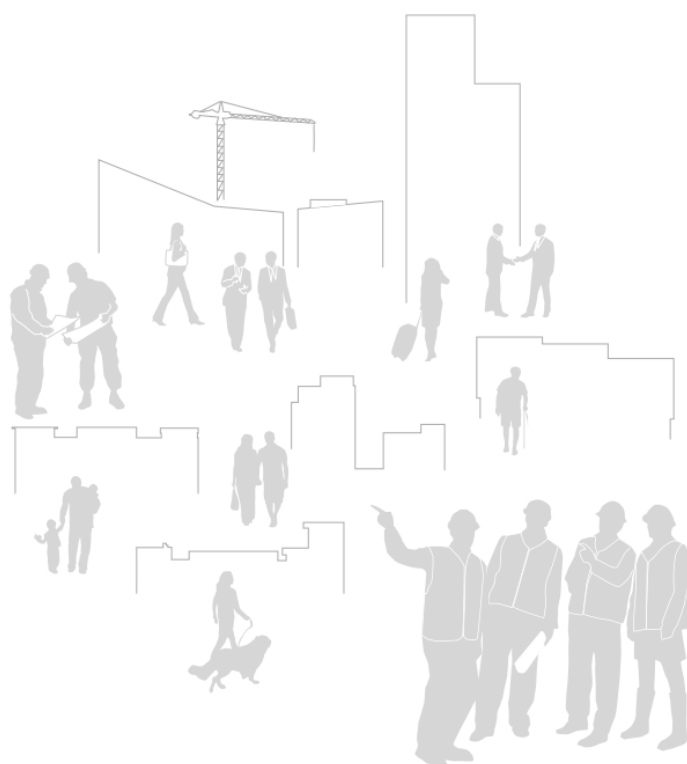




BUILDSMART

Energy efficient solutions ready for market



D.1.10 “Experience exchange and knowledge transfer between demonstrated residential buildings”

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X	PU = Public
	PP = Restricted to other programme participants (including the JU)
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Summary

Regarding residential buildings the main objective of the Buildsmart project is to demonstrate that with satisfactorily solved building designs it is possible to integrate advanced and even fully innovative solutions into residential buildings, with affordable costs, increased comfort, and system reliability and durability comparable to current standards.

The adequacy and energy performance potential of any specific combination of design strategies and technical solutions is set by the constraints existing in each building, and the optimum solutions for a specific project will not be directly adequate for significantly different boundary conditions (technical, economic and regulatory).

Taking this into account, in this document an assessment of the innovative solutions deployed on the different residential demo buildings is provided. Additionally, the existing potential regarding knowledge transfer and experience exchange between the residential buildings of the project has been evaluated, focusing especially on the influence of climatic conditions on the performance potential of the innovative solutions.

The assessment of the technical solutions implemented in the Swedish demos is based on the experiences of the involved technical stakeholders during the design, construction, commissioning and operational stages of the buildings. In this case, special attention has been given to the performance values obtained from the analysis of the monitored data for the first year of operation of the buildings.

However, in the case of the Spanish demo, for technical and administrative reasons beyond the control of the project partners, the monitored data available at the time of completion of this document (in terms of monitored period and data consistency with a standard residential building user behavior), was not enough to be used in the assessment of the performance of the deployed solutions, and in the evaluation of experience exchange potential between the residential buildings of the project.

In any case, project partners are aware about the key role of the Spanish residential demo building in the frame of the project, due to some of its features in comparison with the rest of the demos (it is the only building not located in Malmo, etc). As a consequence, in order to evaluate the fulfillment of the existing performance target, before the end of the project, a contingency plan has been implemented.

According to this plan a very accurate prediction of the performance of the building has been obtained through an updated and calibrated Energy Plus model of the demo building that has allowed confirmation of the consistency of the performance of the finally implemented building design with the energy efficiency target existing in the frame of the project.

On the other hand, and as part of this contingency plan, several discussions are ongoing with the ESCO that operates the Portugalete demo building, to define the most appropriate procedures to educate tenants and dissipate all the possible prejudices and misunderstandings regarding the

Experience exchange and knowledge transfer between demonstrated residential buildings D1.10
energy prepayment system of the building, that somehow is creating user behaviour patterns that are not consistent with standard user behaviour.

It is expected that in the coming weeks these procedures will enable fully adapting current user behaviour to standards allowing the collection of high quality and consistent monitored data, to complete the one year monitoring period after the end of the project. The monitored data will be delivered to the Smart Cities Information System as soon as they become available.

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1 Scope and goals

The objective of the Buildsmart project is to demonstrate innovative and cost effective techniques and methods for constructing very low energy buildings in various climates.

Two countries, Sweden and Spain, participate in the project and represent different European climatic zones. The residential demo buildings developed in the frame of the project have allowed the demonstration of new and innovative techniques applied to the residential sector.

A systematic approach has been taken in the measures applied to reduce the energy use and the environmental impact of the demonstrated buildings and specific techniques for optimizing building envelopes have been combined with different typologies of energy efficient installations (HVAC, distributed generation, etc).

The objective of this document is to provide an assessment of the innovative solutions deployed on the different demo buildings and additionally to evaluate the existing potential regarding knowledge transfer and experience exchange between the residential buildings of the project.

As it is well known the design of a building is affected by its use (specification of the required internal conditions) and by the technical, economic and regulatory constraints existing for each specific project. The adequacy and energy performance potential of any specific combination of design strategies and technical solutions, is set by the existing constraints and the optimum solutions for specific cases will hardly be adequate for significantly different boundary conditions.

As a consequence, an analysis of the potential of the innovative solutions deployed in the residential demo buildings of the project for different boundary conditions will be provided, mainly focused on climatic conditions.

The assessment of the technical solutions implemented in each of the demo buildings is presented in Chapter 2, including a summarized description of the technical aspects of the design of the 3 demos, in order to configure a self-descriptive document.

The assessment of the knowledge and experience exchange potential between different demo buildings has been provided in Chapter 3. Specific sections have been included to analyze the exchange potential between the Swedish demos and the exchange potential between the Swedish and the Spanish demos.

Finally, a summary of the obtained conclusions is presenter in Chapter 4.

2. Assessment of the implementation of innovative technical solutions

In this chapter the assessment of the implementation of the technical solutions deployed in the residential demos sites and the evaluation of the fulfillment level of the energy efficiency target defined in the frame of the project (60 kWh/m² year in primary energy) will be provided.

The procedure to display the consistency of the actual building performance with the existing target is based on the comparison of the energy consumption figures of the demo buildings measured for the first year of operation, with the energy performance target. Obviously, the availability of high quality monitored data for a complete year is necessary in order to enable the implementation of such procedure.

Unfortunately, and for reasons beyond the control of project partners, in the case of the Spanish demo building the lack of a sufficiently long period of building performance monitored data impeded the assessment of the performance of the deployed solutions according to this procedure before the end of the project. This issue will be analyzed in a specific section of this document.

2.1. Skanska Residential Building, in the KKH area in Malmö

This building is located in the KKH area in Malmö, within walking distance from the Central Station and the new City Tunnel station, between the old city center and the new modern district of the West Harbour. The gross floor area is 16 000 square meters, North building with 7500 m² and South building with 8500 m².

The northern building includes 72 apartments and 5 facilities. The building has a broader base of five floors and a tower on top with thirteen floors and a basement.

The southern house includes 86 apartments and 4 facilities. The house is projected as a building with three assembled buildings with five, eight and fourteen floors with a joint basement.

2.1.1. Description

The energy efficient design concept of the building is based on a minimized energy demand, optimized system technologies and integration criteria, and on an advanced control and monitoring platform, necessary to ensure the optimum operation of all the systems of the building.

With the implemented solution after the first year of operation of the building according to the collected monitored data, the building displays a consumption figure in primary energy of 58 kWh/m² and year.

Thermal envelope

As described in D1.9, the facade of the North building is a concrete solution (Concrete, PIR, Bricks,) with a PIR layer of 190 mm (λ value of 0,023W/mK) as insulating material, and a total thickness of the façade of 450 mm (U = value 0,168 W/m²K)

The facade of the South building is a concrete solution (Concrete, foam, mineral wool, Plaster) with a mineral wool layer of 50 mm (λ value of 0,037W/mK) as insulating material, and a total thickness of the façade of 460 mm (U = value 0,144 W/m²K).

Regarding glazing, the deployed solution consists of triple glazing with a U value of 0,8 W/(m²K), and a very high noise insulation capacity.

The air tightness testing has been carried out in accordance with EN 13829 Dry-IT AB and meets the requirements of the position FEBY 12.

The average air density of four (5%) tested apartments was 0.28 l / sm² when air leakage compared to the buildings envelope. Then the air leakage compared to the total area encircling the building the average air leakage 0.08 l / sm².

Air Pressure testing showed an airtightness of the south building of 0.19 l / sm².

HVAC equipment

The building is connected through a heating substation to the district heating system of the city of Malmö. The substation incorporates all the elements and the integrated control necessary to supply the building with all the required services at the required conditions (radiator system, domestic hot water system and mechanical ventilation air pre-heating coils).

The base heating of the apartments is solved with preheated ventilation to each apartment through air handling units equipped with heating coils. The ventilation is dimensioned to heat the apartments to 21 degrees. A conventional hot water radiator system allows regulating the heat delivery to each apartment to adjust the temperature to the desired comfort level. The radiator system receives the hot water supply from the building substation located in the basement.

The mechanical ventilation system of the building is formed by several AHUs and their supply and return duct networks. The AHUs are equipped with high efficiency heat recovery devices providing sensible heat recovery efficiencies above 80% (FTX-system). The AHUs include outdoor and exhaust air dampers, outside air filters (class F7), and exhaust air filters (class F6).

The monitoring of the ventilation system includes all the sensors and meters necessary to monitor all the relevant system status variables and apartment comfort and internal air quality parameters. The control and monitoring of the ventilation system is integrated into the central server through Modbus RTU communications protocol.

Lighting

Lighting in the entrance hall, post room and elevator halls, is controlled through movement detection strategies implemented through the deployment of IR presence detectors. The basement and the garbage room are also included in the area covered by the presence detection based lighting control system. In order to reduce lighting electricity consumption LED lighting is the prevalent technology.

Control and monitoring system

A control and monitoring platform has been deployed in order to control the operation of all the existing systems and to evaluate the energy performance of the facility. In the next picture an overview of the architecture of the platform is provided.

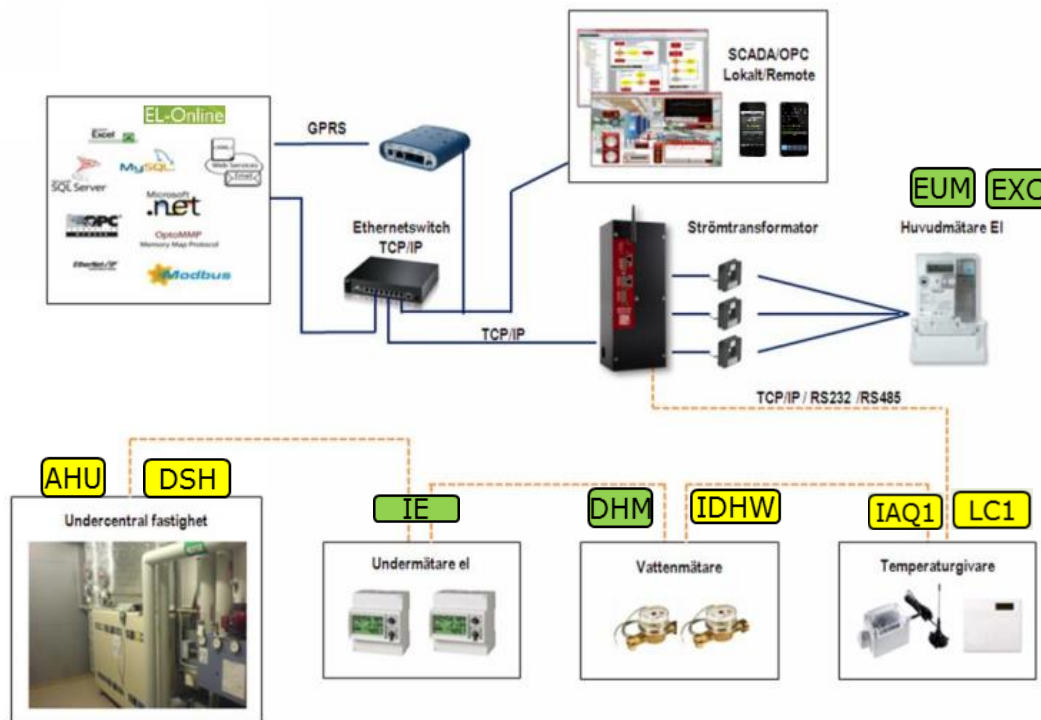


Figure 1. Architecture of the control and monitoring platform

The system collects the information monitored by the deployed sensor and meter networks formed by remote sensors and meters focused on the monitoring of the electricity consumption of households, comfort, internal air quality, etc.

