This Project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement N. 818329

Sun coupled innovative Heat pumps

D5.1 – Prediction models and demand characterization

Due date of deliverable: **30/09/2019**

Actual submission date: **07/10/2019**

Organisation name of lead contractor for this deliverable: CARTIF

List of contributors: CAR, IES, CEA, CNR, EXE, RINA-C

Dissemination Level		
PU	Public	X
CO	Confidential	

History of deliverable	
V1	Submitted on 30/09/2019 – then revision required by PO for minor changes to DLV template
V2	Submitted on 07/10/2019

Project Contractual Details

Project Title	Sun coupled innovative Heat pumps
Project Acronym	SunHorizon
Grant Agreement No.	818329
Project Start Date	01-10-2018
Project End Date	30-09-2022
Duration	48 months

Supplementary notes: This document will be publicly available (on CORDIS and project official websites as soon as approved by EC or *This document will be available only to SunHorizon Consortium partners.*

Summary

SunHorizon will demonstrate up to TRL 7 innovative, reliable, cost-effective coupling of solar and HP technologies. It addresses three main research pillars that interact each other towards project objectives achievement, demonstration and replication: i) optimized design, engineering and manufacturing of SunHorizon technologies, ii) smart functional monitoring for H&C, iii) KPI driven management and demonstration.

D5.1 reports those advances during the first year of the project concerning modelling and simulation of the SunHorizon solutions aiming at building energy demand and systems' performance prediction. Such predictive capabilities will contribute to the development of a smart-integrated control system that will be fully deployed and demonstrated in real conditions within two representative SunHorizon demo sites and partially validated in simulation in some other.

Key objectives covered by D5.1 are to (1) select those two demo cases where the SunHorizon Controller will be fully deployed in real conditions (2) develop simulation models of the building for demand characterization and energy systems models for renewable energy sources contribution, (3) develop prediction algorithms for demand and production forecasting, (4) define a weather forecast service, and (5) define the necessary interfaces for model and service interaction. In this sense, the following main activities have been conducted:

- Collection of details from SunHorizon demo sites, which are relevant for the selection of demonstration cases and the generation of suitable energy models
- Definition of a common simulation methodology to provide suitable prediction capabilities to the SunHorizon advanced controller thanks to the integration of the building digital twin (in IESVE software) and energy systems' models (in TRNSYS software) into the overall control workflow.
- Definition of requirements for a weather forecast service and identification of relevant input/output variables to enable the interaction of the prediction models and algorithms with the self-learning and end-user feedback controller features.

The output of the task is a first step for the implementation of prediction algorithms to estimate the energy demand and the renewable energy contribution into the SunHorizon controller. The algorithms will feed tasks 5.3 and 5.4, for self-learning and optimization strategies capabilities.

This study provides a complete and adapted methodology for demand and RES contribution prediction of the project for two different cases, residential and tertiary building, which sets a robust basis for replication and scalability in future developments that will contribute to a more efficient energy supply and the decarbonisation of heating and cooling applications.

Keywords

Advanced control; performance prediction; energy demand; simulation models; co-simulation; weather forecast

Table of Contents

1 Introduction

1.1 Motivation and objectives

SunHorizon project aims to demonstrate that, the proper combination of innovative renewable-based technologies (Technology Packages- TP from now on) such as solar panels (PV, hybrid, thermal) and heat pumps (thermal compression, adsorption, reversible), adequately managed by an **advanced integrated control system** with fault detection and maintenance surveillance capabilities, among others, is capable of maximize the energetic and environmental performance of the heating and cooling energy supply thanks to: (i) avoidance of waste energy, (ii) identification of malfunctioning of equipment, (iii) maximization of energy coming from renewables, (iv) increase of energy self-consumption, (v) reduction local energy bills and (vi) cut of derived CO_2 emissions.

In order to ensure optimal efficiency energy management and to maximize the renewable energy contribution in the built environment, the amount of energy demand to be satisfied and how much renewable energy is available need to be consider in advance, so that the most suitable exploitation of resources (taking advantage of storage and building thermal inertias) can be planned. **Demand and RES forecasting** has helped building operators to make wiser control decisions as well as to implement smart energy management and operation systems that allows for production optimization and avoids waste energy.

Demand prediction allows for anticipation of the energy systems production and peak-load management. It have been widely studied in literature and depending on the amount of data need and expert know-how, the four most used methods are: (i) statistical analysis (e.g. regression analysis, ARIMA), (ii) energy simulation programs (e.g. TRNSYS, Energy Plus, IDA-ICE, IESVE), (iii) data-driven intelligent computer systems (e.g. Artificial Neural Networks – ANN, Machine Learning techniques) and (iv) simplified models such as “degree day methodology” or “bin hours” (Zhao & Magoulès, 2012).

Particularly, SunHorizon will implement **building and energy system simulation models** to provide demand and performance prediction capabilities to the control and energy management strategies of the proposed TPs. However, a commitment between accuracy and processing time should be also considered. Complex models are normally able to provide better accuracy but, at the same time, they are more time-consuming. This requirement is even more critical when simulation models should be run multiple times as part of a decision-making iteration workflow to derive optimal control strategies. This is the case of SunHorizon, which aims to use the suitable ‘just-enough-accurate’ models and tools that provide a balanced solution in this sense.

Furthermore, building energy models are greatly affected by climate conditions, which determine a dominant part of the energy loads, affected at the same time by the thermal inertia of the walls (White & Reichmuth, 1996). Thus, in order to provide reliable predictions, building simulations should be fed with **weather forecast data** and the proper interfaces between simulation tools and climate services are required.

Simulation models by themselves and reliable weather forecast information are, however, not enough to ensure that prediction requirements for control purposes are met. In this sense, robust model calibration with real data that can be automatically managed (like the simulation-based decision-making process itself also should be), is essential to ensure that control decisions are adequate and optimized for real operation. Self-learning algorithms can enable the **automatic model calibration process**. In addition, other model parameters and input variables, such as the **end-user behavioural habits**, will affect prediction results and should be reliably anticipated.

Therefore, the selection of a **suitable integrated architecture of all the prediction services** and/or relevant data sources (simulation models, user feedback interface, monitoring data, etc.) must be devised to reach SunHorizon predictive control goals.

According to all these aspects, T5.1 (reported in this document D5.1) has been conducted with the **main objective** of defining and developing those methods and models to provide the SunHorizon advanced control approach with the required prediction capabilities both in terms of building energy demand, renewable energy contribution and energy systems' performance.

In this sense, being the simulation models the core element of the targeted predictions, a **specific objective** of this document is to summarise the modelling steps and assumptions related to the creation of the following energy models:

- building energy model of the Sunisi house located in Riga
- building energy model of Sant Cugat demosite, located in Sant Cugat.
- energy system's model of Sunisi house (including existing systems and SunHorizon energy systems).
- energy system's model of Sant Cugat demosite (including existing systems and SunHorizon energy systems).

The document is organised following the logical steps for energy model creation. As the amount of information for accurate modelling of the building case study is quite limited, the current document should be considered as a reference of the initial inputs adopted to overcome data gaps and missing building details. The results of the simulations should be considered only as initial estimations and not as completely representative of the building physical phenomena of the case study. Iterative modelling and calibration steps are required to improve the reliability of the results and gradually substitute the modelling assumptions.

Finally, it should be noted that, since T5.1 constitutes the initial task of the control developments and is strongly related to other project activities (see Section 1.2), D5.1 also focuses on the definition and description of the main methodological solutions adopted as part of the **development / implementation strategy of the SunHorizon advanced controller**.

1.2 Relation to other tasks and deliverables

This deliverable (D5.1) is the result of Task T5.1 in WP5. Figure 1 shows the conceptual approach of the whole WP5, which is mainly devoted to develop an integrated control system with advanced capabilities relying on the integration of: (i) demand and performance predictions, (ii) self-learning features/algorithms and (iii) end-user feedback information. In particular, this conceptual map situates T5.1 in relation with the detailed activities to be conducted and those relevant information flows within the Project.

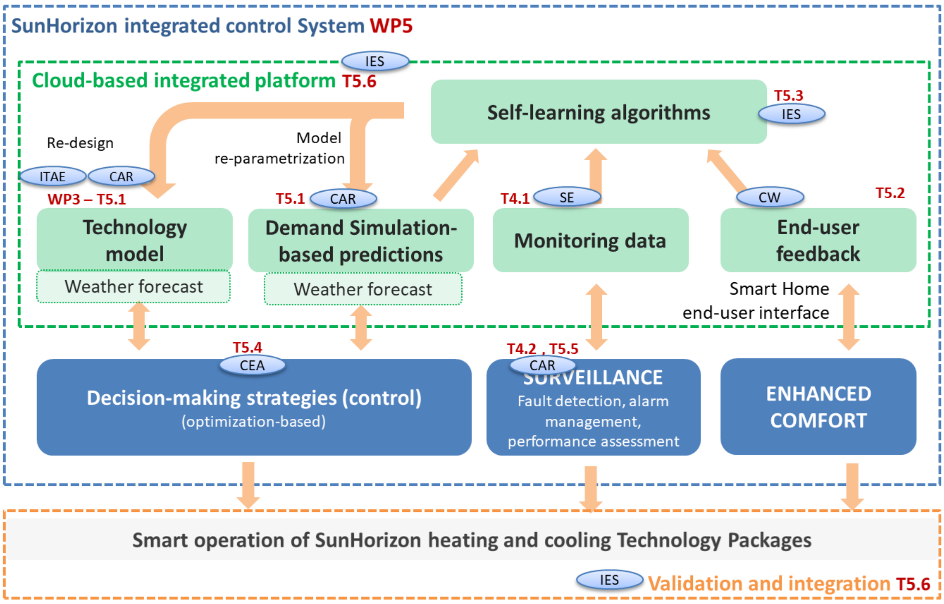


Figure 1. General concept of the SunHorizon integrated control system with advanced capabilities

Specific links between T5.1 and the rest of the project activity are described in Table 1 and illustrated in Figure 2 particularly within WP5 context.

