 for problem identification

Fifth step

If the previous steps do not reveal a cause for poor performance, it is possible that the results might be given from false data and the monitoring equipment should be checked for possible malfunction, data loss etc.

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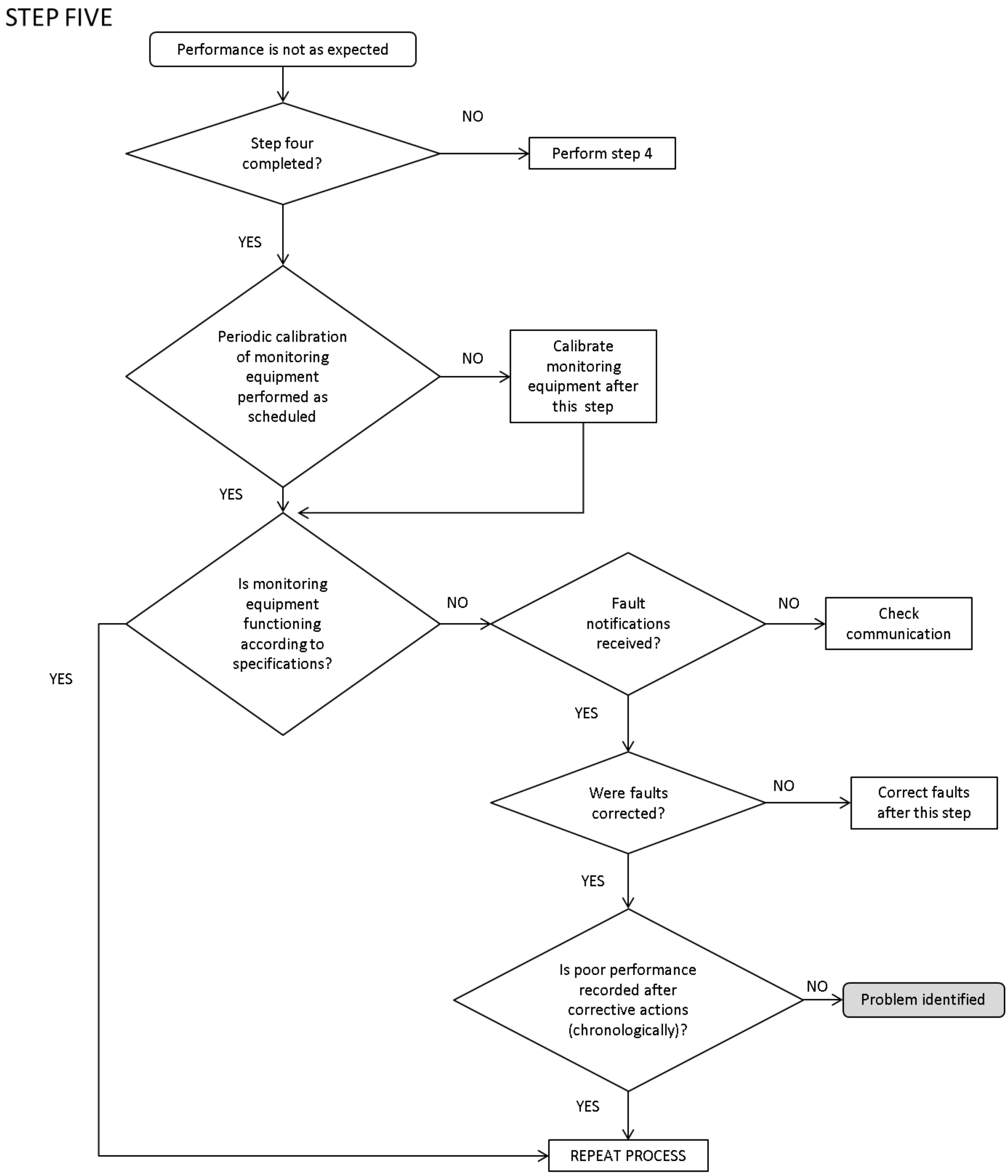

Figure 80: Flowchart of step 5 for problem identification

Pre-installation, installation and functional tests of the monitoring equipment will be performed as part of the measurement and verification procedures that have been described in the Measurement and Verification Plan as well as in D6.7 Building Commissioning Plan. Initial function should be as expected and required.