The data monitored by groups of sensors is collected through concentrators strategically deployed over the facility, and delivered to the main communication device, which sends the information to the central server.

The communication of the monitoring system and the central server, where all processing and data evaluation is performed, has been solved via the Internet. In any case, capabilities to connect via LAN, WiFi or GSM are available through specific modules added to the communication unit.

All the communications between different equipment, devices and sensors deployed all over the building is carried out through Mobus RTU (RS485), enabling an easy integration.

The visualization module of the system is installed in a local computer deployed on the building. Below a summary of the main advantages of the implemented system is given:

- **Simplicity:** Changes in the system parameters are performed via a centralized server through the Internet
- **Flexibility and interoperability**

- Effectiveness: The information communication box (Communicator) collects and sends all the data to the centralized server through the Internet. There the information can be processed, presented and supplied to external systems.

2.1.2. Technical barriers

Although in some case not common in the residential building sector, most of the technical solutions implemented in this residential building demo are based on reliable, well known and proven technologies in other building typologies (high performance ventilation energy recovery system, advanced control and monitoring platforms, etc.).

As a consequence, with the exception of the non-critical technical problems included in the list below, no mayor technical problems were reported by this demo building developer partners.

- Due to an extremely low U-value specification set for the glazing of the building, big problems were faced to find manufactures that could provide glazing with thermal properties compliant with the established specifications in terms of thermal and acoustic insulation capacity.
- Due to the critical role of airtightness within the design concept of the building, a lot of care was put into maintaining the air tightness of the insulation, in order to avoid any kind of damage during transport and construction stages.

2.2. Roth Residential Building in Hyllie, Malmö

The building is located in the southern part of Malmö in an area called Hyllie. The area is specifically focused on solutions for the future urban environment. All areas are considered from a transportation, water, waste, energy etc perspective, to develop a sustainable area for the future. The Roth residential building is a good example of these sustainable solutions.

The main features of the building are summarized in the table below:

Demo building main features	
Building area	5 466 m ²
Rented area apartments	3 461 m ² (53 apartments)
Rented area office	74 m ² (a single office space)
Number of apartments of type 1 (1 room and kitchen)	8
Number of apartments of type 2 (2 room and kitchen)	31
Number of apartments of type 3 (3 room and kitchen)	12
Number of apartments of type 4 (4 room and kitchen)	2

Table 1 Roth Residential demo building main features

2.2.1. Description

The energy efficient design concept of the building is based on a minimized energy demand, optimized system technologies and integration criteria, the deployment of onsite thermal production technologies, and on an advanced control and monitoring platform, required to ensure optimum

Experience exchange and knowledge transfer between demonstrated residential buildings operation of all the systems of the building, and provide demand side management implementation capabilities. D1.10

Cooling demand has been avoided by the application of passive design strategies, which enable to minimize solar gains, and to take advantage of the free cooling possibilities provided by the mechanical ventilation system, whose air intake duct is coupled to a heat exchanger with the ground.

With the implemented solution after the first year of operation of the building, according to the collected monitored data, the building displays a consumption figure in primary energy of 66 kWh/m² and year.

Thermal envelope

The high performance of the envelope of the building is based on the following aspects:

- Very high insulation capacity of the thermal envelope
- Very low infiltration level thanks to the tight envelope created using concrete as the main constructive solution.
- Special care during the building construction stage, in order to avoid thermal bridges and uncontrolled infiltration.
- The optimized selection of window technology to meet the insulation demands for low energy consumption buildings.

The building is a mixture between bricks, plaster and concrete facades with very low U values and triple glazing ($U = 1,2 \text{ W/m}^2\text{K}$) to minimize energy losses and maximize noise insulation.

HVAC equipment

The building is equipped with a centralized heating and domestic hot water production system which supplies energy according to the specific supply temperature level required by each thermal load (heating and domestic hot water). The required thermal energy is received from the district heating system of the city of Malmo through the corresponding thermal substation.

Heating is distributed through floor heating to get the highest efficiency. This system uses the thermal mass of the building to accumulate the heat and release it according to the existing thermal loads, providing the required comfort conditions only to the occupied zone of the heated rooms. The radiant emission mechanism makes it possible for a very efficient energy delivery (avoidance of stratification, etc).

Furthermore, radiant floor systems can operate with low water supply temperatures (35-40 °C) which contributes to reduce the energy wasted from the pipe circuits on the distribution of heating water.

The radiant floor is a key element of the demand side management functionalities provided by the smart control system. During special occasions it is possible to turn down or off the delivery of heating to the building without having a critical negative impact on the thermal comfort. The high thermal inertia of this heating system reduces the negative impact of a temporary lack of energy delivery on the comfort level of the apartments.

At apartment level, all rooms have independent heating circuits and can be controlled separately with specific thermostats. It is also possible to control the settings of each room through a specially designed app running on an Ipad touch available in all apartments.

Apart from comfort condition adjustment and monitoring functionalities, the app provides real time data on water (cold and warm) and electricity consumption. The connection to EON's central pricing system allows the user also to follow the evolution of energy consumption cost according to the instantaneous fluctuation of market price.

Ventilation

The building incorporates a mechanical ventilation system with high efficiency heat recovery devices to provide fresh air to the apartments. The air handling unit includes a hydronic heating coil to ensure an acceptable supply air temperature value during the cold season

Additionally, the air intake duct of the ventilation system is coupled to a heat exchanger with the ground to preheat ventilation air during the heating season and to precool it during the cooling season.

This system provides a key contribution to the energy efficiency of the building, thanks to the availability of heat recovery of the exhaust air, and the preheating and free cooling functionalities obtained taking advantage of the steady temperature of the ground (15 °C) all over the year.

Renewable Energy Sources (RES)

A solar thermal system has been deployed on the flat roof on the north part of the building with a total solar collection field of 62 m², to contribute to domestic hot water production.

The solar collection field is formed by 36 flat plate solar collectors and has been installed with the optimum orientation and slope to provide the maximum efficiency and total hot water production.

The solar hot water storage system consists of 6 vertical tanks, located in the basement, with a unitary capacity of 1 m³. The integration of the storage enables to decouple solar production from DHW demand.

Lighting

The deployed lighting system is formed by low energy consumption LED type lamps.

The control of the lighting system is based on strategies and control mechanisms that enable to provide artificial lighting only during the periods with actual demand (actual presence of people in the rooms), including:

- Lighting status control in common areas according to the presence of people, monitored through the deployment of movement detectors, mainly in the basement and garbage room.
- Stairway lighting status controlled by dedicated light sensors (switches).

Control and monitoring system

A smart metering system has been deployed on the building including smart grid connection to the electric distribution grid of EON. The availability and implementation of demand side management strategies is one of the most innovative aspects of this building.

The smart metering system provides real time usage data on electricity consumption, DHW, cold water and heating energy request, to enable control decisions focused on cost reductions.

Control functionalities are provided by the installed BASTEC system integrated with the central systems of EON, to enable demand side management strategies. The Bastec system uses Modbus as communications protocol.

In the following lines a summary of the functionalities supported by the system is given:

- Communication with the smart grid system for information, control and reporting.
- Prioritization and handling of loads and groups of loads (demand side management. peak shaving performed by E.ON)
- Measurements and reporting of energy data to the smart grid system.
- Visualization of relevant information to and from the smart grid system in dynamic flowchart pictures.
- Logging of data for relevant signals to and from the smart grid system.

2.2.2. Technical barriers

Although in some cases not common in the residential building sector, most of the technical solutions implemented in this residential building demo are based on reliable, well known and proven technologies in other building typologies (high performance ventilation energy recovery systems, advanced control and monitoring platforms, solar collectors, etc).

As a consequence, with the exception of the non-critical technical problems included in the list below, no mayor technical problems were reported by this demo building developer partners.

- Some prefabricated concrete walls came with the wrong sizes and holes in wrong places. This was fixed as they were found.
- Some problems were experienced with considerable amounts of water entering inside the construction during rainy periods. This created and unexpectedly high pumping consumption to evacuate this water.

The implementation of the demand side management system created a technical challenge, but thanks to the strong involvement and strong commitment of EON with the project it was successfully overcome without facing too many problems

2.3. Residential building in Portugalete, Basque Country

The building is located in the neighborhood of Repélega in the town of Portugalete and has been constructed by the regional Basque Government for social housing purposes specifically oriented to

low-income people. The plot where it has been erected is rectangular with its longer side aligned with Juan de la Cosa street. The topography is an inclined plane with an approximate slope of 10% from west to east.

In order to adapt the building to the existing slope of the street (about 6 meters) it is formed by three blocks of 5 floors. Each of these blocks has 10 dwellings, 2 per floor, and two additional adapted apartments on the ground floor of one of the blocks, giving a total number of 32 dwellings. Furthermore, the building includes 2 underground parking floors.

All the dwellings have a similar configuration where the living room and kitchen face to the south, bedrooms face to the north and bathrooms are located in interior spaces. In the following table, the uses included in the building are summarized:

Use	Features	useful surface	Number
Apartment type 1	two-bedroom	57,42	16
Apartment type 2	three-bedroom	86,24	14
Apartment type 2	two-bedroom adapted apartments	88,39	2
Storage rooms	Not applicable	Not applicable	32
Parking spaces	Not applicable	Not applicable	34 (two of them adapted)

Table 2 Uses of the Portugalete demo building

In the following table an overview of the technical solutions deployed in each of the blocks of the building is provided:

Solution	Block 1	Block 2	Block 3
South façade	Ytong block	Solar Wall	Trombe Wall
Rest of facades	Ytong block	Ytong block	Ytong block
Ventilation	Centralized with heat recovery and bypass damper	Centralized with heat recovery and bypass damper	Centralized with heat recovery and bypass damper
Number of PV panels	32	28	28

Table 3 Overview of the technical solution deployed in each of the Block of the Portugalete demo building

2.3.1. Description

The energy-efficient design concept of the building is based on a minimized energy demand, optimized system technologies and integration criteria, the deployment of onsite electricity production technologies and an advanced control and monitoring platform to ensure optimum operation of all the systems of the building.

Thermal envelope

The low demand for external heating of the building is achieved by the combined effect of a highly insulated envelope and heat provided by active facade elements. The north, east and west facades of the 3 blocks, as well as the south façade of block 1, consist of Ytong ceramic block solution, whereas

the south facades of block 1 and 2 where the active façade solutions have been deployed, are made of lightweight materials, glazing and metal panels.

A multistory Trombe wall solution has been deployed in block 3. It is coupled to the ventilation system of the block, acting as distribution mechanism of the collected energy. The trombe wall is divided into two sections, both located in the same place relative to the apartments (between the kitchen and the living room).