Table 1. SunHorizon tasks interacting with the activity reported in D5.1

Task / WP	Name	Relationship
WP2	SunHorizon use cases scenario definition	T2.1 data collection (including building geometry and constructive characteristics as well as technical specifications of the existing systems) were used as inputs for the creation of energy models. Moreover, T5.1 has been developed with a strong link to T2.4 system definition and preliminary simulation studies. Particularly, D5.1 TRNSYS models for HVAC equipment build on T2.4 activity with the corresponding adaptations for their integration into the control loop.
WP4	Functional monitoring platform and optimization tool	SunHorizon prediction algorithms/models rely on calibrated models that require real monitored data. WP4 (T4.1) is in charge of defining the specifications and develop the monitoring architecture capable of providing monitored data to the models
WP6	Demonstration	Prediction algorithms is the core element of the SunHorizon advanced control system, which will be fully demonstrated in 2 representative project demo sites within WP6 activities (as explained in Section 1.3)
T5.2	Smart Home EUI	T5.2 will define and develop a Smart Home End-User Interface in the form of an end-user mobile app that will collect information from user habits. This information will be used to get predicted end-user behaviour as model input
T5.3	Self-learning algorithms	Self-learning algorithms derived from T5.3 will contribute to a twofold purpose: (i) enabling automatically calibrated simulation models, (ii) learning from user habits to provide usage patterns as model inputs
T5.4	Decision-making strategies	Decision-making strategies to be developed within T5.4 will be the base of the SunHorizon controller, orchestrating those different data sources and smart services. Among them, model-based predictions are at the core of the control decision-making process.
T5.6	Control modules integration and validation	T5.6 will produce the final deployment of the integrated control system to be demonstrated in WP6. This will be an iterative process (develop-test-refine) in which T5.1 prediction algorithms and models will be included. Conceptual and software integration is aimed.

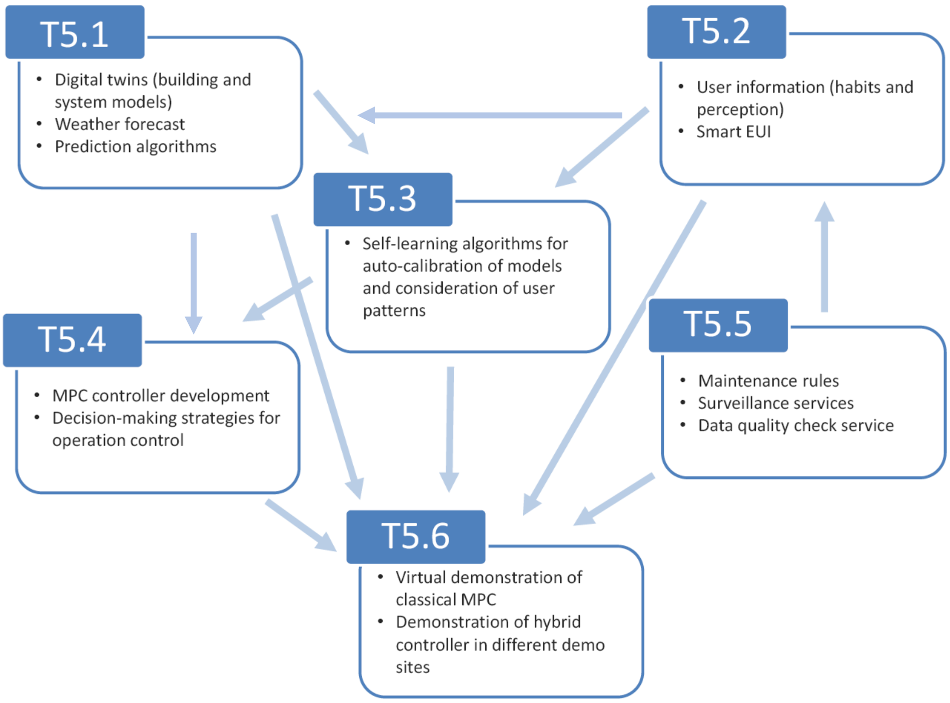


Figure 2. Links among SunHorizon WP5 developments for an advanced integrated control system

1.3 Methodology

This section briefly describes those main steps followed during the first year of the project to achieve SunHorizon T5.1 goals and prepare the ground for upcoming developments for the integrated control system.

Particularly, Table 2 illustrates a summarized organization of the work during the T5.1 development.

Table 2. Gantt chart for those activities conducted according to T5.1 methodology of work

	2018			2019								
T.5.1 Activities / Month	Oct. 1	Nov. 2	Dec. 3	Jan. 4	Feb. 5	Mar. 6	Apr. 7	May 8	Jun. 9	Jul. 10	Aug. 11	Sep. 12
Detailed concept of SunHorizon smart control												
Identification of prediction services requirements and interconnection needs												
Selection of tools												
Development / Implementation / Demonstration strategy												
Collection of demosite feedback and constraints for control demonstration												
Selection of demo sites for controller full deployment												
Data collection												
WP2 initial data collection from demo sites and TPs												
Continuous upgrade of demo site and TPs data												
Creation of simulation models												
Building digital twin models in IESVE												
Energy systems' models in TRNSYS												
Weather service (Requirements definition)												

Coordination of links to other WP5 activity	
T5.2 (Prediction of end-user behaviour considering feedback app outcomes)	
T5.3 (Self-learning algorithms for model auto-calibration and comfort predictions)	
T5.4 (Co-simulation approach)	

Brief explanation of the abovementioned methodology and specific activities are included below:

1.- **Detailed concept definition** – The general concepts for the proposed SunHorizon hybrid controller and their objectives where first revised in order to provide further details on the actual role and interconnection of the different smart services (particularly focusing on prediction modules) as well as on the specific software tools to be used. Section 2.1 summarizes the main outcomes of this activity.

2.- **Development / Implementation / Demonstration strategy** – This stage concentrated most of the efforts during the initial phase of the project control-related activity, since it was crucial to analyse all the technical and non-technical constraints for the controller demonstration in the 8 different demo sites of the project and decide the most balanced and representative demonstration scope, also accounting for the available development resources. In this sense, it was decided to make a difference between two different levels of demosites: (i) Type A, where the full deployment and demonstration in operational conditions of the SunHorizon hybrid controller will be performed, and (ii) Type B, where the control developments will be validated in simulation.

More details are explained below:

Within **demo cases 'Type A'** the following actions will be accomplished:

- Complete digital twin developed in IESVE
- Classical MPC controller developed and validated in simulation, which will be used for comparison with the SunHorizon hybrid controller.
- Hybrid controller developed and validated in simulation as a first step for the full demonstration
- Hybrid controller deployed and validated in real demo operational conditions (as the rest of solar and heat pump SunHorizon integrated TPs will). SunHorizon control will be implemented physically, so there would be real interaction of sensors/actuators with the high-level controller and its smart capabilities.

Within **demo cases 'Type B',** the following actions will be accomplished:

- Hybrid controller developed and validated in simulation
- Simplified building model developed. (Auto-calibrated) digital twin using IESVE software will not be needed for validation in simulated conditions, so it will not be developed. Benefit from IESVE model is the easiness for autocalibration. Since the building model in this case will be considered to ideally represent the reality (and then it will be considered as perfectly calibrated at any time), the whole modelling (building + energy systems) will be created in TRNSYS. WP2 energy modelling of the SunHorizon TPs will be reused for this purpose, while the building model using TRNBuild application will be created.

The following list of benefits, potential risks and mitigation actions related to the full demonstration of the controller in Type A demo cases were evaluated:

Benefits to be demonstrated in 'Type A' demo cases:

- Accounting for feedback of users/tenants, which enables improved comfort/user satisfaction
- Collection of vast amount of data, which will be available to better understand and solve any potential problem or underperformance of the HVAC systems
- Integration of optimised maintenance information and rules, which contributes to reduce the maintenance costs and extends systems' life
- Digital twin will be developed and available for extended analyses that might be interesting for demo owners

- Enhanced reduction of energy consumption and related economic costs

Potential risks and planned mitigation actions considered:

- SunHorizon controller may be seen as interfering with the local control rules of the different technologies and/or existing equipment at the demo sites. However, it will perform a high-level/supervisory control, not affecting low-level control rules, so physical integrity of the facilities is not compromised.
- Unexpected control decisions in first stages of validation/deployment may occur, but different operational modes will be integrated (e.g.: optimized/automated/manual) so the operator has access/control of the facilities at any time

The decision was made taking into consideration the following **criteria**:

- Type of building
- Previous existence of a Building Energy Management System (BEMS) and constraints for the interaction of the existing and new control systems.
- Data availability and restrictions
- Owner requirements
- Technical adequacy and relevance: variable boundary conditions to maximize potential of storage were preferred, in order to test the controller in the most challenging conditions and demonstrate their real interest/benefit.
- Possibilities to integrate end-user feedback. If end-users were not likely to be involved with the project and new solutions, trying to demonstrate this kind of capabilities would not be interesting.
- Demo owner requirements (e.g. budget restrictions, managerial preferences, authorization process constraints)

The main characteristics of each project demo site according to the aforementioned criteria are presented in Table 3.

	Type of Building	Existing BEMS	Data Availability	Owner Requirements
Berlin	3-storey residential terraced house	No	Not yet – Annual might be available	Different ownership cases
Nürnberg	4-apartament building	No	Not yet – Annual might be available	Concerns on complexity of control system
Sant Cugat	Tertiary building (civic centre)	Yes (limited)	Energy bills + 15 minute data of supply and return temperature from the HVAC system	None
Madrid	9-apartment building	No	Not yet – Annual might be available	Owner concerns on complexity of control system
San Lorenzo	Single-family detached house	Yes	Energy bills Daily temperature and setpoint reporting	Overall control preferred to be developed by the same technology provider
Verviers Sport Centre	Tertiary building (sports centre)	High-level BEMS	Energy bills Some measured data	SunHorizon will only address a small part of the demand. Interaction with the high level BEMS and existing systems can make the SunHorizon controller application complex
Verviers Swimming Pool	Tertiary building (swimming pool)	High-level BEMS	Energy bills Some measured data	SunHorizon will only address a small part of the demand. Interaction with the high level BEMS and existing systems can make the SunHorizon controller application complex
Riga	Two single-family detached houses	No	Not yet – Annual might be available	None

Table 3. Demosite characteristics for control development strategy decision

As a conclusion of this decision stage, Riga and Sant Cugat demo buildings were selected as the two 'Type A' demo sites for the full deployment and demonstration of SunHorizon controller in real conditions.

This particularly enables to demonstrate SunHorizon potential in one residential building (with heating demand dominance) and one tertiary building in which cooling demand is also required as a dominant energy load. This supports the selected demonstration strategy in terms of the coverage of the widest variety of scenarios according to building types and addressed energy uses.