A periodic calibration plan for sensors will be established and fault detection of monitoring (building sensor readings and technology sensor readings) has been designed and will be implemented as part of WP7.

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For this step, the "Rescue Person" will have to coordinate the audit of the commissioning test results, of the calibration schedule and of the fault notifications for the monitoring equipment.

Problem Identification Overview

Coordinator of the Problem Identification is the Rescue Team.

Problem Identification Initiation

The Web-GIS platform will generate monthly a performance report. The report will be sent via e-mail to the Rescue Person.

The reason for initiation will be non-satisfactory performance results compared to the expected results for that period

The steps of the process

Table 71: Overview of the Problem Identification steps

	Step 1	Step2	Step3	Step 4	Step 5
Subject of investigation	Weather	Building fabric	Technologies	Occupants	Monitoring
Coordinator of step	Rescue Person				
Participating partners	Case study modelling teams	Case study modelling teams	Technology providers, Maintenance	Case study modelling teams	Person responsible for equipment calibration
Related Documents		Commissioning report	Commissioning report, Maintenance schedule, Fault Notifications		Commissioning report, Maintenance schedule, Fault Notifications
Comments		This step can be omitted during the first year of the building's life	There has to be for each case study someone responsible for technologies' maintenance and for keeping a maintenance schedule		

Problem Identification Results

The Rescue Person will document the results in a report following the template below:

Problem Identification Procedure No: (eg 1st)

On (Date), (Name of Person Notified) received the Performance Report No…… that is attached.

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(Name of Person Notified) informed about the results:

(Name) on (Date)

(Name) on (Date)

………

Actions taken:

- **1st step: YES/ NO**

If Yes:

Date of initiation:

Participating partners:

Date of completion:

Results:

If NO:

Reason:

- **2nd step: YES/ NO**

If Yes:

Date of initiation:

Participating partners:

Date of completion:

Results:

If NO:

Reason:

- **3rd step: YES/ NO**

If Yes:

Date of initiation:

Participating partners:

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Date of completion:

Results:

If NO:

Reason:

- **4th step: YES/ NO**

If Yes:

Date of initiation:

Participating partners:

Date of completion:

Results:

If NO:

Reason:

- **5th step: YES/ NO**

If Yes:

Date of initiation:

Participating partners:

Date of completion:

Results:

If NO:

Reason:

- **Final Results:**
- **Notes/Recommendations:**

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Annex G - Additional Information on HIVE, freescoo and FAE HCPV.

HIVE

HIVE comes with an online app that allows:

- Heating control: Switch heating on and off, up or down; the boost button allows extension of heating outside of regular schedule
- Hot water control: Turn hot water on and off; the boost button allows extension of water heating outside of regular schedule
- Geolocation: Based on the user's phone location, HIVE will send reminders to turn heating on before arriving at home, or off if left on accidently
- Heating & hot water schedules
- Frost protection: To help protect pipes from freezing, HIVE automatically activates when the heating is off and the temperature inside your home dips below 7°C.

The full HIVE Energy Management system that is installed consists of:

- HIVE smart learning thermostat
- HIVE Window or Door Sensor, which provides notifications if a door or window is opened when the resident is away and works with HIVE Actions to save on heating and lighting.
- HIVE motion detection
- HIVE Active Lights, which allow lighting to be set to schedules brightness levels, with the ability to save energy by controlling lights remotely.

HIVE Active Plug, which allows for Control from smartphone, tablet or laptop, and to schedule appliances to switch off automatically.

HVAC freescoo system

The characteristics of the freescoo system are shown in Table 72.

Table 72: Characteristics of the freescoo system

Characteristics		Remarks
Dimensions	1986 mm x 1000 mm x 283 mm (both evaporative and absorption units)	
Weight	Ca. 150 kg	
Kind of installation	Wall mounted	
Hot water	Two pipes of 1/2” for supply and return	Adsorption unit directly connected to the circuit of solar hot water; a boiler can be used as a backup system;
	Two pipes of 1/2” for evaporative unit and	Evaporative unit uses water treated by a small osmosis system

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Characteristics		Remarks
Cold water	drain	
Electrical characteristics	220V AC or 24V DC	

For the installation in the ZERO-PLUS demobox, the freescoo HVAC system is equipped with a frame designed with features, such as using minimum parts, which are flexible, interchangeable, and upgradable, lightweight, and suitable for mass production. In total, three types of frames were proposed within the project. All frames are made of structural steel profiles and are fixed to the freescoo system. For ventilation purposes, the external vent cover is designed to bridge up the connection between the external environment and the inlet/outlet air grills of the adsorption bed. The internal vent grill cover consists of two parts, an upper section and bottom section. The upper section provides an adjustable vent grill cover for interior use. The bottom section has two openings that provide easy accessibility during installation of the pipes and during later maintenance, as shown in Figure 81.