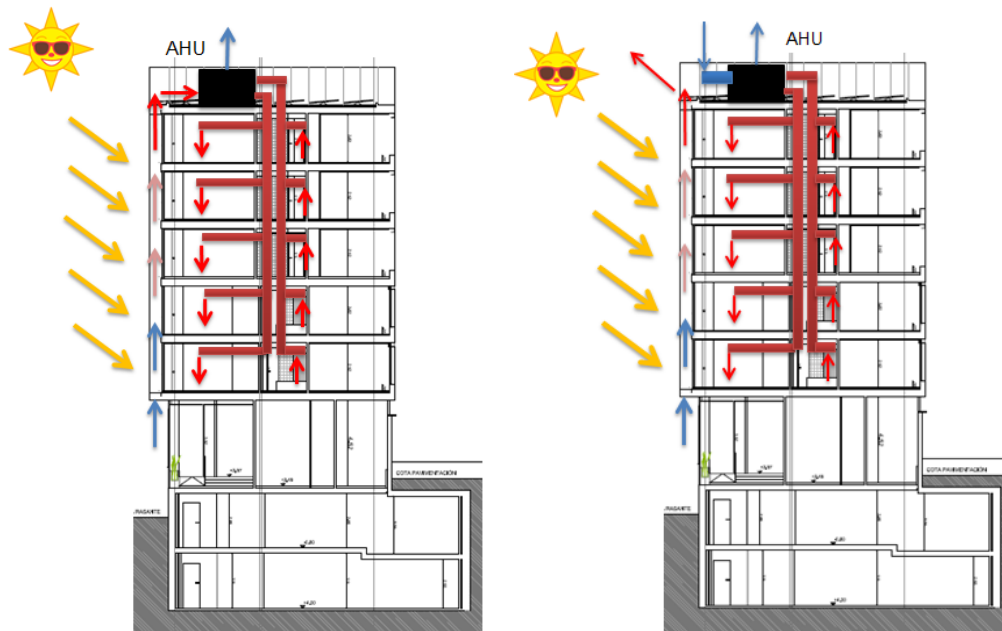


Figure 2 Trombe Wall operational principle (left winter mode and right summer mode)

The outlet of the trombe wall on the roof of the building is connected through a dedicated duct to the AHU of block 3, enabling the delivery of the hot air produced by the trombe wall.

When heating is not needed, the system can exhaust the hot air produced by the trombe wall, in order to reject the collected energy and avoid overheating risk. This is possible through dedicated dampers that enable the delivery of the preheated air to the AHU or its rejection, according to the presence or lack of heating demand.

The solarwall façade solution is installed in the central block of the buildings (Block 2). It consists of a black colored perforated sheet of metal that allows the inlet of exterior air into the air gap, where the air is heated through the collected solar energy.

The air preheated by the solar wall is used as heat source of the air to water high performance heat pump deployed on the roof of the central block. The temperature increase provided by the solar wall to the air, used as energy source by the heat pump, will allow very high mean seasonal performance values for the heat pump. The air flow preheated by the solar wall is delivered to the heat pump through a specifically deployed duct network, including a variable air flow rate fan to facilitate air circulation through ducts.

However, in the absence of a relevant heating or DHW production demand on the building, the heat pump and the variable air volume fan will be deactivated and the preheated air flow rate produced by the solar wall exhausted.

The heating and DHW production plant deployed in the building to meet its energy request is formed by a CHP unit, a high performance air to water heat pump and a condensing boiler. Additionally the heating plant includes a storage subsystem formed by a storage tank coupled to the CHP unit and a second tank for DHW storage.

- The High performance air to water heat pump.
- The CHP unit and its storage tank.
- The condensing boiler.
- The DHW storage tank and the DHW production heat exchangers.
- The heat exchanger for energy delivery to the low temperature system from the storage tank coupled to the CHP unit.

- The variable and constant volume pumps deployed on the different hydraulic circuits to produce water circulation.

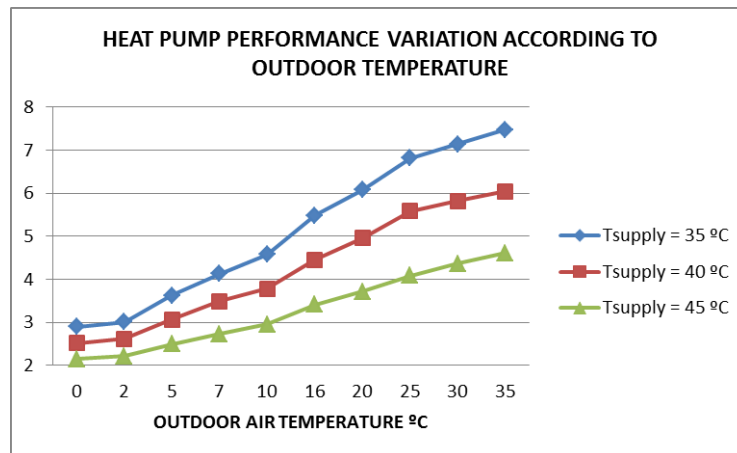


Figure 4 COP of the high performance heat pump

The heat transfer between the different hydraulic circuits of the generation subsystem and the distribution subsystem of the building is enabled through heat exchangers specifically deployed in the heating plant room of the building. These heat exchangers enable:

- DHW production using the energy provided by the CHP storage tank and the condensing boiler.
- DHW preheating using energy delivered by the heat pump.
- Heating production using the energy stored in the CHP storage tank.

It is necessary to mention that in order to ensure the energy efficiency of the system, the critical pumps of the heating plant and of the distribution subsystem will operate according to variable flow rate strategies. This operational strategy will enable to operate the critical hydraulic circuits with optimum temperature difference values for the complete range of existing thermal loads and to minimize the electricity consumption of the pumps.

Regarding ventilation, each of the 3 blocks of the building has its own ventilation system formed by an AHU with heat recovery (90% efficiency) and the corresponding supply and return duct networks to distribute the ventilation air necessary to maintain satisfactory levels of internal air quality inside the building.

Renewable energy sources

A PV system formed by 88 photovoltaic panels distributed all over the roof of the 3 blocks of the building has been deployed. The maximum installed power of the complete solar field is approximately 22 kW. The produced electricity is consumed onsite to supply the required electricity to the following equipment:

- Heat pump.
- Dwelling ventilation system.
- Parking floor ventilation systems.

- Pumps of the heating and DHW production system.
- Elevators
- Lighting of the common areas (entrance, storage rooms, etc).
- Domestic appliances

Control and monitoring platform

An advanced control and monitoring system has been deployed, in order to enable the operation of all the integrated systems according to their designed strategies and to provide monitoring and optimization functionalities. The platform is formed by a dedicated sensor network, a dedicated actuator network, a meter network and control hardware and software.

This platform will permanently supervise the operation of all the systems (setpoints and active operational modes), according to the evolution of internal and external boundary conditions, and will read the values collected by the dedicated sensor and meter networks and write them in the data base.

The monitoring system monitors the evolution over time of the values of the variables that have an impact on the final performance of the building, including climatic conditions, thermal comfort and the operation of all the sub-systems/systems of the building.

Visualization system

One of the main objectives of the project is to develop procedures to promote an energy efficient behavior of building occupants. Visualization technologies that can supply accurate real-time information about the existing comfort conditions and the energy consumption and cost necessary to deliver them, is considered the best strategy to give the opportunity to users of optimizing their use of energy.

Each dwelling incorporates a thermostat (field controller) that the dwelling occupant can use to adjust the desired thermal comfort profiles (setpoint temperatures and heating availability schedules on a daily, weekly or seasonal basis), and a visualization screen that displays real time energy consumption figures

2.3.2. Non-technical barriers and analysis of building performance

One of the main objectives of the project is to demonstrate that with satisfactorily solved building designs it is possible to integrate advanced and even fully innovative solutions on residential buildings, with affordable costs, increased comfort, and system reliability and durability comparable to current standards.

The procedure to demonstrate the fulfilment of this objective, regarding the energy efficiency of the deployed solutions, is based on the comparison of the energy consumption figures of the demo buildings with the energy performance target set in the frame of the project (60 kWh/m² year in primary energy). Obviously, the availability of high quality monitored data for a complete year is necessary in order to enable the implementation of such a procedure.

Unfortunately, and for reasons beyond the control of the project partners, in the case of the Spanish demo building the lack of a sufficiently long period of building performance monitored data impeded the assessment of the performance of the deployed solutions according to this procedure before the end of the project.

More specifically, at the moment of completion of this document and regarding the heating season, the available data included only the last 2 weeks of November. In the next paragraphs a short summary of the reasons behind the lack of reliable high quality building performance monitored data are provided:

- Due to several technical and administrative problems during the construction and occupation phases, the building was not fully occupied until July 2016. Additionally, and as will be further discussed later, even if officially the building is fully occupied, some uncertainties remain regarding the actual use of some of the apartments of the building (Block 1 apartments).
- Due to the mild climatic conditions typical of Portugalete the months of September and October are part of the intermediate season and are characterized by outside temperature values that even for standard buildings don't generate any relevant heating demand. August is obviously part of the cooling season but thanks to the optimized passive design of the building and the mild summer weather conditions the presence of cooling loads can be avoided without the intervention of any HVAC system. As a consequence, from the perspective of the analysis of the performance of the building the data collected during the months of July and August are of relatively low value.
- During the first 2 weeks of November, a problem with the data base of the monitoring platform created the loss of the monitored data during that period, limiting the availability of relevant data regarding the heating season, at the moment of completion of this document, to the last 2 weeks of November. Additionally, it is necessary to consider that for Portugalete typically the most severe climatic conditions take place during December and January. Therefore, the available data can't be considered representative of the most demanding local weather conditions.
- Additionally, the analysis of the monitored data, especially for the last 2 weeks of November, have revealed a behaviour from building tenants that is not consistent with standard residential building user behaviour, regarding heating energy request and DHW demand, with values that are very low even in the context of a low consumption building. A combination of several of the following reasons is probably behind this circumstance:
 - As already stated the building has been constructed for social housing purposes and at this moment a big proportion of the tenants of the building is formed by low-income people (significantly higher proportion than initially foreseen). It is believed that one of the main features of this kind of users is a higher tolerance to low levels of comfort in comparison to standard users.
 - Current lack of understanding of the capacity of the systems existing in the building to provide satisfactory comfort conditions in an affordable way, with very low cost in comparison with Spanish standard buildings.
 - Current lack of confidence of some of the tenants in the energy prepayment system of the building. Another feature of this kind of building users is their reluctance to pay for the energy in advance.

- Current misunderstanding of the free energy system concept that contributes to increase the reluctance of some of the tenants to use the centralized thermal energy delivery systems of the building.

In any case, the final result of this situation is a lack of consistency between the heating and DHW consumption figures currently available in relation to the figures that could be expected with standard residential building user behaviour.

- Due to delays in the administrative permit granting process, the PV system of the building is not in operation yet and, as a consequence, the contribution to the local electricity production to be provided by this system is not available.
- Due to a minor problem with the control platform during first 2 weeks of November, the heat pump operated as main heating and DHW production generator using a production setpoint value of 60 °C. As a consequence, during this period the heat pump operated with low performance values.
- Due to a minor problem with the sensors measuring the return air temperature of the ventilation systems of block 2 and block 3, unrealistically high temperature values were measured. As a consequence, for that period the exploitation of the hot air produced by the trombe wall was considered unnecessary by the control system, and the hot air rejected to the environment, wasting the energy collected by the trombe wall.

In summary, the period with available monitored data and the consistency level between the currently existing user consumption patterns and standard user behaviour at this moment are not enough to evaluate the level of fulfilment of the existing energy performance target.

In any case, project partners are aware about the key role of the Spanish residential demo building, in the frame of the project, due to some of its unique features in comparison with the rest of the demo buildings:

- It is the only demo building of the project that is not located in Malmö
- It is the only building with active façade solutions that interact with the HVAC system of the building.
- It is the only residential demo building with locally deployed distributed generation systems (CHP plant and PV system)

Taking this into consideration, and in order to demonstrate the fulfillment of the existing performance target before project ending, a contingency plan has been implemented. According to this contingency plan a very accurate prediction of the performance of the building has been obtained through an updated and calibrated Energy Plus model of the demo building.

More specifically, a big effort has been invested to update the last version of the available Energy Plus model of the Portugalete demo to include all the modifications included during the construction stage of the building in the deployed solutions and their operational strategies. Finally, the model has been calibrated according to the possibilities offered by the quality of the existing monitored data. With this procedure it was possible to maximize the capacity of the model to reproduce the actual behaviour of the building and to provide accurate predictions of the energy performance of the building, enabling the evaluation of the fulfilment of the existing energy performance target.