3.- **Data collection** – The creation of the simulation models that will act as the core components of the prediction capabilities require relevant amount of information about building and energy systems characteristics. During the first 6 months of the project, in close collaboration with WP2 activity (T2.1) building geometry and constructive details and typical building use patterns were collected from demosites. In addition, technical specifications an sizing details of existing HVAC systems and novel SunHorizon solar and heat pump technologies were gathered. This is an iterative process in which the second part of the year was devoted to information upgrade, particularly concerning the specific Technology Package schematics and sizes for the different demo sites. Since their definition is still an open topic to be delivered later in the project, the energy system models developed for T5.1 purposes are quite consolidated versions, but still subject to final adjustments.

4.- **Creation of simulation models** – Once all the technical characteristics of the buildings and HVAC systems were collected, the energy simulation models reported in Section 3 were developed.

5.- **Weather service requirements** – Once the previous steps concerning the development strategy were clearly defined as well as the first draft version of the models were created, the requirements to integrate a weather forecast service into the control loop during the operational phase were addressed. Different options are described in Section 4 and the final solution will be selected in T5.4 when the main optimization algorithm of the controller will be developed.

6.- **Coordination with other WP5 tasks** – Finally, simulation models require to consider adequate input/output variables that can be defined according to the communication with other smart services of the SunHorizon controller, particularly deriving to the upcoming project activity (extending up to the end of the second year of the project) in terms of self-learning techniques and end-user feedback. Self-learning will be applied for model calibration, addressing those model parameters that most influence the prediction results of the building simulations. End-user feedback collected from the Smart Home EUI will contribute to substitute standard occupancy/usage profiles by reliable predictions of the user behaviour within the target prediction horizon.

For this reason, in parallel to the creation of the simulation models, the coordination with first advances and decisions from T5.2 and T5.3 were considered. Main aspects in this sense are described in Section 5. Moreover, the co-simulation approach that will enable the implementation of IESVE-TRNSYS simulations to support T5.4 control decisions also allocated a substantial part of the activity once the controller demonstration scope and requirements were defined. Within SunHorizon, model coupling through co-simulation is considered as important as the creation of the individual building and systems' simulation models. Then, the feasibility for different co-simulation alternatives were tested in this phase of the project. Main conclusions are included in Section 3.3.

2 Prediction capabilities of the SunHorizon smart control

2.1 Revised SunHorizon controller concept

The SunHorizon smart control concept was defined during the proposal stage as outlined in Figure 1. Nevertheless, at the beginning of the project, this concept has been detailed and the following software architecture and dataflows between the different smart services has been devised:

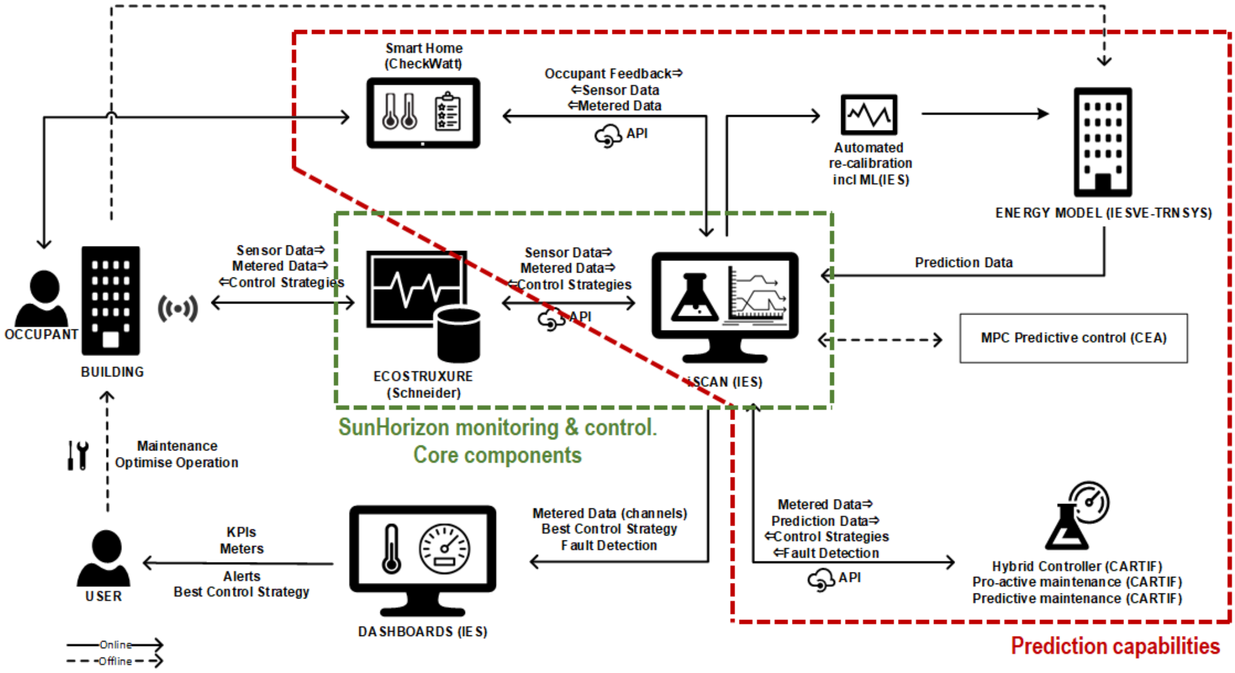


Figure 3. Detailed SunHorizon integrated software architecture and dataflows

Two software components will act as the core of SunHorizon integrated monitoring and control solution (remarked in green in Figure 3). On one hand, a cloud-monitoring platform developed by Schneider will centralize the interaction with field devices (sensors and actuators) for data monitoring and high-level control setpoints communication. Monitored real data will be made accessible for iSCAN application developed by IES, which will be the core component particularly for control, surveillance and KPI processing.

In what concerns the advanced controller, iSCAN will act as the 'brain' of the proposed solution and will manage the communication between different services involving prediction capabilities. Specifically, iSCAN will (i) directly manage the simulation running of the building energy models for demand characterization that will be developed using IESVE simulation environment, and (ii) may incorporate the main algorithm of the advanced predictive controller implemented in Python scripts.

The key characteristics of this main SunHorizon control algorithm have been detailed in the revised concept developed in T5.1. (Figure 4 shows a graphical representation of its different components and functionalities) and the involved steps are described next:

1.- The algorithm launches the **optimization calculation loop** aiming to determine the most suitable control strategy for the next prediction horizon. During T5.3-T5.4 iterative development process, different options will be tested in regards to the frequency with which this loop is activated. As a minimum restriction, the algorithm will be launched once during the prediction horizon (e.g. each 6h, 12h, 24h). However, if the computational effort of the involved simulations enables higher triggering rate for the process, maximum frequency will be tested. This is expected to provide interesting benefits to reduce deviations between predicted and actual behaviour. Finally, an event-driven triggering of the optimization process will be also considering. This will indeed monitor the existence of new weather and/or use predictions as well as the gap between predicted and monitored data; in case such deviation exceeds certain limits, the optimization loop would be launched again.

Moreover, different timespans will be considered as possible prediction horizons to find the optimal balance about accuracy and relevance of the simulation-based prediction itself and the computational effort and feasibility for the simulations to be run according to the operational requirements in terms of fast enough control response.

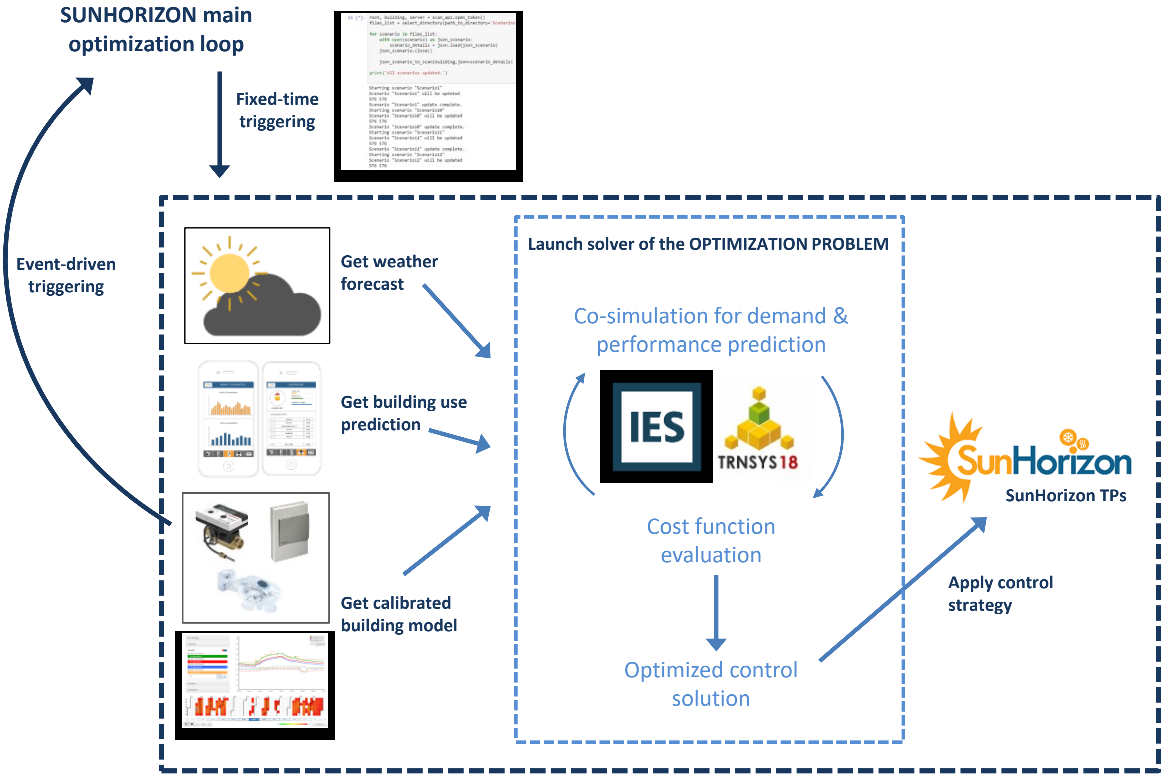


Figure 4. SunHorizon controller main optimization loop concept

2.- The optimization calculation loop will set up and solve an **optimization problem** in which the mathematical function is in this case substituted by the set of equations behind the simulation models. Then, several energy simulations will be launched to predict the energy demand and systems' performance under different operational decisions, so that the algorithm will lead to the most suitable ones. This, in the end, is the purpose of SunHorizon T5.4, where decision-making strategies will be defined. Such process should indeed set the guidelines to describe the optimization problem including:

- A reference of reasonable operational decisions that should be considered. This will also define those model inputs (normally corresponding to high-level control setpoints) to be optimized.
- The cost function and constraints (e.g. accounting for energy use, economic and comfort criteria) that will allow the system to decide which the best set of control actions is for the next period.
- The solver algorithm, which will be also selected to adapt to the particular optimization problem.