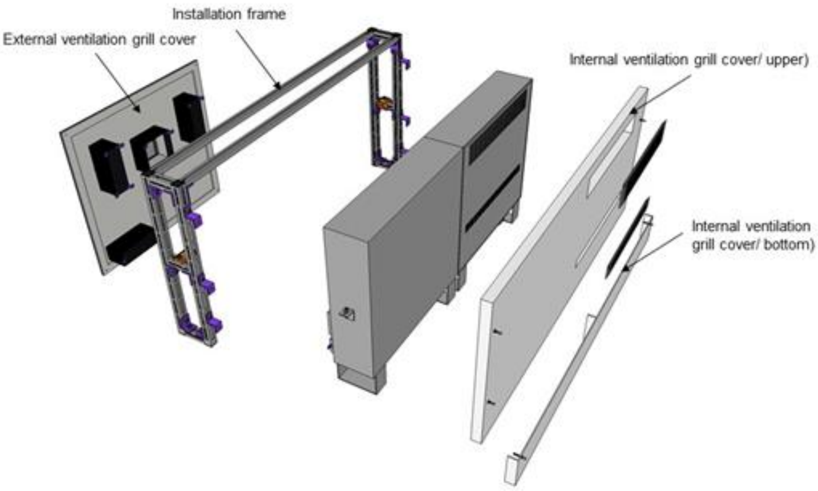

Figure 81: freescoo system installation frame details

The structural details of the building, the connection methods, the accessibility of the site, etc. must all be considered prior to final installation. The main installation tasks include uploading the system off the truck, hoisting the system and lowering it down to the assembly floor level, transporting the system at the installation location, remove the existing window, make openings for ventilation grills, install the steel installation frame, install freescoo system along with accessories, construct the wood stud back support structure, install the aluminium supporting frame, clips, profiles, and fixtures, install FIBRAN insulation panels, install the side cladding panels, and the left, right front panel, and finally, install the frontal cladding panels, see Figure 82.

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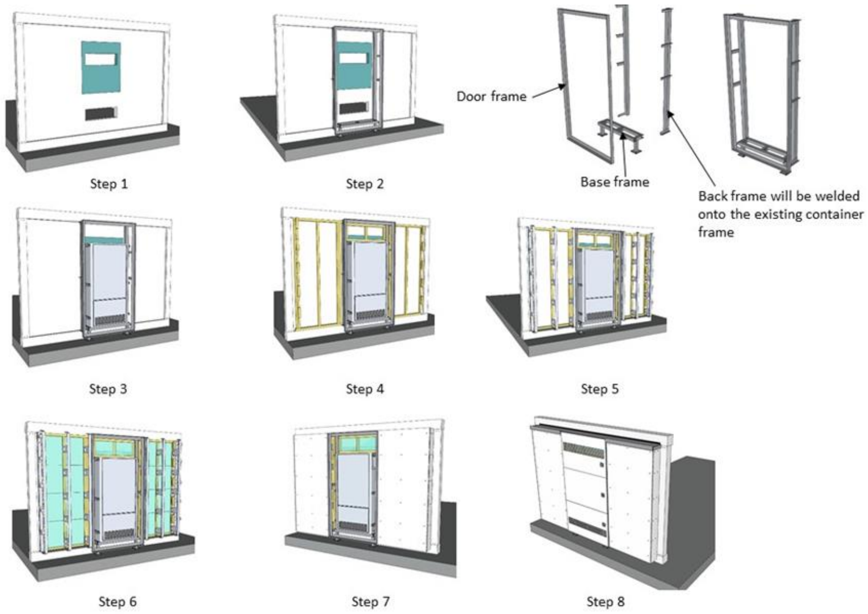

Figure 82: freescoo system installation method

FAE HCPV

The characteristics of this system are summarized inTable 73.The complex system requires some specific considerations for the installation, such as:

- The height of the supporting foot might be reduced to avoid unpleasant visual impact;
- Special qualified engineers are required to assemble and install the technologies, following instructions from the technology providers.
- The potential installer needs to be trained by the technology providers (condition in tender);
- Importance of collaboration with the Main Contractor;
- Proper maintenance from qualified people during the lifetime of the technologies.