On the other hand, and as part of this contingency plan, several discussions are ongoing with the ESCO that operates the Portugalete demo building, to define the most appropriate procedures to educate tenants and dissipate all their prejudices and misunderstandings regarding the energy prepayment system.

It is expected that in the coming weeks these procedures will enable fully adapting current user behaviour to standards, allowing the collection of high quality and consistent monitored data to complete the one year monitoring period after the end of the project. The monitored data will be delivered to the Smart Cities Information System as soon as possible.

2.3.2.1. Analysis of user behaviour in relation to requested comfort conditions

As previously stated the behaviour of the building occupants in relation to the requested thermal comfort and DHW demand cannot be considered consistent with a standard residential building use. Up until now, this created unrealistically low values of energy consumption for thermal comfort and DHW delivery.

In order to evaluate this issue, first of all the integrity and the reliability of the data collected by the monitoring platform have been confirmed. After that the heating demand (kWh), DHW demand (m3) and cold water demand (m3) of each of the apartments of the building has been studied on a 15 minute basis, for a 7 day period (from the 15th to the 21st of November).

Additionally, the heating energy request of each dwelling has been mapped to the evolution over time of the internal temperature of each apartment, in order to discard that the lack of heating energy delivery could be explained by the passive capacity of the building to reach satisfactory comfort conditions without any energy delivery from the heating system.

The frequent presence of temperatures clearly below 20 °C (especially in Block 1 apartments and in the first and last floors of all the blocks) clearly eliminates this possible explanation of the origin of the detected behaviour.

The tables below display the mean daily values for the heating energy request, the DHW demand and the cold water demand for each apartment for the already defined seven day period.

Apartment	DHW demand (l/day)	Heating energy request (kWh)	Cold Water request (Y/N)
P1_P0A	0	0	N
P1_P1A	0	0	N
P1_P1B	0	0	N
P1_P2A	0	0	N
P1_P2B	0	0	N
P1_P3A	135,71	0	y
P1_P3B	0	0	N
P1_P4A	10	0	y
P1_P4B	0	0	n
P1_P5A	75,71	0	y
P1_P5B	0	0	n

Table 4 Mean daily DHW, heating energy and cold water requested by Block 1 apartments for the studied 7 day period (from the 15 th to the 21st of November)

Apartment	DHW demand (l/day)	Heating energy request (kWh)	Cold Water request (Y/N)
P2_P1A	50	76	Y
P2_P1B	100	34	Y
P2_P2A	21,42	0	Y
P2_P2B	80	85	Y
P2_P3A	128,57	76	Y
P2_P3B	0	0	N
P2_P4A	51,42	0	Y
P2_P4B	0	0	Y
P2_P5A	55,71	51	Y
P2_P5B	131,42	0	y

Table 5 Mean daily DHW, heating energy and cold water requested by Block 2 apartments for the studied 7 day period (from the 15th to the 21st of November)

Apartment	DHW demand (l/day)	Heating energy request (kWh)	Cold Water request (Y/N)
P3_P0A	0	0	N
P3_P1A	168,57	0	Y
P3_P1B	70	0	Y
P3_P2A	0	0	Y
P3_P2B	50	103	Y
P3_P3A	21,42	14	Y
P3_P3B	42,85	0	Y
P3_P4A	148,57	40	Y
P3_P4B	40	0	Y
P3_P5A	0	0	Y
P3_P5B	64	0	y

Table 6 Mean daily DHW, heating energy and cold water requested by Block 3 apartments for the studied 7 day period (from the 15th to the 21st of November)

The analysis of the values displayed in these tables confirms the unrealistically low values, especially in the case of heating energy request. More specifically:

- The presence of heating energy request, DHW demand and cold water demand is almost non-existent in Block 1. The almost complete lack of heating request and DHW demand might give an indication of the possibility of some apartments, although formally occupied, not being used.
- The heating energy request existing in block 2 and block 3 is unrealistically low, even in the context of a low consumption building.
- The DHW demand of some of the apartments of block 2 and block 3 are relevantly below standard values.

The situation regarding DHW demand becomes even more evident if the monotonous DHW demand curve is represented and analysed, as displayed in the next figure.

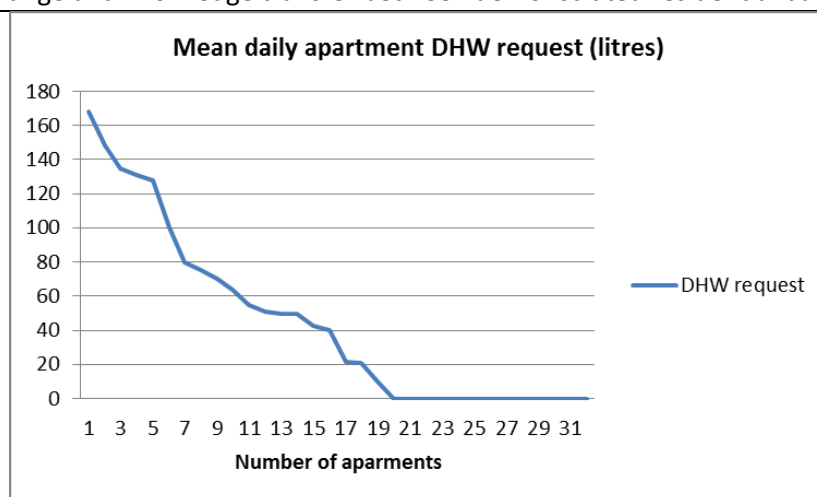


Figure 5 Monotonous curve of the mean daily apartment DHW request for the complete building for the studied 7 day period (from the 15th to the 21st of November)

As depicted by the previous figure, almost half of the apartments of the building display a mean daily DHW request of less than 20 litres, and 13 of the apartments do not have any DHW demand at all (most of them located in Block 1).

The following figure shows the typical daily DHW demand of one of the apartments of the building. As displayed by the graph the peak value of the DHW request tend to take place at early morning hours.

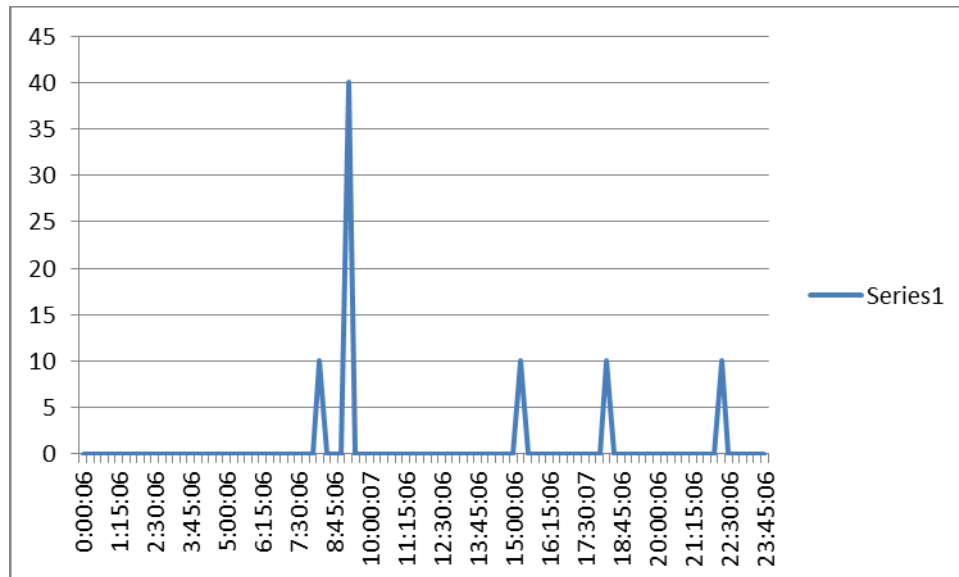


Figure 6 Typical DHW request daily profile (18th of November, apartment P2_P1A of Block 2)

In the case of the heating energy request, as represented in the monotonous heating energy request curve, included in the next figure, the unrealistically low energy request can be clearly observed.

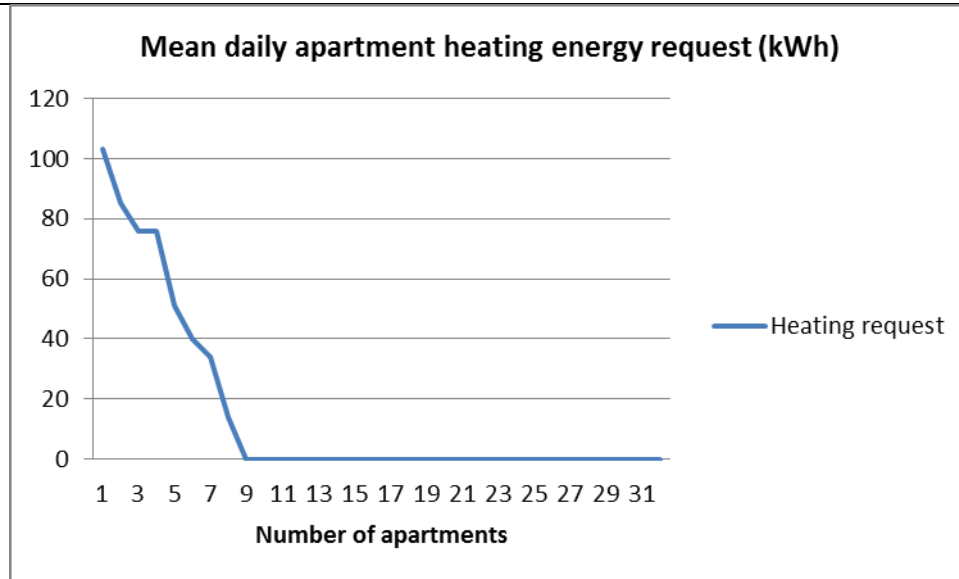


Figure 7 Monotonous curve of the mean daily apartment heating energy request for the complete building for the studied 7 day period (from 15th to 21st of November)

In this case, with the exception of 9 apartments, most of the apartments of the building don't request any energy for heating. These figures are specially unexpected for Block 1 apartments, taking into account the presence of the most demanding boundary conditions (corner block) and the deployment of the a priori less efficient façade solution (Ytong block)

The next figure represents the heating energy request profile of one of the apartments of the building on a 15 minute bases. According to this figure, the heating demand concentrates in the first morning hours, and the energy stored in the thermal mass of the building (mainly the floor) is enough to compensate the small energy loss through the envelope taking place all over the day.

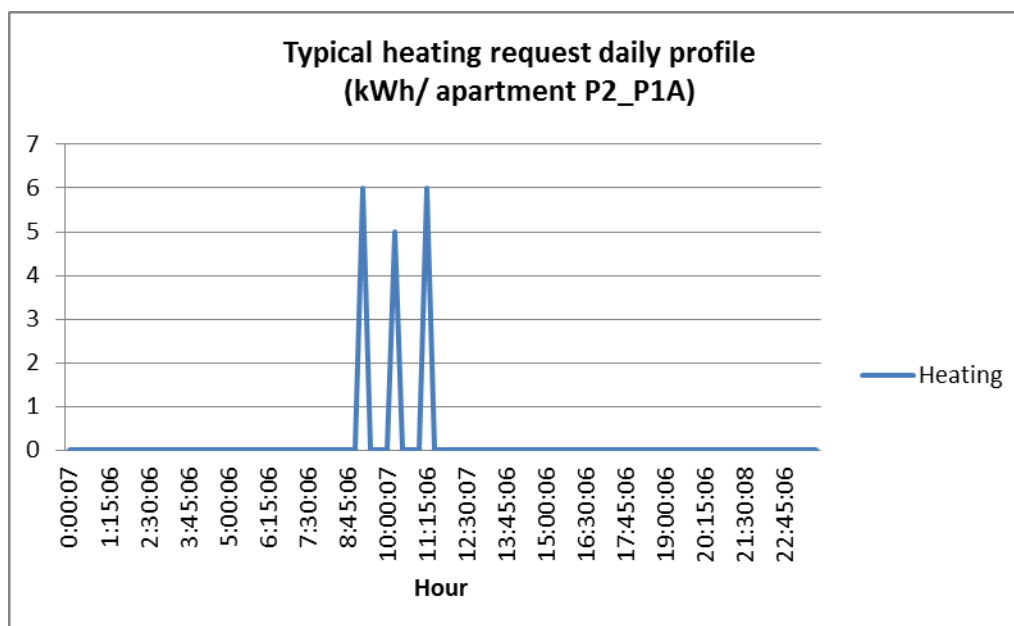


Figure 8 Typical heating energy request daily profile (16th of November, apartment P2_P1A of Block 2)

2.3.2.2. *Scope of the model*

In the following lines a short overview of the modelling detail level is provided in order to illustrate the capacity of the model to reproduce the actual behaviour of the building.