3.- **Energy simulations** (acting as the 'mathematical function' to be optimized) will run taking advantage of 2 different simulation environments: (i) IESVE for the building energy demand characterization, and (ii) TRNSYS for the prediction of the energy systems' performance. The selection of these simulation tools is further justified in Section 3, including the description of the co-simulation approach that is required to couple IESVE and TRNSYS calculations (see Section 3.3).

IESVE will provide prediction of the energy demand/needs of the building according to the expected weather and use patterns for the next prediction horizon. Although standard building energy simulations may be applied in all phases of the building project/life from design to commissioning and operation, in this case, the operational use of the models particularly requires addressing the discrepancies between design performance and actual performance, and thus creating a digital twin of the actual building. This is achieved through model calibration that will be satisfied by iSCAN, and other modules of the VE tool suite such as HONE[1] and PARAMETRIC[2], thanks to an automatic process in which key model parameters are identified and refined based on the comparison of simulation outputs and real data.

TRNSYS energy simulation models will include all the energy systems of the building (particularly SunHorizon TPs) accounting for their technical specifications and realistic low-level control rules and setpoints. TRNSYS will receive as input the building energy demand to be supplied in each targeted time period and will allow the optimizer to test different control strategies.

Finally, each time that the optimization algorithm launches one energy simulation, **weather and building use predicted profiles** have to be provided as model inputs. To that purpose, iSCAN will also manage the connection to the weather forecast service to be developed in upcoming stages of the project (see Section 4) and will make the weather prediction available for the simulation tools. Similarly, end-user feedback information provided through the Smart Home EUI and field data from Schneider's monitoring platform will be stored in iSCAN databases, so machine learning techniques can be applied and more accurate predicted building usage profiles will be considered in the models.

[1] HONE [online]https://www.iesve.com/software/ve-for-engineers/module/Hone/5949

[2] Parametric tool [online]https://www.iesve.com/software/ve-for-engineers/module/Parametric-Tool/5948

3 Simulation models

As already advanced in Section 2, SunHorizon will rely in combined IESVE + TRNSYS energy simulations for the core predictive capability of the hybrid controller. The purpose of this section is to describe the creation of the energy models and present their main features and assumptions. However, first the selection of the simulation tools is explained. The corresponding decision was made according to the following criteria:

1.- The simulation approach should **facilitate model auto-calibration** in order to provide the highest reliability of the performed predictions. At the same time, being at the core of the control workflow, the simulation models should **easily communicate with the rest of the proposed smart services**.

In this sense, IESVE simulation environment already offers all the required fundamental capabilities and flexibility to define detailed building simulation models that can be run with comparable accuracy to other renowned software such as EnergyPlus or TRNSYS. In particular, IESVE tool suite incorporates iSCAN application, which is able to interact with field monitoring data and integrate them together with the simulation results in order to perform an automatic calibration process at any time. Moreover, iSCAN can also compute further calculations (e.g. KPIs), manage the dataflows with other external applications (like SunHorizon controller services), and integrate any third-party script developed in Python to run even more specific routines. The automatic calibration process is described in more detail in Section 5.2.

The use of other simulation software instead were possible, but would have obliged to develop automatic calibration algorithms from scratch wasting valuable efforts that otherwise can be dedicated to improve the intelligence of the controller through the analysis and development of enhanced calibration algorithms.

Nevertheless, IESVE presents the limitation of the available simulation modules embedding energy models of innovative energy technologies such as SunHorizon solar panels and heat pumps. Then, it was not consider the most practical tool to create the required energy systems' models. Instead, TRNSYS was selected for this particular purpose. TRNSYS constitutes a renowned dynamic simulation tool among the international research community which provides great flexibility to model new configurations and combinations of different systems and easily integrate user mathematical models (e.g. of novel energy technologies).

2.- A **balance between computational effort and prediction accuracy** must be ensured, in order to enable the practical operation of the overall hybrid control approach.

In this sense, there are different energy modelling techniques (such as RC-networks and Reduced Order Models, ROMs) that have proven to perform satisfactorily for a number of problems (e.g. in District Heating applications). These solutions opt for reducing the computational effort thanks to limited model complexity, while the prediction accuracy is not exploited at its best. This limitation in the prediction accuracy may not make a big difference when fast control actions are not needed and/or an aggregated energy demand is addressed (thus compensating model simplifications and variable usage profiles in favour of a reduced prediction error). However, when energy ecosystems with lower thermal inertia and or higher influence of inputs' uncertainties are addressed, an increased accuracy is expected to be critical.

For this reason, SunHorizon will use more complex simulation models for a building-level problem. This will involve evident higher computational effort and expected better accuracy. This is the case of IESVE and TRNSYS models. However, even if the computational requirements will be more important, efforts for model creation (also considering the automatic calibration process) are normally reduced. Additionally, it should be noted that running calculations for 6h-24h simulated time (i.e. for the prediction horizon) will normally last a few seconds of actual time, thus not risking the practicality of the proposed hybrid predictive controller.

In any case, in order to mitigate the potential risk of excessive computational efforts, verification tests within the first integration proofs of concept will be done, also allowing for the corresponding adaptations of the optimization algorithm[3].

3.1 Building models

The objective of this section is to summarise the modelling steps and assumptions related to the creation of the building energy models for Sant Cugat's and Riga's selected demo sites. It is organised following the logical steps for energy model creation. As the amount of information for accurate modelling of the building case studies is limited at the current stage of the project, this should be considered as a reference of the initial inputs adopted to overcome data gaps and missing building details. Resulting simulation models and calculations should be considered as preliminary estimations and not as completely representative of the building physical phenomena of the case study. Iterative modelling and calibration steps in upcoming stages of the project will enable to improve the reliability of the results and gradually substitute the modelling assumptions. The overall process followed a data-driven and evidence-based modelling approach with the intent to use as much metered data as possible for the creation of the energy model of the corresponding demo cases.

Next, those main steps and relevant information to be provided during the creation of the IESVE building models are described:

- **Definition of building boundary conditions** (location and weather) - Neighbouring buildings and surrounding obstacles (e.g. relevant close hills/mountains) that may affect solar incident radiation should be considered. To that end, a topographical analysis of the target building location is recommended. In case of relevant shading effects, the corresponding elements will be included into the building energy model as external shading objects. Moreover, weather information is indispensable for simulation-based energy demand characterization. In this sense, two different information sources/formats are considered: (i) design data (e.g. as those contained in [1]), and (ii) time-series data included in a weather file from the closest weather station and/or suitable weather data models based on historical registers. Design data is only used as reference to understand the average climatic conditions on site, the climatic zone and the reference values for the estimation of heating and cooling loads, whereas time series data extracted from actual measurements, historical registers or weather forecast services are used to generate weather files for energy simulations of the demo-site. Annex A.1 shows an example of weather design data for Riga's site, while typical time series information of main influencing ambient variables (temperature, relative humidity and solar radiation) is included in Section 3.1.1 also for Riga's site.

- **Creation of building geometry and specification of constructive properties** - Building geometry of target demo buildings were created using the ModelIT module in IESVE tool. Constructions were created and included in the model considering the available data from technical specification of the layers of each wall. Materials and thickness of each layer were imported in the model approximating them to the available material information in the IESVE database. However, metered U-values are not available, so it is not possible to evaluate if the suggested materials and constructions match properly the constructions in the demo buildings. In future modelling steps within the project additional information and/or tests may be carried out to refine the initial input parameters of the energy models.

[3] It should be reminded that different triggering criteria for the main optimization algorithm will be analysed in T5.4 in order to accommodate the energy simulations to the control workflow.

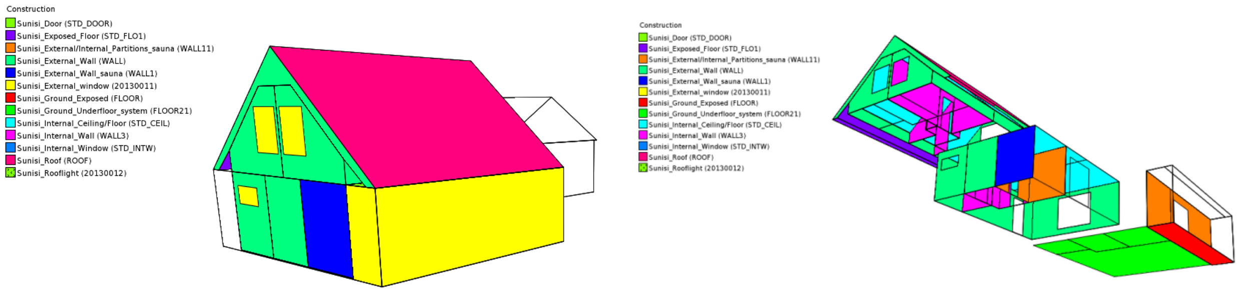


Figure 5 Example visualisation of constructive information in IESVE software

Figure 5 shows an example of how IESVE presents the constructive characteristics and co-existence of different constructive elements within the same model after constructive properties are assigned to the previously-created building geometry.

- **Sunlight/sun-path analysis** (*optional*) - A simple sunlight / sun-path analysis (see Figure 6) can be optionally carried out during the creation of the building energy model in order to better understand/estimate the importance of direct sunlight on the energy performance of the building in different periods of the year, and thus, adapt certain modelling assumptions for improved accuracy and optimized computational effort.