Before the final installation of the FAE HCPV/T system, the ground in the proximity of the case study building will be prepared. Afterwards, the final assembly steps will be performed according to the instruction provided by IDEA.

Briefly, the individual installation steps are: positioning the centre foot and installing the worm reduction gears; installing the side feet and the external axes; installing further components such as the optic port, the transmission system, the actuation system, the optical concentrator, the heat sink, the hydraulic mounting connectors, the fitting sinks, and the rotary encoder.

To ensure the functionality of the system, the mirrors require regular cleaning. The cleaning task needs to be done manually and carefully in order not to scratch the mirror surface. The hydraulics and electric connections require regular inspection and maintenance, as well. Access for maintenance needs to be ensured as well as protection from unintended access.

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Table 73: Characteristics of the FAE HCPV/T system

General characteristics of FAE HCPV module	
Net surface of each concentrator	2.025 cm^2
Solar concentrator	≈ 2.000x
Optical efficiency	90%
Tracking system	Two-axis Alt-Alt
Dimension	1.4 x 6.5 m
Weight	280 Kg
Wind resistance	3.4KN/m (wind speed 20m/s)
Heating temperature	60 – 70°C (Compatible with the inlet of the Solarinvent freescoo cooling units)
Mirrors	Ultraclean glass with silver coating, Reflectivity >95%
Structure	Galvanized steel

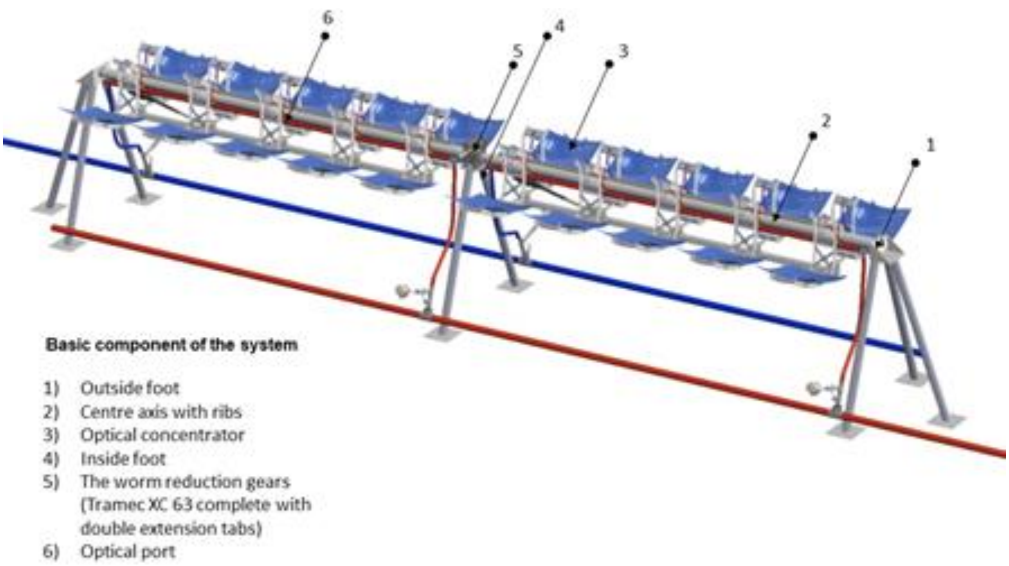

Figure 83: FAE HCPV/T system components

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Annex H – Confidential reports

The following reports could not be publicly disclosed:

- HI: Monitoring equipment
- HII: Positioning of the sensors
- HIII: Pre-occupancy checks report for the Italian Case study
- HIV: Pre-occupancy checks report for the French Case study
- HV: Pre-occupancy checks report for the UK Case study
- HVI: Pre-occupancy checks report for the Cypriot Case study

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