- Detailed geometric definition of the building and of the surrounding elements that might produce shading over the demo building.
- Detailed thermal zoning defined to optimize the thermal and visual analysis of all the relevant spaces of the building.
- Detailed constructive definition including the solar wall façade solution coupled to the heat pump of the building and the active trombe wall façade solution coupled to the ventilation system of Block 3.
- Detailed definition of all the systems and subsystems of the building.
 - Heating plant including the CHP plant, the high performance heat pump and the condensing back up boiler
 - DHW production subsystem (heat exchangers, etc)
 - The storage subsystem including the storage tank coupled to the CHP plant and the DHW tank coupled the DHW production subsystem
 - Detailed definition of the heating distribution subsystem according to the actual hydraulic topology
 - Detailed definition of the DHW distribution subsystem according to the actual hydraulic topology
- Detailed definition of the emission subsystem (radiant floor)
- Detailed definition of the mechanical ventilation system of each of the 3 blocks.
- Detailed definition of the distributed electricity generation facilities deployed at the building (CHP plant and PV system).
- Detailed definition of the ventilation system of the parking.
- Detailed definition of operational control strategies of all the relevant systems and subsystems of the building.
- Lighting system.
- Detailed definition of user behaviour (internal loads and comfort settings).
- Detailed definition of internal gains due to electric equipment.
- Detailed analysis of the impact of solar gains and infiltration.
- Etc.

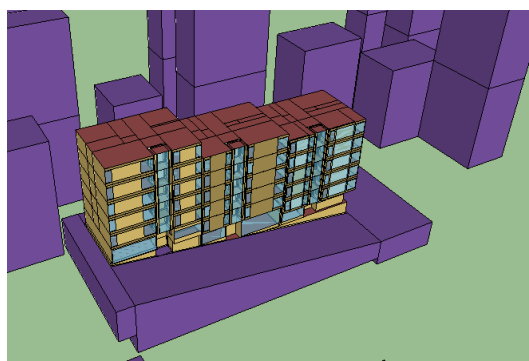


Figure 9 Portugalete demo building view (south facade including surrounding elements)

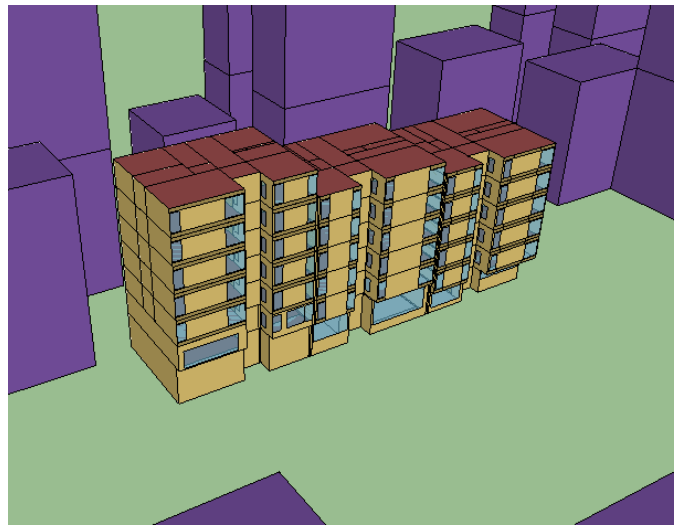


Figure 10 View of the simulation model displaying underground parking floors.

2.3.2.3. Calibration

As already stated, in order to maximize the capacity of the model to reproduce the actual behaviour of the building and increase the accuracy of the results, to display the fulfilment of the existing performance target, the model has been calibrated using the data available from the monitoring platform.

Through this process the following uncertainties of the model have been reduced:

- Energy efficiency of the heat recovery of the ventilation systems of each block.
- Performance of the heating generators
- Infiltration values of the building.
- Thermal mass of the building.
- Trombe wall system performance.

However, due to the short period of data availability and the non-standard user behaviour, only a partial calibration of the model was possible, not having the choice to calibrate the use patterns and some additional key parameters of the building:

- Solar wall performance (almost negligible operation due to the very low heating energy request from building apartments).
- DHW demand profiles.
- Realistic comfort settings (heating setpoint temperature values).

For these parameters standard values adjusted according to the experience acquired in similar projects have been used. The use of the monitored user behaviour has been discarded, in order to

Experience exchange and knowledge transfer between demonstrated residential buildings D1.10
 eliminate the risk of distortion of the prediction of the actual building performance that would lead to unrealistically low energy consumption figures.

2.3.2.4. Description of the operational logic of the active systems of the building

In this section an overview over the main operational criteria implemented in the model are presented in a compact shape:

Heating production

- As long as the electric load of the building is high enough to absorb the electric production of the CHP unit (5,5 kW) it is operated until the temperature at the bottom of the storage tank reaches the maximum allowable return temperature (72 °C according to efficiency and safety criteria).
- As long as the temperature at the top of the CHP storage tank remains above 60 °C, the base energy to meet the heating demand of the building is provided by the CHP plant.
- If the energy provided by the CHP plant is not enough to meet the heating request of the building, the additional energy is provided by the heat pump operating with the lowest possible supply temperature setpoint, according to weather compensation control strategies (between 35 and 45 °C).
- The condensing boiler would only provide backup energy for heating purposes, if the temperature at the top of the CHP storage tank is below 60 °C (energy delivery from the CHP plant stops), and the capacity of the Heat pump is not enough to meet the heating energy request of the building. Therefore, the simultaneous energy delivery from the CHP plant and from the backup condensing boiler is not allowed.

DHW production

- As long as the electric load of the building is high enough to absorb the electric production of the CHP unit, it is operated until the temperature at the bottom of the storage tank reaches the maximum allowable return temperature.
- As long as the temperature at the top of the CHP storage tank remains above 60 °C, the energy to meet the DHW production requested by the building is provided by the CHP plant.
- The Condensing boiler would only provide energy for DHW production if the temperature at the top of the CHP storage tank is below 60 °C (energy delivery from the CHP plant stops). As previously stated, simultaneous energy delivery from the CHP plant and from the backup condensing boiler is not allowed.
- The heat pump will only be used to provide energy for DHW production if:
 - The temperature of the CHP storage tank is below 60 °C.
 - No contribution is necessary from the heat pump for heating purposes.
 - The electricity produced by the PV system is high enough to cover the electricity consumption of the heat pump operating with the low performance values present when the setpoint temperature of the heat pump is fixed at 60 °C.

Heating distribution subsystem

- This subsystem operates according to weather compensation (evolution over the year of the outdoors air temperature), and variable flow control strategies in order to maximize the flexibility to adapt production to the evolution over time of the demand of the building, simultaneously allowing operating permanently with the lowest possible supply water temperature settings.

Solarwall

- The operation of the fan that enables the circulation of the air through the air gap of the Solarwall façade and the delivery of the preheated air is linked to the operational status of the heat pump. As a consequence, this fan will be activated as soon as the delivery of energy from the heat pump is detected by the monitoring system of the building and will remain in operation, as long as the outlet temperature of the solarwall is higher than the outside temperature and the energy request to the heat pump persists.

Trombe wall operation

- 2 Different operational modes have been defined depending on the prevalent presence/absence of heating demand in the apartments of Block 3. In case of a prevalent presence of heating demand the trombe wall will operate according to the heating mode. Otherwise the trombe wall will operate according to the cooling mode.
- Heating mode (return temperature of the ventilation system of Block 3 < 23 °C)
 - When heating mode is active, as long as the air temperature at the outlet of the trombe wall is higher than the value of the return temperature of the ventilation system of Block 3, the connection damper of the trombe wall to the inlet of the ventilation system remains open, and the outside air inlet damper, and the trombe wall collected energy rejection dampers are kept closed.
 - However, if the air outlet temperature of the trombe wall is lower than the return temperature of the ventilation system, the outdoor air inlet damper remains open (ventilation air directly taken from outside the building), and the dampers that connects the trombe wall to the inlet of the ventilation system and the damper for the rejection of the energy collected by the trombe wall are kept closed. In this situation the trombe wall continues collecting energy until the air temperature is high enough to be delivered to the building.
- Cooling mode (return temperature of the ventilation system of Block 3 > 23 °C)
 - When cooling mode is active, the outdoor air inlet damper remains open and ventilation air is directly taken from outside the building. Additionally, in order to enable the rejection of the undesired energy collected by the trombe wall, the damper that connects the trombe wall to the inlet of the ventilation system is kept in close position whereas the rejection damper remains in open position.

PV system

- After the modification in 2012 of the Spanish regulations affecting to the distributed electricity generation system, the operation according to a daily net balance strategy is no longer possible.
- Instead, the PV system deployed in the demo building will have to operate according to an hourly net balance approach, which means that the maximum instantaneous production of this system will be limited to the instantaneous total electric demand of the building (after deducing the production of the CHP plant)
- In principle this will have a negative impact on the yearly electricity production of this system that will be accurately evaluated once the monitored data for a complete year are available.
- In any case it is believed that this regulations modification is contrary to the energy efficiency principles and it is expected that in the short term there will be a return to daily net balance approaches

2.3.2.5. Building performance

In this section, the performance results obtained for the complete building and for its most relevant systems operating according to the strategies described in the precedent section will be evaluated through the calibrated Energy Plus model of the demo building.

Before presenting the results it is necessary to mention that taking into account that, as previously discussed, the PV system is not in operation yet, in this evaluation the expected PV system electricity production hasn't been considered. As a consequence, the figures provided for the total energy consumption of the building are conservative and remain on the safe side regarding the fulfilment of the existing energy efficiency target.

This decision has been taken considering the relatively high value of the peak power of the PV system (22 kW) that for a relevant number of hours per year will exceed the total instantaneous electric loads of the building. For those periods, in practice, this will mean that the production of the PV system will not be defined by the availability of solar irradiation but by the value of the available electricity sink.

Taking into account the short period of the monitoring data available at the moment of completion of this document and the non-standard building tenant behavior, it has been considered that the accuracy of the calculation of the electric appliances consumption of the building would probably not meet the accuracy necessary to carry out a realistic calculation of the PV system yearly electricity production, without introducing some risk of overestimating the actual production of the PV system and a possible distortion in the calculation of the total primary energy consumption of the building.

In any case, once the one year period of monitored data is available, the impact of the production of the PV system in the performance of the building will be incorporated before delivering the information to the Smart Cities Information System.

In the following tables these consumption and performance values are presented in a compact shape.