- **Definition of spaces and building use information** - This modelling step comprises the identification of a representative space distribution of the total building volume accounting for input information related to room functions and uses. These are normally characterised in IESVE through the specification of the '*Thermal template data*', which encloses information for:

    - Heating and Cooling Set Points
    - Domestic Hot Water Usage
    - Auxiliary plant schedule
    - Internal Gains
        - Number of People and Occupancy Schedule
        - Lighting Power Density and usage schedule
        - Miscellaneous equipment density and usage schedule
    - Air Exchanges
        - Infiltration (Air Permeability)
        - Auxiliary Ventilation
        - Natural Ventilation

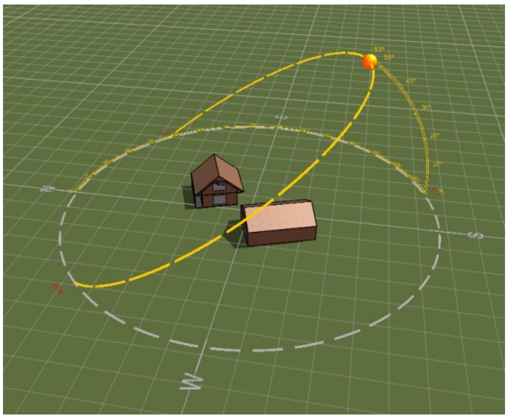


Figure 6. Example visualisation of sun-path analysis over Riga's building case study

Concerning those different schedules required in order to characterize the different uses of the building spaces, different profiles were set. They represent the dynamic behaviour of people, systems, and internal gains. For these preliminary models, input data are based on traditional profiles used for similar building topologies; however, in future refinements of the energy models, feedback from the end-user interface/app and monitoring data will gather the actual information from the demo site and will contribute to an increased prediction accuracy.

3.1.1 Riga demo site

Riga's demosite comprises two single-family residential detached houses, Imanta and Sunisi. Sunisi has been chosen for the full demonstration of SunHorizon controller. The main characteristics and assumptions relevant for the creation of the Riga's building model using IESVE software are described next.

3.1.1.1 Building boundary conditions

Location

The demo building is located in Sunīši village, Garkalne municipality neighbouring the city of Riga which is the capital of Latvia. The exact coordinates of the building are 56°58'40.1"N 24°21'09.1"E. The exact elevation from sea level of the site is unknown; therefore, it has been approximated to the one of the city of Riga, which is about 26 m. The site of the house is about 15 km from the city centre. The proximity of the site from the capital of Latvia allows considering Riga as the reference place to select most of the modelling information.

The building demo-site is located in a rural area sparsely inhabited. An aerial image of the site extracted from Google Maps is reported in Figure 7. The property is the one underlined in the blue box.

Figure 7 Aerial Image of the Sunisi house [Google Maps]

From an initial investigation of the surrounding area, it is clear that only one neighbour building is close to the Sunisi house at about 20 m of distance, being a low rise residential detached house (7.1 m high). Given the elevate latitude of the location, it is expected that the sun follows a low path in terms of elevation all year around with peaks at summer time. Nevertheless, the distance and the height of the neighbour building affects only for a very small portion of the time of the year the solar incident radiation. Therefore, the neighbourhood building will not be considered as part of the energy model of the house.

Moreover, a topographical analysis of the surroundings of the house was also performed using both geographical visualisation software (Google Earth) and topographical maps of Latvia, which shows that there are not mountains or high peaks worth including in the model as topographical shade. The highest hill close to the site is Gaizinkalns situated 98 km E-SE from the demo-site with a height of 311 m and therefore it is neither likely to play any effect on the incident solar radiation on the site.

Weather

In terms of weather design data the Riga was considered as reference city. Design data have been extracted directly from [1] and are presented in Annex A.1. The number of yearly Heating Degree Days (HDDs) for the city case study is quite high 4098, indicating that the heating season is quite extended and demanding in terms of heating requirements. On the other side, the Cooling Degree Days (CDDs) is pretty low 94; therefore suggesting that dedicated cooling systems may not be required for this site or will operate for relatively a small portion of the hottest months. The coldest month is February and the hottest is July.

For what concerns simulations and the requirement of weather time-series data, two different approaches were considered when creating this preliminary model:

1. The selection of a reasonable typical weather file corresponding to a near location, directly selected from IES repository or weather files.

2. The generation of a tailored weather file for the year 2018 gathered from Riga airport weather station. iSCAN software tool was used to both gather the relevant data from the closest station using the integrated service provided by Athenium Analytics, as well as to generate the weather file for the dynamic simulation.

Figure 8 shows the trend and percentage distribution (respectively) for the external ambient temperature in Riga for the year 2018. In terms of distribution it is interesting to notice the high percentage of temperatures close to 0°C as well as presence of extreme temperature values ranging from -20 ºC to 30ºC.

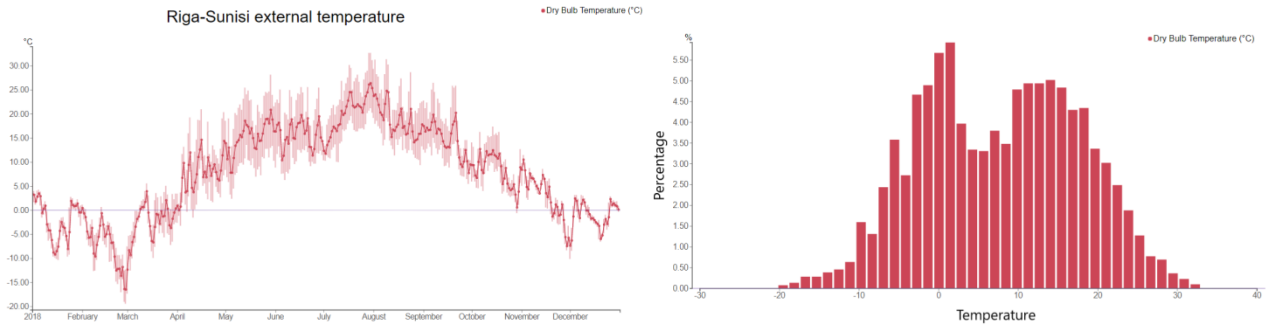
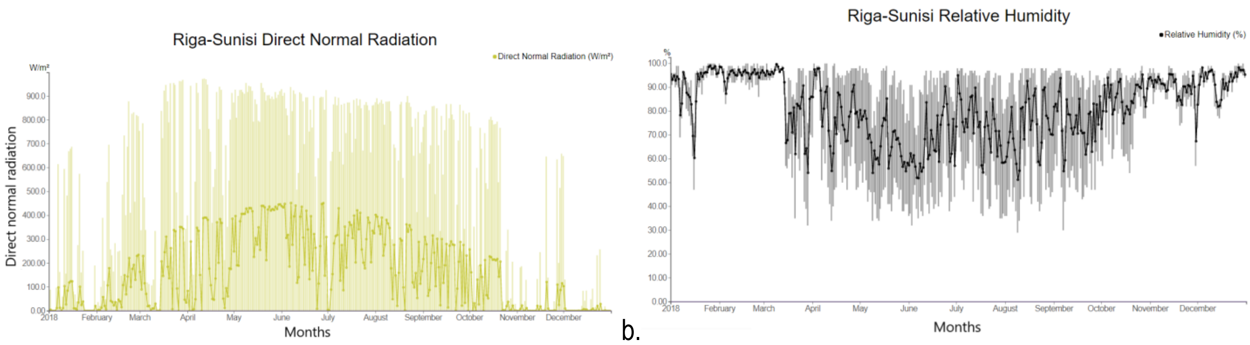


Figure 8 External temperature trend and percentage distribution for the year 2018 for the city of Riga

Similarly, other relevant ambient variables were considered within the weather files as an input for the building simulation models. Particularly, Figure 9 shows the trend of the ambient relative humidity and direct normal solar radiation as time series for the year 2018 in Riga. It can be observed that values of the direct normal radiation are low especially in winter time. The period May/June reaches the highest average values for the year under analysis. Moreover, the analysis of the relative humidity data collected from the weather station in Riga underlines a humid winter season with an average value close to 90% and a quite humid summer with values ranging from 40 to 90%.



a. b.

Figure 9 (a) Ambient relative humidity, and (b) direct normal solar radiation for the year 2018 in Riga

3.1.1.2 Building geometry and constructive properties

According to the previously-mentioned methodology for the model creation process, the building geometry was generated using the ModelIT module in IESVE. Available technical drawings from WP2 activity were used as reference information for this step.

The whole Sunisi's property is formed by two buildings: a main house and a garage area (see Figure 10). The total floor area for internal spaces of the ground floor is of about 50.1 m^2, while the total floor area in the model for the ground floor as reproduced in the building energy model is of about 51.8 m^2 indicating a quite accurate reproduction of the geometry and heating spaces of the building. The evaluated total net volume for space conditioning is of about 220 m^3.

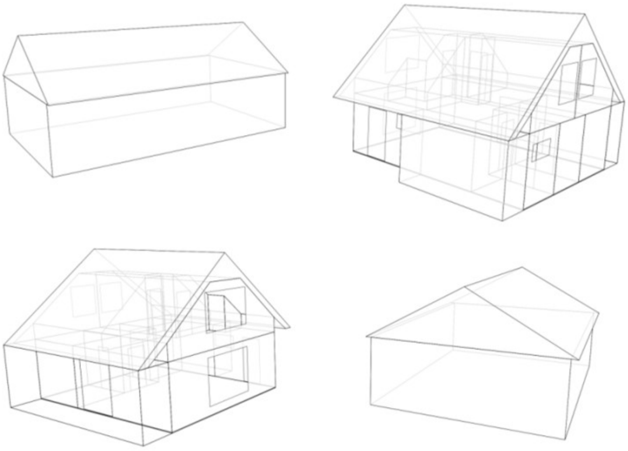


Figure 10. Sketch 3D view of Riga's building geometry

Figure 11 represents different views of the 3D model generated in IESVE for Sunisi's project demo building.

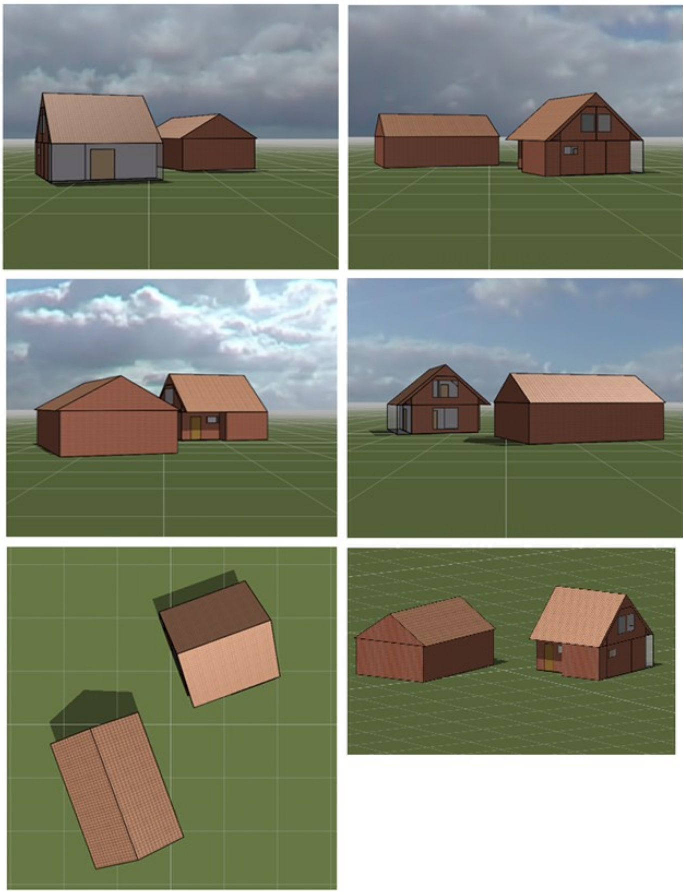


Figure 11. Views of the Riga's building case-study modelled in IESVE. From top left to bottom right: North, East, South, West, Above and Orthographic view

Concerning model inputs related to constructive characteristics of the building, a summary of the main surface properties is reported below in Table 4.

Table 4. Main constructions and relative U-values

Construction Type	Name	Area m²	U-Value (W/m²K)	G-Value
External Wall	Sunisi_External_Wall	69.27	0.2	-
External Wall	Sunisi_External_Wall_sauna	6.14	0.15	-
Roof	Sunisi_Roof	0.0	0.11	-
Ground Floor	Sunisi_Ground_Exposed	10.57	0.16	-
Door	Sunisi_Door	8.96	2.17	-
Internal Ceiling/Floor	Sunisi_Internal_Ceiling/Floor	54.81	1.05	-
Internal Partition	Sunisi_External/Internal_Partitions_sauna	34.11	0.25	-
Internal Partition	Sunisi_Internal_Wall	43.59	0.47	-
External Window	Sunisi_External_window	38.13	1.24	0.41
Roof Light	Sunisi_Rooflight	8.98	2.19	0.55
Internal Window	Sunisi_Internal_Window	1.12	4.14	0.87

3.1.1.3 Sunlight/Sun-path analysis (*optional*)

For what concerns sunlight preliminary analysis, first, a sun-path diagram for the close city of Riga was generated using one of the IESVE modules: SunPath. The diagram (Figure 12) shows that for most of the year the sun does not go over 40 degrees in elevation. In summer time, the sun path spread from 40 to 315 degrees whereas in winter time the sun is always low close to the horizon (10 degrees in elevation) and covers a small portion of the sky from 135 to 225 degrees. Sunrise is from 04.00 am in June and 09.00 am in January. Dawn time is at 21.00 in June and 15.30 in January.

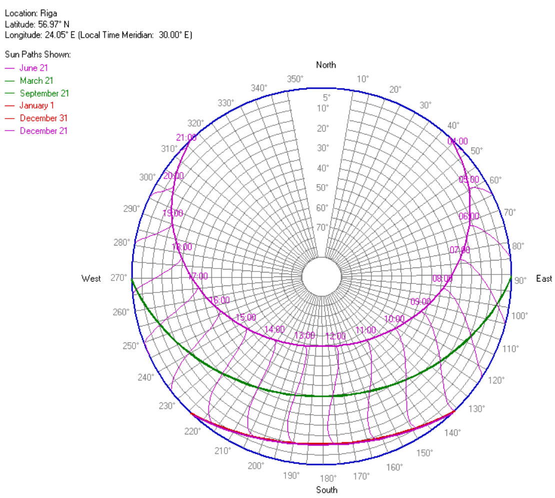


Figure 12. Sun path for the city of Riga

Moreover, it should be considered that the window-to-wall ratio of the demo building, without considering the external veranda, is quite low about 0.15. Glazing structure are evenly distributed on the west and east façade while the south side of the building has only a small window. This suggests that the overall contribution of sunlight as internal gain for the building may be quite low. Interestingly, the building is characterised by an external veranda mostly composed by glazing structures. Although the veranda is located outside of the building and therefore in an un-conditioned space, sunlight in the latest hours of the day could locally increase the temperature of that space and therefore alter the boundary conditions of the adjacent rooms. If the veranda is not considered, the entire north façade of the building would be modelled as exposed to the external temperature. It is expected that the variation between external temperature and the temperature in the veranda in winter time is quite limited while it could be quite important during the last hours of the day in spring-summer time. Figure 13 shows an example of incident sun-light for the 15th Sept 2018 at 17.00.

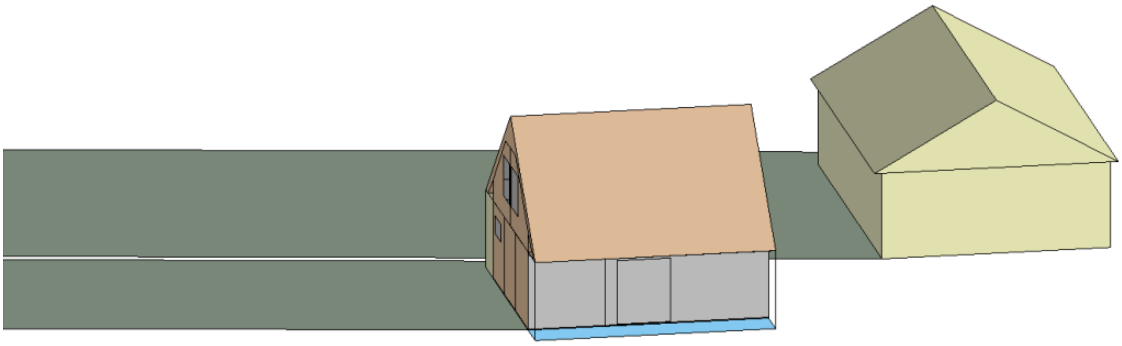


Figure 13 SunPath analysis. Incident solar radiation analysis for the terrace/veranda. (15th Sept 2018 17.00. Sun position: elevation 10 degrees, position 250 degree SW)

In addition, results from the SunCast analysis of the available incident solar energy on the surfaces of the building for the entire year 2018 reveals that the south facing part of the building is characterised by an annual incident solar energy radiation of about 1330 kWh/m^2·yr. The west facing walls are characterised by a total of about 800 kWh/m^2·yr. The north facing wall and the north facing roof are both characterised by values between 600 and 300 kWh/m^2·yr

3.1.1.4 Definition of spaces and building use information

Figure 14 shows different grouping per floor and per space final use. White objects represent shading objects (adjacent building or spaces) that are not considered as thermal spaces for simulation but have an active effect in terms of shading for the building demo-site. Six main room functions were identified during the process of model creation. Those functions were selected based on the data reported in the document describing the geometry of the building. The main room functions identified are: living room/kitchen, sitting room (sauna), terrace/veranda, toilet, bedroom and other.

The terrace/veranda being outside of the building is not accounted as a conditioned space. Nevertheless, given that the space has a large percentage of glazing surfaces it is interesting to take into account the effects of the solar radiation on this area of the building and see how the space temperature changes in comparison to the external air temperature during the year (see section 3.1.1.6).

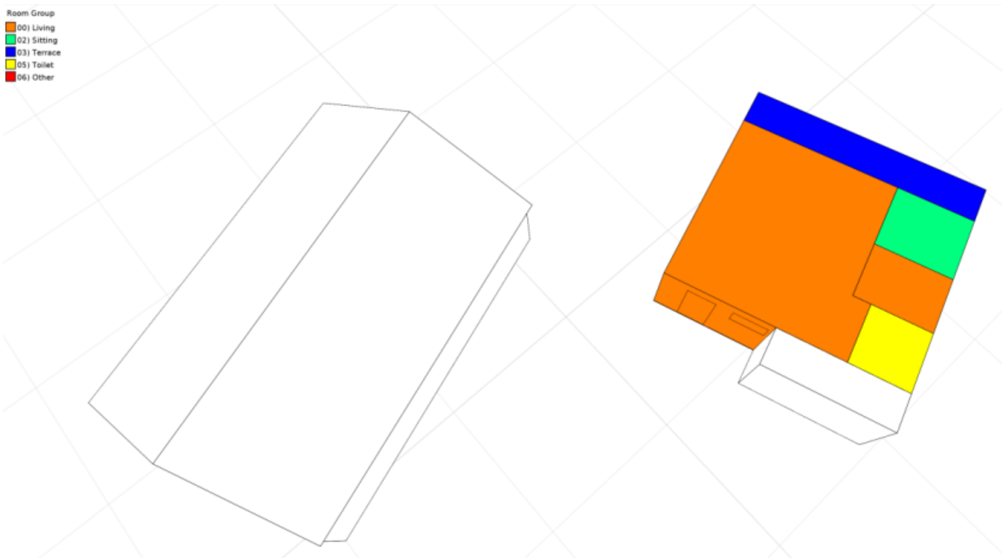
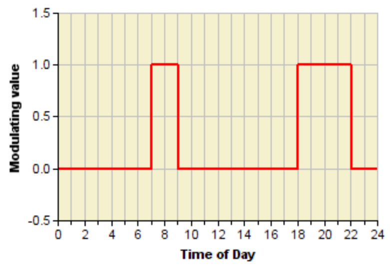
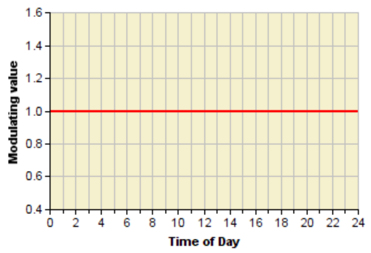
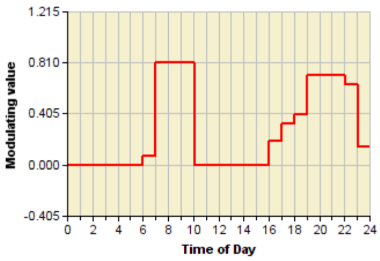
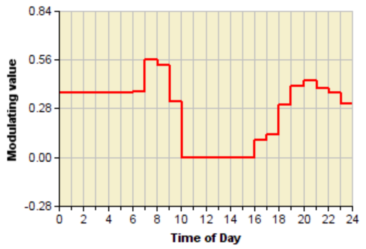
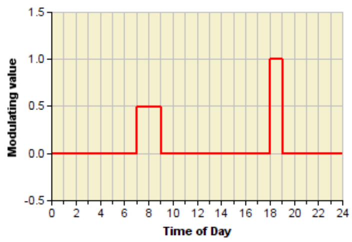
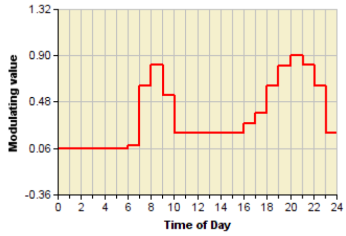
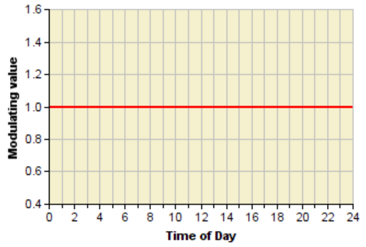
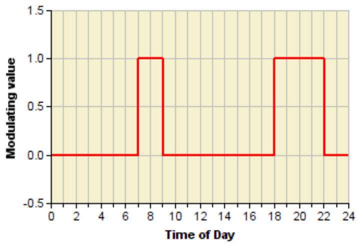
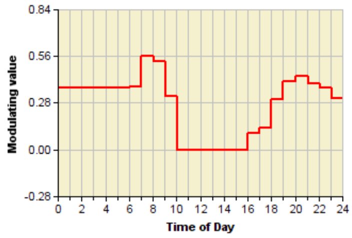