Domain	Electricity consumption (kWh)
Heat_Pump	3.135,93
Fans	16.212,26
Pumps	4.669,05
Lighting	29.941,90
Common_Areas	3.723,00
Total	57.682,14

Table 7 Total building HVAC and Lighting yearly electricity consumption

Plant	Electricity production (kWh)
CHP	30.362,44
PV	0,00
Total	30.362,44

Table 8 Total building yearly onsite electricity production

Item	Net electricity consumption (kWh)
Consumption	57.682,14
Production	30.362,44
Net_Consumption	27.319,71

Table 9 Total building yearly net electricity consumption

Equipment	Net_gas_consumption (kWh)
Boiler	16.840,17
CHP	126.546,78
Total	143.386,95

Table 10 Total building yearly gas consumption

Equipment	Thermal_Production (kWh)	Thermal_Production (%)
CHP	67.684,23	71,43
Heat_pump	11.130,95	11,74
Boiler	15.931,90	16,81
Total	94.747,07	

Table 11 Total building yearly thermal production distribution

Equipment	Thermal_Use_Distribution (%)
DHW	58,36
Heating	41,63

Table 12 Total building thermal energy use distribution

Block	Heating_Energy_Use_Distribution (%)
Block_1	36,67
Block_2	28,05
Block_3	35,28

Table 13 Total building heating energy use distribution

Equipment	DHW_Energy_Use_Distribution (%)
Block_1	34,32
Block_2	31,37
Block_3	34,32

Table 14 Total DHW thermal energy use distribution

Heating generator	Mean seasonal efficiency (%)
CHP	77,48
Boiler	94,60

Table 15 Generator mean seasonal performance value (referred to the High Heating Value of the natural gas)

Heating generator	COP
Heat Pum	3,55

Table 16 Mean seasonal coefficient of performance of the heat pump

Equipment	Primary energy consumption (kWh/m ² year)
Gas	38,94
Electricity	18,06
Total	56,99

Table 17 Building total yearly primary energy consumption per m²

From the analysis of the results displayed in the precedent tables the following conclusions can be obtained:

- Thanks to the optimization of the architectonic design of the building the heating demand of the building is slightly below the energy demand associated to DHW production.
- More than 70% of the total thermal production of the heating plant of the building is provided by the CHP plant.
- Even if the total energy demand of the building is very low according to current standards, the analysis of hourly energy use figures have revealed that most of the energy use is concentrated in the first morning hours. For this reason, the existing thermal peak load values are relatively high in comparison to the low energy use and this contributed to increase the back-up production provided by the condensing boiler.
This is also explained to a certain level, due to the prevalence of the energy need for DHW production.
- The energy collected by the solarwall is used as energy source for the heat pump to improve its operational performance, and therefore the impact of the solarwall is distributed between all the 3 blocks of the building and does not have a direct impact in the energy use figures of Block 2.
- A direct comparison of the energy use figures of Block 1 and Block 3 seem to display the relatively low impact of the trombe wall in terms of energy use reduction. As it will be discussed in the next section this can be explained, at least to a certain extent, by the presence of a suboptimal control strategy.
- Even after design modifications that were necessary to introduce during the construction stage of the building, and despite the negative impact of the modifications on the Spanish distributed generation regulations, the building fulfills the existing energy efficiency target. It is reasonable to expect that with the inclusion of the impact of the expected PV system electricity production these figures will probably improve.

2.3.3. Technical barriers

Most of the technical barriers to be faced during the design, construction and commissioning phases of the project have been a consequence of the modifications that were necessary to introduce in the initial design concept of the building, in order to adapt it to the following modifications over time, of some of the existing technical and economical boundary conditions:

- Lack of agreement with the manufacturer of the initially considered active curtain (Intelliglass) wall solution to provide the durability guaranties for the curtain wall, for all the hydraulic components of the system (pumps, heat exchanger) and for the integrated system.
- The change in 2012 of the Spanish regulations affecting to the distributed electricity generation systems.
- Need to adjust the budget to assume the deviations created by the problems with the foundation of the building.

In the following paragraphs an overview of the technical barriers and problems created by the mentioned modification will be given, and their relation with the final performance of the building or of some specific systems described.

2.3.3.1. *Change in the Spanish distributed electricity generation system regulations.*

As previously described, after the modification in 2012 of the Spanish regulations affecting the distributed electricity generation systems, the operation according to daily net balance strategies was no longer acceptable.

Instead, the distributed generation systems deployed at building level have to operate according to an hourly net balance approach, which means that the maximum instantaneous production of these systems is limited to the instantaneous total electric loads of the buildings where they are deployed. Therefore, the delivery of the local electricity production surplus to the electric grid, latter to be recovered at almost no cost, is no longer possible.

This change had a huge impact on the design concept of the Portugalete demo building that was initially based on minimizing the local electricity loads (affected by a relatively high conversion factor to primary energy), and on maximizing local electricity production, taking advantage of the electric grid as electricity storage element at almost no cost.

In order to minimize the negative impact of this change in the energy performance of the building, the design concept was substantially modified, to achieve a better balance between local electricity production and local electric loads. This was achieved by reducing the size of the CHP plant of the building (1 of the 2 CHP units was eliminated) and introducing a high performance air to water heat pump as second heat generator of the building.

The reduction of the local production capacity was not extended to the PV plant as it is believed that this regulations modification is contrary to the energy efficiency principles, and it is expected that in the short term there will be a return to daily net balance approaches.

In any case, it is not necessary to mention that the modified approach presents a significantly higher primary energy use, as the production of the CHP plant and the PV plant of the building will have to be coupled to the local electricity demand, what will cause a significant reduction of local electricity production, besides the local electricity consumption increase associated to the deployment of the heat pump.

2.3.3.2. *Substitution of the Inteliglass active trombe wall by the Solarwall façade solution*

Another group of technical barriers and difficulties originated from the change of the initially included Intelliglass active curtain wall solution to the SolarWall facade solution with integrated air solar collectors.

The solarwall solution was initially conceived to be integrated into industrial buildings as a ventilation air preheating system that could serve as an alternative to the deployment of energy recovery devices.

The integration of this solution into residential buildings, where the deployment of high efficiency heat recovery systems is mandatory, was considered a promising and innovative approach. For this application the solarwall would have to play the role of a complementary system to the heat recovery, instead of the traditional role of an alternative. In order to enable a successful simultaneous integration of both systems, it is necessary to define operational criteria for the

solarwall that could avoid overlapping risk of the operational ranges of the heat recovery and the solarwall system.

In order to fulfill this goal, the initially conceived design of the solarwall system of the demo building was sized to operate with low air flow rates in relation to the surface area of the deployed solarwall façade. With this approach it would have been possible to maximize the value of the temperature increase provided by the solarwall upgrading system functionality from ventilation preheating to heating delivery under favorable solar irradiation availability conditions.

The rationale behind the combined deployment of the solarwall and the heat recovery system was as follows:

- In winter days with a relatively high availability of solar irradiation the solarwall would be able to increase the temperature value of the supply air flow to values significantly higher than the temperature of the return air flow of the building, and therefore, it would be possible to bypass the heat recovery device.
- However, in winter days, with low solar irradiation availability, the temperature increase provided by the solarwall solution would be significantly lower than the return temperature of the ventilation system. As a consequence, ventilation air could be directly taken from outside the building and leave the preheating of the ventilation air to the heat recovery device.

Even though according to the performed simulation analysis this integration approach was considered promising, with the integration of the heat pump in the heating plant of the building, the use of the hot air produced by the solarwall as energy source of the heat pump, was identified as an alternative way of exploitation of the collected solar energy.

With this approach the operation of the solarwall and the heat recovery system can be decoupled (avoiding any energy waste risk due to operational overlap,) and the performance value of the heat pump increased thanks to the higher temperature of the air used as energy source.

However, according to this arrangement the operation of the solarwall is linked to the operation of the heat pump and, as a consequence, the exploitation of the collected solar energy can only take place during periods with a relevant heating energy request to the heat pump.

According to building owner preferences, this was the approach that was finally implemented. However, the results obtained for the simulation analysis described in precedent sections have displayed an improvement of the seasonal mean performance of the heat pump that is clearly below the existing expectations. The following reasons would explain to a certain extent this behavior:

- The relatively mild winter climatic condition existing in Portugalete allows a very good baseline performance for the heat pump.
- Due to the high air flows necessary as energy source of the heat pump, the temperature increase of the solar wall air is not as high as expected.
- Additionally, the peak energy request to the heat pump take place in early morning hours, when the availability of solar irradiation is still low and as a consequence the heating potential of the solarwall is equally low.

- The discharge of the preheated air delivered by the solarwall to the air inlet grill of heat pump is not airtight and, therefore, some level of outdoor air inlet takes place, reducing the actual temperature of the air used as energy source.

The deployment of a storage tank coupled to the heat pump could significantly improve the increase of the performance of the heat pump, as it would allow moving the operational periods of the heat pump to those with the highest availability of solar irradiation.

In any case, the final evaluation of the actual performance of the current solarwall production exploitation strategy will be carried out once the one year monitoring data are available, but according to the already performed analysis the initially designed integration approach might provide a higher exploitation potential.

2.3.3.3. *Design modification introduced to absorb cost deviations*

At the beginning of the project, some problems were experienced with the foundation of the building that created a relevant and unexpected increase of the cost. In order to absorb this deviation it was necessary to adjust the cost of other parts of the project.

In order to absorb the impact of these problems some simplifications were introduced in the initial design of the building.

Multistory trombe walls connected to the ventilation system of Block 3

According to the initial design of the building, 10 single story active trombe walls were included in the south façade of Block 1.

These trombe walls were located adjacent to the dining room of each of the apartments of block 1 and had a direct connection to these rooms through automated inlet and outlet grills, designed to enable direct delivery of the collected energy to the rooms. The idea was to control the energy delivery from the trombe walls to the rooms according to the evolution of the temperature of the trombe wall cavity and the temperature of the dining room. The control of the actuators of the automated grills was assigned to a controller deployed in each of the dining rooms of Block 1.

However, during the construction phase of the building for the reason already stated it was necessary to transform this solution into a solution with 2 multistory trombe walls coupled to the ventilation system of Block 3, to use it as mechanism for the delivery of the collected solar energy.

With this modification, a big simplification of the solution implemented in Block 1 was achieved, not only in relation to the constructive solution of the trombe wall itself, but also regarding the strong simplification of the control system and the field elements (actuators) to be deployed at dining room level.

With this approach a moderate reduction of the aggregated energy delivery from the trombe walls was expected as instead of the direct energy delivery concept considered in the initial approach, in the implemented solution the energy delivery takes place through the ventilation system. As was the case for the solarwall, some risk of operational range overlapping between the trombe wall and the energy recovery device was expected.

The operational strategy for heating season defined for the implemented trombe wall solution is similar to the strategy designed for the initial solar wall production exploitation strategy.

- In winter days with a relatively high availability of solar irradiation the trombe wall will be able to increase the temperature value of the supply air flow to values significantly higher than the temperature of the return air flow of the building, and therefore, it will be possible to bypass the heat recovery device.
- However, in winter days with low solar irradiation availability, the temperature increase provided by the trombe wall solution will be significantly lower than the return temperature of the ventilation system. As a consequence, ventilation air will be directly taken from outside the building and the energy collected by the multistory trombe wall will be stored until the temperature is high enough to enable the delivery of the collected energy through the ventilation system of the building.

However, according to the available monitored data, and the simulation analysis described in previous sections, the energy delivery from the multistory trombe wall has been lower than expected. This is explained to a great extent by the impossibility to have an explicit control from the control platform of the bypass damper of the heat recovery device. This element is not integrated in the control platform; instead it is operated autonomously by a dedicated local controller, according to the evolution over time of the outdoors air temperature.

More specifically, when the trombe wall is able to provide supply temperature values significantly higher than the supply return temperature during the winter season (relatively low outdoors temperature conditions), the bypass damper is not activated, and the hot air delivered from the trombe wall goes through the heat recovery device. Due to this suboptimal integration of the trombe wall and the heat recovery device, a significant part of the energy collected by the trombe wall is wasted (the air coming from the trombe wall is cooled by the return air of the ventilation system).

In order to eliminate this energy wastage it will be necessary to integrate the controller of the heat recovery device in the control platform of the building.

In any case, the final evaluation of the performance of the trombe wall will be possible once the one year period monitored data is available.

Constant volume ventilation system

The initial design of the building was based in a variable flow rate system with heat recovery for each of the 3 blocks of the building, defined to operate according to an on/off strategy at apartment level. According to this initial design the delivery of the nominal air ventilation flow rate at apartment level was linked to the occupancy (presence/lack of people at apartment level).

During the periods with no occupancy at apartment level, the ventilation system was decoupled from the ventilation air supply and return networks of the building, through specifically deployed automatic dampers managed by a local controller. At the same time, the value of total flow circulated at block level, was adjusted through variable frequency drives installed in the supply and return fans of the ventilation system of each block.

However, for the same reason already stated in the previous sections the finally implemented ventilation solution was simplified to a 24/7 constant volume ventilations system for each of the 3 blocks of the building.

In order to minimize the impact on the thermal energy consumption associated with the ventilation high performance (nominal value of 90%) heat recovery devices have been installed in the ventilation systems of the buildings. According to the monitored data, the actual efficiency of the heat recovery devices is consistent with their nominal value.

2.3.3.4. Relative complexity of the heating plant of the building

Due to the relative complexity of the heating plant of the building (based on the integration of 3 different generation technologies) and the presence of the 2 active façade solutions, it was necessary to perform an analysis through simulation, in order to optimize as much as possible the operational strategies and settings to be implemented in the initial commissioning of the building.

Additionally, the ESCO in charge of the exploitation of the facility will permanently supervise the operation of all the active systems of the building, and perform a continuous commissioning of the facility as needed, periodically fine tuning the settings of the facility.

3. Exchange of knowledge and experience between demo buildings

As it is well known, in order to ensure the successful definition of a low consumption and high performance building design, the implementation of a holistic design methodology in which the design of the building is solved as a global problem affected by project specific constraints is of critical importance.

For this reason and even if it was not formally an expected output of the project, a common design methodology has been developed to be implemented in the design of the demo buildings of the project. This methodology is formed by the following sequence and is based on the use of dynamic simulation as a support tool during the design process:

- Building demand minimization through an optimized architectonic design of the building (compactness, orientation, percentage of openings in each façade, thermal properties of the envelope, air tightness, exploitation of natural ventilation, exploitation of natural lighting, etc) for the climatic conditions existing in the location of each specific demo building.
- Use of high performance technologies adequately integrated to define high performance building systems (HVAC, lighting, etc), that will minimize the energy consumption necessary to meet the energy demand of the buildings.
- Integration of distributed generation technologies and renewables, in order to maximize the exploitation of the local production potential existing in each of the demo sites.
- Deployment of a control and monitoring platform with the functionalities necessary to operate all the systems of the building according to the defined operational strategies, to obtain the all energy efficiency associated to the potential of the building design.

Independently of the specific solutions used in each demo building, all of them have been designed according to this methodology, and for this reason share most of their main design criteria. In this sense, knowledge and experience exchange between the demo buildings was implicitly implemented from the very beginning of the project.

However, the availability of a relatively low number of residential demo buildings deployed only in 2 different locations somehow limited the knowledge and experience exchange potential between different demos, regarding specific innovative solutions.

In any case, in the following section, the knowledge and experience exchange regarding specific solutions between the buildings exposed to the same climatic conditions and buildings operating under different climatic conditions are discussed.

3.1. Same climatic conditions

In this section the applicability of some of the solutions used in the Roth demo to the Skanska residential building have been qualitatively analysed with positive results. In the following table a comparison of the technical solutions used in the Swedish demo buildings is displayed.

Design criteria	Residential demo building	
	Skanska	Roth
Highly insulated envelope	X	X
Very air tight envelope	X	X
High thermal mass	X	X
Mechanical ventilation with high performance heat recovery	X	X
Ventilation air pretreatment through an air geothermal system		X
District heating	X	X
Radiator system	X	
Radiant floor		X
Passive cooling	X	X
Led lighting	X	X
Movement detection lighting control in common areas	X	X
Solar thermal collectors		X
Demand side management/demand response		X
Control and monitoring system	X	X

Table 18 Comparizon of the technical solutions used in the Swedish residential demo buildings

Even though the exact technical solutions used in both buildings might be somehow different, these buildings were designed according to the holistic methodology described at the beginning of Chapter 3, and as a consequence share their main design criteria.

In some cases the implemented technical solutions were similar or even the same. Therefore, it can be stated that the knowledge and experience exchange was implicit from the design stage of the buildings.

There are however some technological solutions implemented in the Roth residential building that could also have been deployed very successfully in the Skanska residential building, since:

- These technical solutions are well known, proven and reliable solutions not very common in residential buildings, but in use for many year in other types of buildings. Therefore, if adequately dimensioned and integrated into the building, their good performance is almost guaranteed.
- Being buildings deployed in the same city, the existing technical, regulatory and economic constraints are in principle identical (with the possible exception of the availability of free space for the deployment of a ground heat exchanger for ventilation air thermal preconditioning and the availability of roof space for solar collector deployment).

Between the solutions that could have been successfully applicable to the Skanska residential building the following seem to be the most promising ones, due to their easy implementation and almost universal applicability.

- Deployment of a solar collector system to contribute to the DHW production
- Use of radiant floor as emission system instead of the used conventional hydraulic radiators

Obviously in the case of Spain this analysis makes no sense as a single demo site has been constructed

3.2. Different climatic zones

In this section, the applicability of some of the solutions used in the Spanish demo building to the Swedish demo buildings have been studied. In the following table a comparison of the technical solutions used in the different demo buildings of the project is displayed.

Design criteria	Residential demo building		
	Skanska	Roth	Portugalete
Highly insulated envelope	X	X	X
Very air tight envelope	X	X	X
High thermal mass	X	X	X
SolarWall Active facade			X
TrombeWall Active facade			X
Mechanical ventilation with high performance heat recovery	X	X	X
Ventilation air pretreatment through an air geothermal system		X	
District heating	X	X	
Onsite CHP plant			X
Onsite PV system			X
Radiator system	X		
Radiant floor		X	X
Passive cooling	X	X	X
Led lighting	X	X	
Movement detection lighting control in common areas	X	X	X
Solar thermal collectors		X	
Demand side management/demand response		X	
Control and monitoring system	X	X	X

Table 19 Comparison of the technical solutions used in the residential demo buildings of the project

According to this comparison many of the design criteria and the implemented technical solutions are similar or at least comparable. It is obvious that the main differences between the design of the Spanish and the Swedish demo building are:

- The use of active façade solutions on the Spanish demo (active trombe wall and the solarwall)
- Choice of deployment of either local high performance thermal generation technologies or a connection to a city-wide district heating system (high performance air to water heat pump)
- The deployment of onsite distributed generation systems (CHP plant and PV system)

From this list the applicability of the active façade solutions, designed for solar irradiation collection and an optimized exploitation of solar gains, seems to be of particular interest. Therefore, in the following section taking advantage of the availability of a very detailed Energy Plus simulation model, the potential applicability of these solutions to the climatic conditions existing in Sweden will be qualitatively analysed.

3.2.1. Methodology for the evaluation of the active façade solution deployment in Sweden

In order to predict the performance provided by some of the solutions used in the Spanish demo in the climatic conditions existing in Sweden with similar energy efficiency levels, the design of the envelope of the Spanish demo building has been modified to adjust its quality to this new and more demanding weather conditions.

The adjustments of the thermal properties of the facades, roof and glazing of the building have been carried out using the specifications of the envelope of the Skanska and Roth demo buildings as a reference.

Additionally, the capacities of some of the equipment of the heating plant and the HVAC system of the building have been recalculated, and when necessary increased in order to be able to meet the slightly higher heating loads.

The characterization of the user behavior hasn't been modified as it was assumed that the standard residential building user behavior in Spain and in Sweden could be considered similar without introducing mayor distortions on the validity of the obtained results, in relation to the goal of this analysis.

After the definition of the required modification on the design of the building, the available Energy Plus model have been updated, and several simulation sets performed focusing specially on the performance of the coupled operation of the active trombe wall and the ventilation system of block 3, and the coupled operation of the high performance heat pump and the solawall façade solution.

The conclusions obtained from this simulation analysis are described in the next sections of the document.

3.2.2. Coupled operation of the solarwall and a high performance heat pump

Taking into account the extremely cold temperatures existing in Sweden during the heating season, the deployment of an air to water heat pump as heating technology, even in the case of the high performance model used in the frame of the project, in principle doesn't seem a very suitable choice.

On the other hand, the limited availability of solar irradiation, in conjunction with the extremely cold temperatures existing during the heating season, configure a scenario of apparent low applicability potential, for the use of the solarwall as air preheating system, to serve as energy source of the heat pump, to increase its mean seasonal performance value.

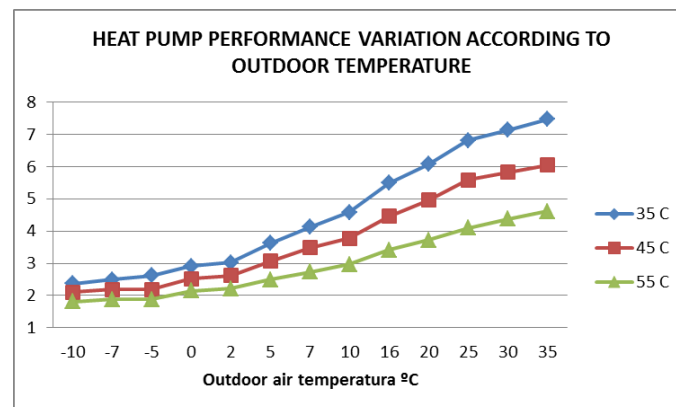


Figure 11 COP value of the heat pump

Supply water temperature (C)	Air temperature (°C)			
	-10	-7	-5	0
35	2,37	2,50	2,62	2,90
45	2,09	2,19	2,18	2,52
55	1,81	1,88	1,88	2,14

Table 20 COP values for different operational conditions of the heat pump

From the analysis of the performance values of the heat pump for several operational conditions it can be observed that in the range of low air entering temperatures, the improvement of the COP is very small (below 0 °C the value of the COP remains almost constant). Being this a high performance heat pump these values are not disastrous (especially considering the relatively low prices of electricity in Sweden), but have nothing to do with the values associated to mild air temperature conditions.

In order to evaluate the capacity to increase the temperature of the air used by the heat pump, in the following figure the monotonous curve of the air temperature entering in the heat pump is presented (with and without the solar wall)

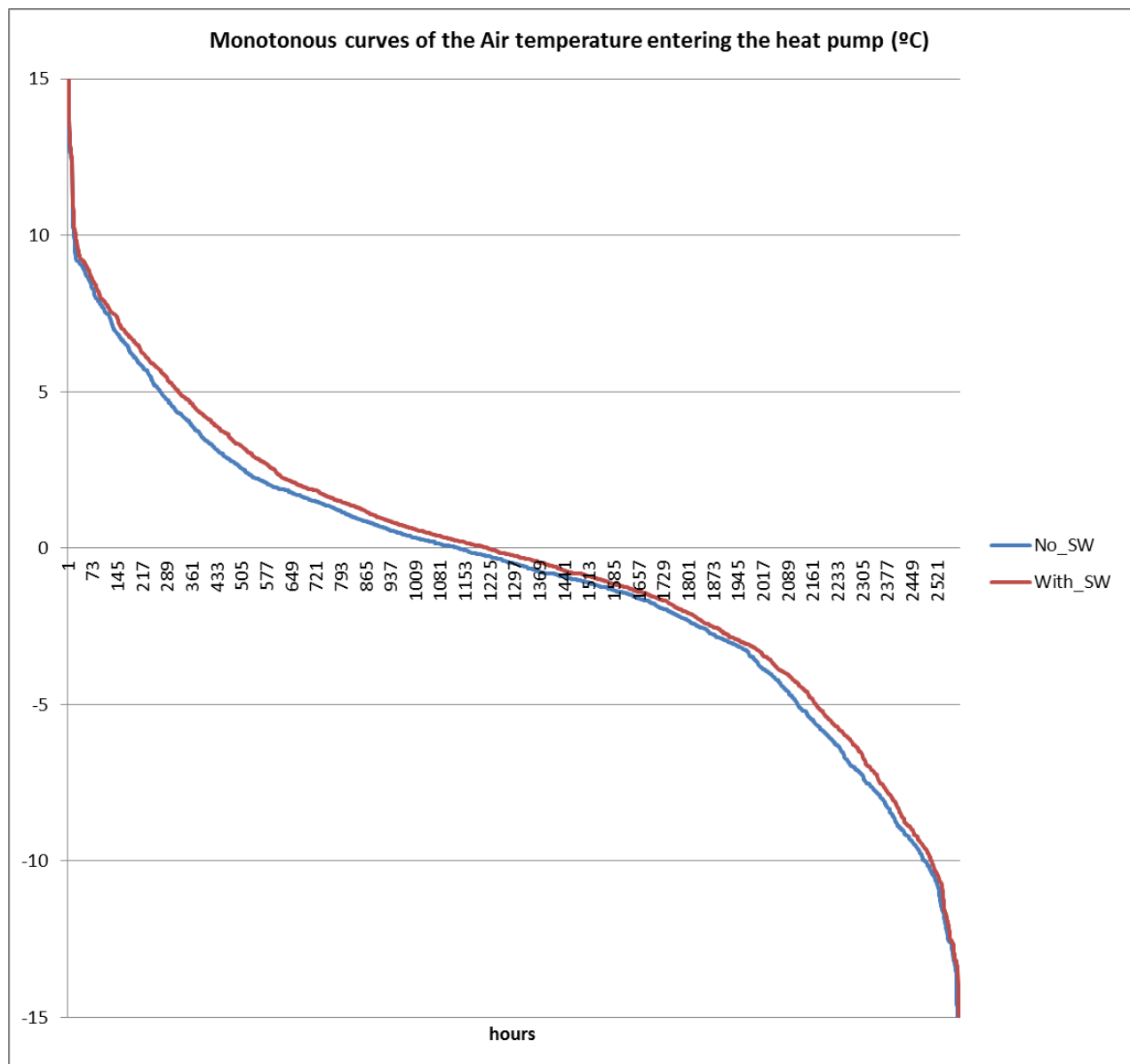


Figure 12 Monotonous curve of the air entering the heat pump with and without the solarwall

As can be seen, the increase on the air temperature entering in the HP thanks to the deployment of the solarwall is too small to produce any significant improvement on the COP values of the heat pump.