Figure 14 – Visualisation example of space use for the main house (ground floor) in Riga-Sunisi house in IESVE.

In addition, each room of Riga's building was characterised by a number of thermal data, provided as inputs for the IESVE model. Some assumptions were made to overcome the missing data and populate the energy model. Those assumptions reflect typical input data for the building typology under investigation (single family detached house). Table 5 summarises some of the main profiles and schedules of the building used to represent the dynamic behaviour of the boundary conditions (people, systems, internal gains and use of the different rooms).

Table 5 Example profiles and schedules for the Riga's building case study

Heating operation profile	Cooling operation profile	Lights variation profile
		
Occupancy variation profile	**Cooking variation profile**	**Equipment variation profile**
		
Infiltrations variation profile	**Auxiliary ventilation profile**	**DHW variation profile**
		

The schedules presented above serve as examples of the required model inputs in order to represent building and energy systems' use. Within the workflow of the predictive controller, SunHorizon will use the user feedback app as well as the actual monitored data from the building as data sources for use pattern identification contributing to more accurate demand and performance predictions.

3.1.1.5 Systems

The main heating system of the Riga's demo building is an underfloor heating system connected to a central boiler serving the ground floor. The heating system of the first floor is formed by radiators connected to the main boiler. Cooling when needed is provided to the main rooms by an air conditioning unit. Domestic hot water is provided by the boiler.

For the purposes of this preliminary building model, the heating system of the house was modelled using the ApacheSystem module. However, in order to be integrated within the control loop to provide predictive capabilities related to the performance of newly implemented SunHorizon technologies, innovative, complex energy systems will be modelled in TRNSYS and connected to the IESVE software thanks to a co-simulation approach.

As a general rule, IESVE software solution enables the use of two different methods for modelling HVAC systems: (i) a simplified approach based on a high level description of the system and (ii) an accurate modelling approach for HVAC called ApacheHVAC. As initial modelling step the use of ApacheSystem was preferred given the small amount of detailed data for characterisation of the building systems. In a later phase for model calibration of the co-simulation model will be conducted and it will be possible to simulate the entire hydronic systems of the building as well as any air-side systems in detail.

3.1.1.6 Building energy demand preliminary characterization

IESVE software provides the capability of generating simulation reports through different frameworks and dashboards. These were used to obtain a preliminary characterization of the building energy demand. The purpose at this project stage has been to understand the model for initial easy tunning, but it will later be replaced by dedicated dashboard as well as by the interface of the user feedback app.

Such dashboards and end-user interface will allow to present simulation results to building tenants and operators as one of the multiple outcomes of the SunHorizon controller and integrated platform. Nevertheless, they will not only refer to simulated demand predictions, but this information will be accompanied by resulting KPIs coming from the evaluation of actual monitoring data as well as by control setpoints and maintenance and fault detection alarms resulting from the different SunHorizon algorithms and services, among others.

For it what particularly concerns Riga's demo site, the metered gas consumption for the year 2018 was equal to about 16120 kWh while for the electricity consumption the house required a total of 9887 kWh. **Simulation results of the building energy model are able to approximate the energy use in the building. Simulation results estimate a total of 15400 kWh for gas consumption** and about 7100 kWh for electricity use. Differences, especially in terms of electricity use, may be reduced with more data gathering session finalised to reduce the uncertainties of the building energy model and use patterns.

The power usage profile for both natural gas and electricity is shown in Figure 15. Small requirements of the buildings in terms of space cooling are evident, while there is a peak in terms of heating requirements during the first days of March.

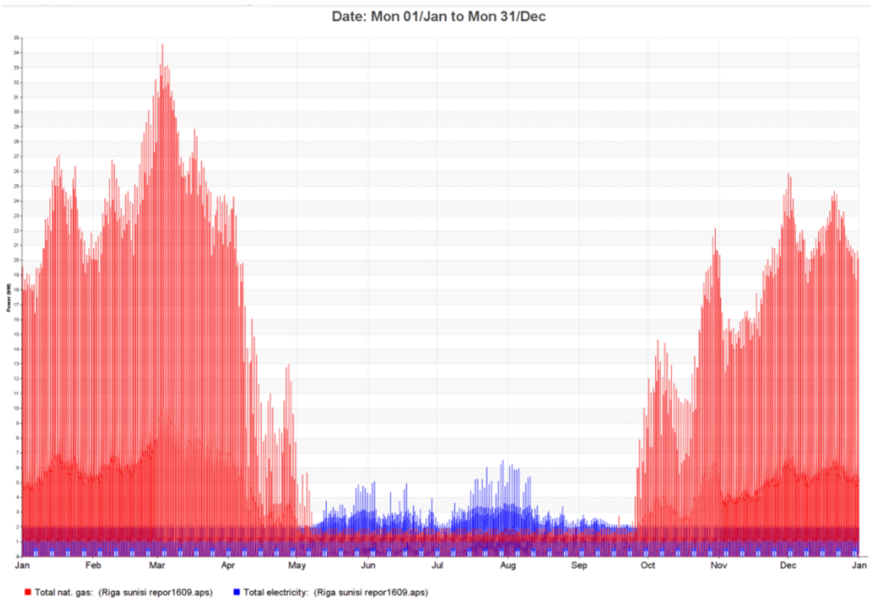


Figure 15 Total natural gas (red line) and total electricity power (blue line) consumption

Moreover, Figure 16 represents temperature and radiation evolutions in typical winter and summer weeks (particularly focusing on the singular effect of the existing veranda), which are also a relevant outcome of the simulation-based characterization of the demo building energy behaviour.

As described in the sunlight/sun-path analysis, the existing veranda is an outside space and is characterised by large glazing structure. Locally the solar gains may play a strong effect in varying the temperature of the room and in altering temperature boundary conditions for the occupied rooms within the building. As expected during winter time the difference between external and internal temperature is low, max 3-4 °C. In summer time when the effects of the global solar radiation are much higher, the difference in temperature is quite large, sometimes as large as 10°C.

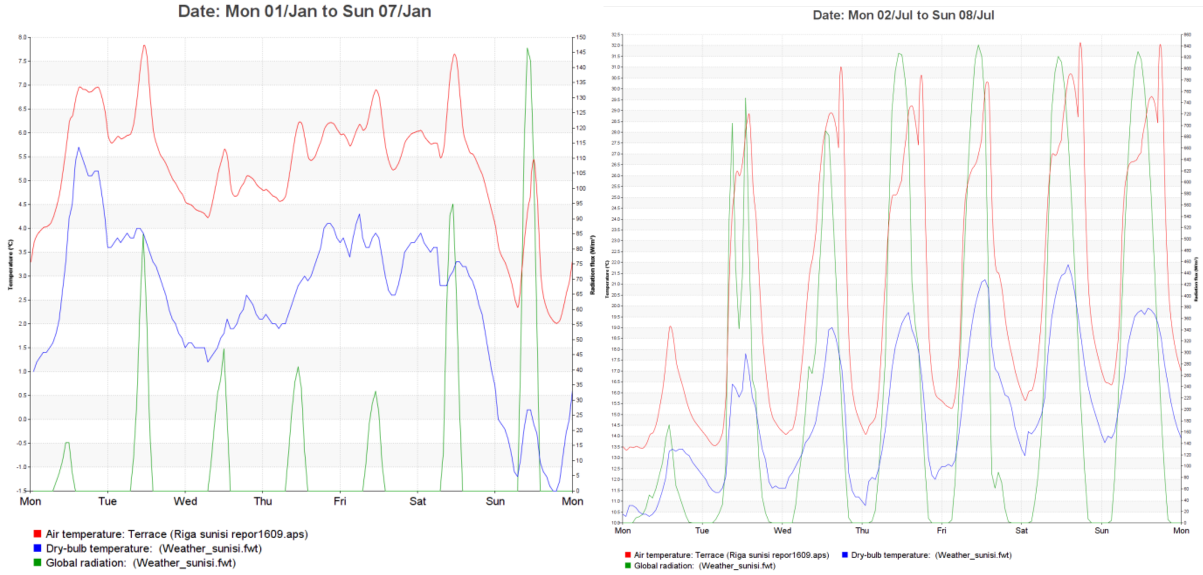


Figure 16 Terrace/veranda temperature and global solar radiation for a week in January (left) and July (right)

3.1.2 Sant Cugat demo site

The main characteristics and assumptions for Sant Cugat's building model in IESVE are described next.