As was the case for the deployment in Portugalete, the presence of the peak loads at the early morning hours when the solar irradiation availability is lower doesn't help to optimize the exploitation of the energy collected by the solarwall system.

As a consequence it can be concluded that the combined deployment of the air to water heat pump and the solarwall solution is not a suitable solution for the climatic conditions of Sweden, and that for example other technologies (ground source heat pump, etc) would provide much higher efficiency values.

It is necessary to mention that possibly the second method identified for the exploitation of the energy collected by the solarwall solution (integration of the solarwall and the ventilation system of block 2) would provide significantly better results.

In any case, the quantitative analysis of this strategy hasn't been included in this document.

3.2.3. TrombeWall

As previously mentioned, being the trombe wall a passive solution designed to collect and exploit solar energy, the low irradiation availability and extremely low outdoors temperature conditions existing in Sweden during the cooling season, do not seem especially suitable for the deployment of the an active trombe wall connected to the ventilation system of a building.

In any case, as in the precedent section, the capacity of the trombe wall to significantly increase the supply outlet temperature of the ventilation system of Block 3 has been studied.

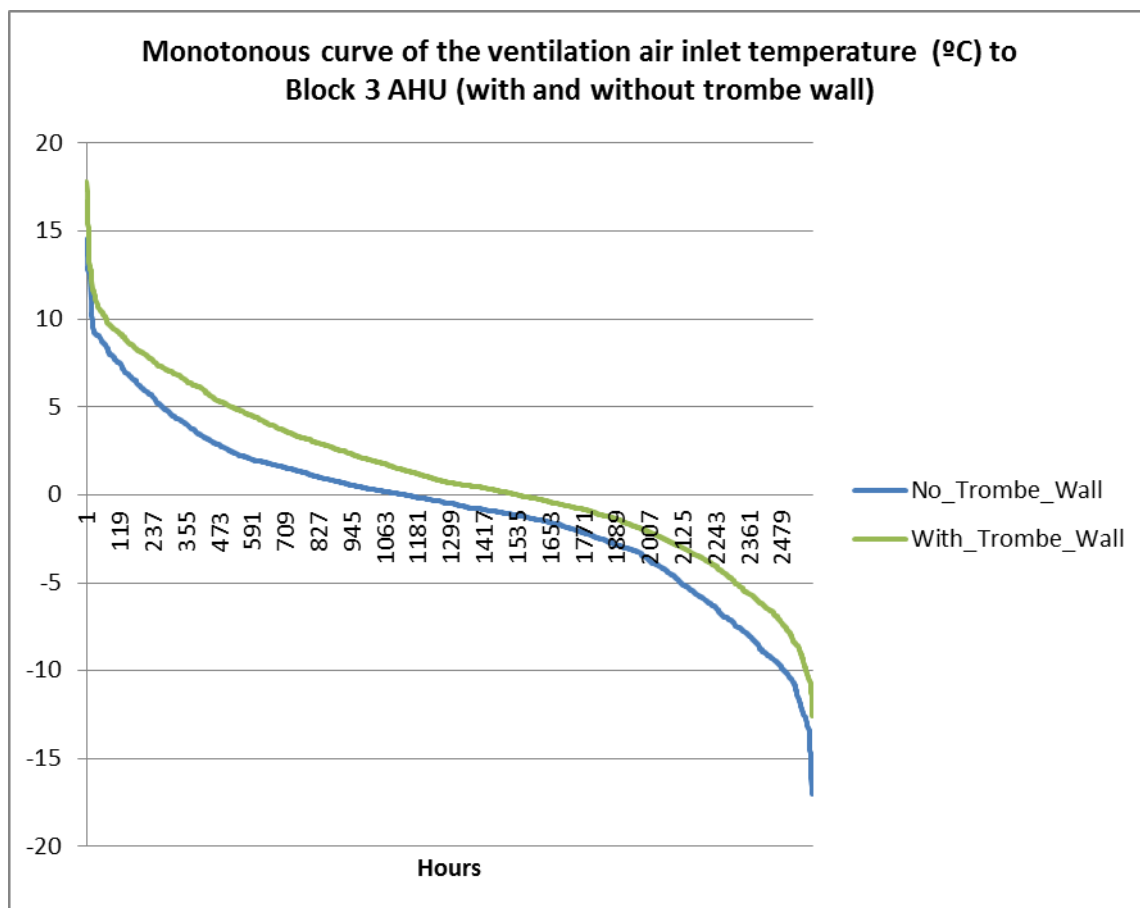


Figure 13 Monotonous curve of the inlet temperature to the ventilation system of Block 3 (with and without the trombe wall)

The previous picture displays that the temperature of the ventilation air inlet temperature to the AHU unit of block 3 is increased some degrees (2/3) thanks to the installation of the trombe wall. However, if the temperatures in the outlet of the heat recovery devices are considered, as displayed in the next picture, then the impact of the trombe wall becomes negligible.

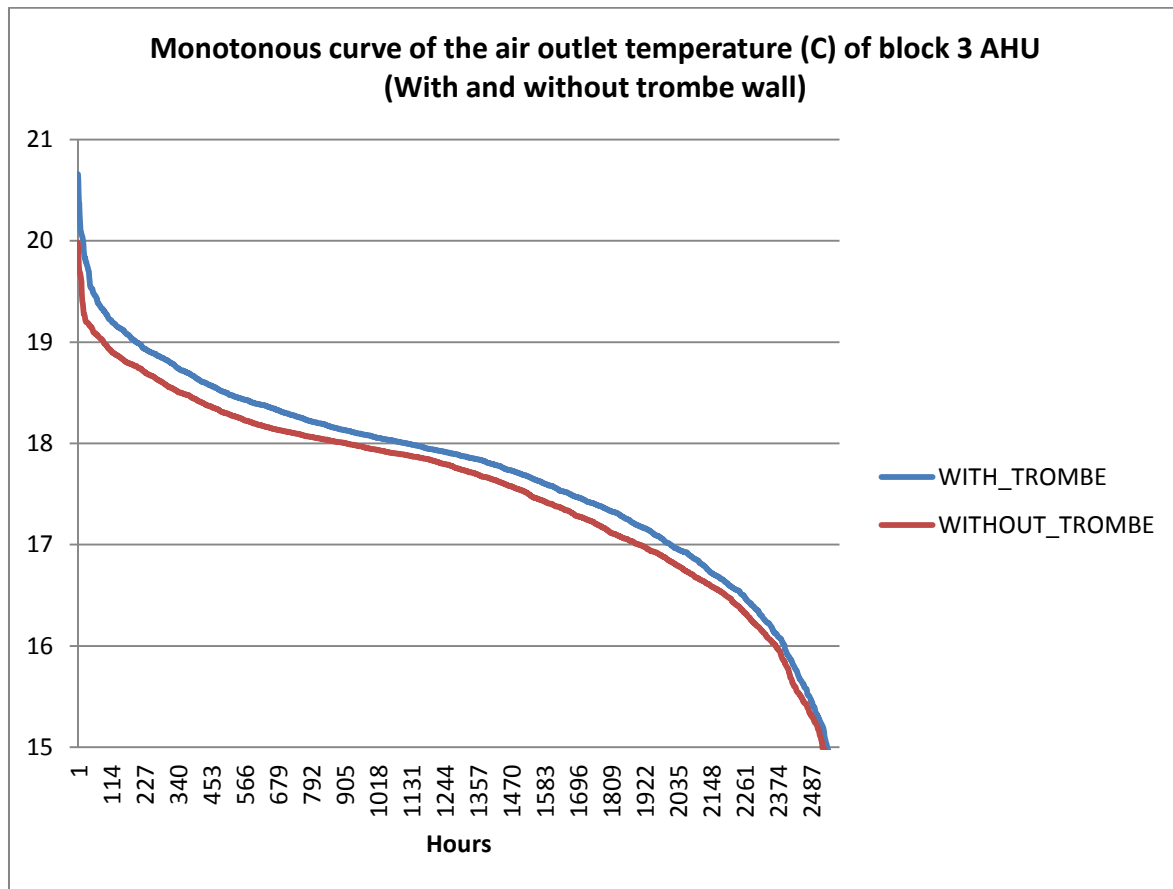


Figure 14 Monotonous curve of the air outlet temperature from the AHU of Block 3 (with and without the trombe wall)

The obtained results have revealed that in buildings where a high performance heat recovery device is available, the trombe wall will not be able to provide significantly higher values of ventilation supply air temperatures for the climatic conditions existing in Sweden.

4. Conclusions

As it is well known, the adequacy and energy performance potential of any specific combination of design strategies and technical solutions is set by the constraints existing in each building, and the optimum solutions for a specific project is not directly adequate for significantly different boundary conditions (technical, economic and regulatory).

Taking this into account in order to ensure the successful definition of a low consumption building design, the implementation of a holistic methodology in which the design of the building is solved as a global problem affected by project specific constraints is of critical importance.

For this reason and even if it was not formally an expected output of the project a common design methodology has been developed to be implemented in the design of the demo buildings of the project. This methodology is formed by the following sequence and is based on the use of dynamic simulation as a support tool during the design process:

- Building demand minimization through an optimized architectonic design of the building for the climatic conditions existing in the location of each specific building.
- Use of high performance technologies adequately integrated to define high performance building systems that will minimize the energy consumption necessary to meet the energy demand of the buildings.
- Integration of distributed generation technologies and renewables in order to maximize the exploitation of the local production potential existing in each of the demo sites.
- Deployment of a control and monitoring platform with the functionalities necessary to operate all the systems of the building according to the defined operational strategies, to obtain the complete energy efficiency associated to the potential of the building design.

At this stage of the project and in view of the performance values after the first year of operation, it can be stated that the design and construction of the Swedish demos according to this methodology enabled the successful fulfilment of the existing building level energy efficiency target.

The same statement is also applicable for the Spanish residential demo, even though at the completion date of this document the availability of monitored data was not enough to be used in the validation of the fulfilment of the existing performance target. In any case, an alternative validation process, based on a calibrated model of the building, has been defined to justify with an acceptable level of accuracy the consistency of the performance of the Spanish demo with the existing target.

On the other hand, independently of the specific solutions used in each demo building, all of them have been designed according to this methodology and for this reason share most of their main design criteria. In this sense, knowledge and experience exchange between the demo buildings was implicitly implemented from the very beginning of the project.

The availability of a relatively low number of residential demo buildings deployed only in 2 different locations somehow limited the knowledge and experience exchange potential between different demos, regarding specific innovative solutions.

In any case the applicability of some of the solutions (solar collector system and demand response system) used in the Roth demo to the Skanska residential building have been qualitatively analysed with positive results.

Finally to conclude the document, the applicability of some of the solutions (solarwall facade and trombewall facade) used in the Spanish demo building to the Swedish demo buildings have been studied quantitatively, with not very promising results.



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ROTH