3.1.2.1 Building boundary conditions

Location

The Sant Cugat's demo building is a municipal facility consisting of a tertiary building (Mirasol civic centre) with different spaces dedicated to host all kind of cultural activities and events. The demo site is located at Mirasol neighbourhood, in Sant Cugat del Vallès (Barcelona, Spain). It is divided in two structural areas that were constructed in two different stages (see Figure 17). Particularly, the part of the construction that will be addressed by the project interventions was built in a second stage in 2006. It is a single-floor construction with a flat roof, comprising several office/classroom-like spaces, an auditorium and a small warehouse.

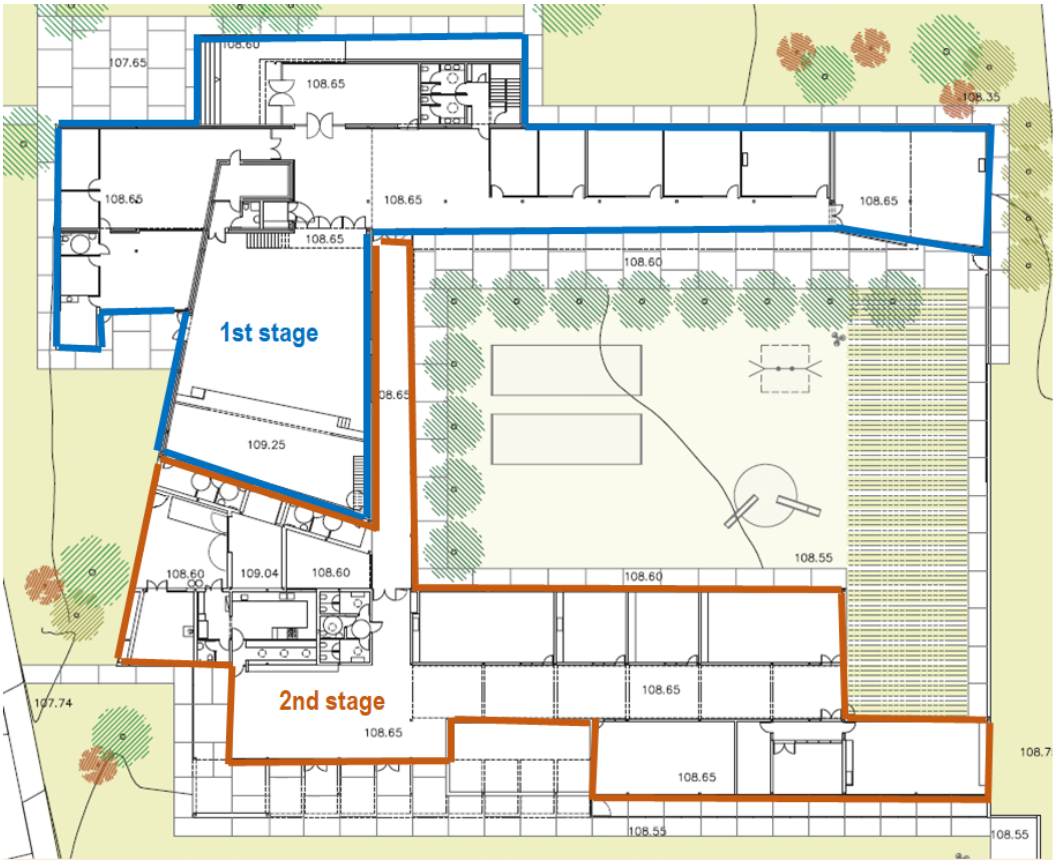


Figure 17. Layout of Sant Cugat's demo building

The distribution of floor areas within the SunHorizon target building area is: (i) warehouse = 13 m^2; (ii) auditorium = 80 m^2; (iii) office/classroom-like spaces = 958 m^2. This computes a total floor conditioned area of 1051 m^2.

Moreover, a rough topographical analysis of the surroundings of the Mirasol building was performed using both geographical visualisation software (Google Earth) and topographical maps of Sant Cugat, which show that there are not mountains or elevate peaks worth including in the model as topographical shade. Also surrounding buildings are not expected to produce any relevant shading effect on the target building (see Figure 18).

Figure 18 Aerial Image of the Sant Cugat [Google Maps]

Weather

Concerning the input weather information required to run the simulations for the building energy demand characterization, it should be noted that the demo building is located in Sant Cugat del Vallès, close to Barcelona, where dominant weather conditions are those typical of Mediterranean climate with high levels of solar irradiation and the following expected average temperature values.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
9.36	9.67	11.3	13.0	16.3	20.1	22.8	23.1	20.8	17.6	13.2	10.6

Table 6: Monthly average ambient temperature in Sant Cugat, Barcelona (°C)

Yearly Average Incident Solar radiation on a Horizontal Surface (kWh/m^2/day)	4.31

Table 7: Yearly Average Incident Solar radiation on a Horizontal Surface

The time series weather data corresponding to the city of Barcelona was considered for preliminary analyses and demand characterization based on the currently developed building model in IESVE. However, weather files from the weather forecast service implemented in the SunHorizon control will be used for demand and performance prediction during the operational phase.

3.1.2.2 Building geometry and constructive properties

The starting point for the IES model of Sant Cugat has been the floor plant provided by the site administration office (Figure 19), together with some satellite views from Google maps (Figure 20 and Figure 21).

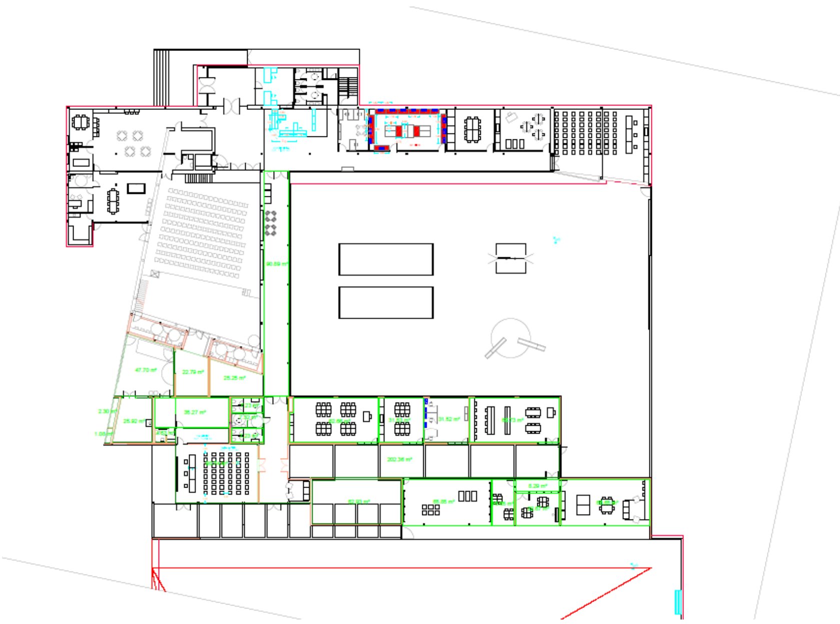


Figure 19. Sant Cugat floor plan

Figure 20 West facade from Google maps (last visited 09.08.2019)

Figure 21 South façade from Google maps (last visited 09.08.2019)

The Sant Cugat administration provided details on building heights and other information, contained in a Building Checklist prepared at an initial stage of the project in the framework of WP2 activity with the purpose to collect relevant existing information from the different project demo sites. First, the building footprint was built. Then, the different blocks were merged when convenient to create suitable thermal zones. Two main types of windows were considered, as deducted from the site pictures: long shaped windows (5 m x 1.4 m high) and curtain walls (see Figure 22).

Figure 22. Interior view with the identified different windows types

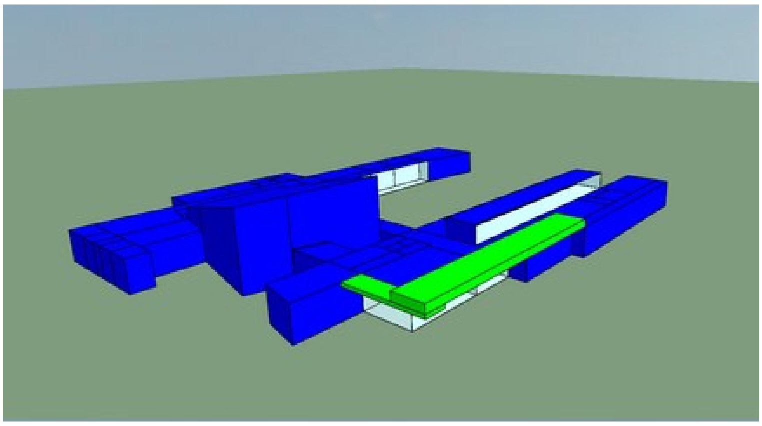
The main type of windows is double glazing (3+3/8/3+3) (Model: TECHNAL "TOPAZ GT")

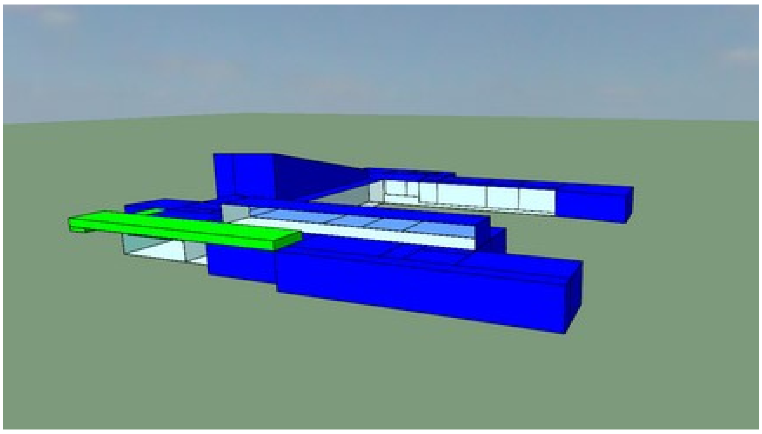
Table 8. Constructive characteristics for different building components at Sant Cugat's demo site

Type wall	Information	Unit	Value
External Walls	Structure type (materials,thickness…)	(m)	0.3 (Grass Reinforced Concrete)
	U value	(W/m^2K)	0.24
	Position of insulation		Indoor
	Window ratio	(-)	80%
Windows	Average window length	(m)	2.8
	Average window height	(m)	2.4
	G value (transmission coeff)	(W/m^2K)	3.1
	Window / glazing type (i.e. double glazing, low emissive, etc)	(text)	double glazing (3+3/8/3+3). TECHNAL "TOPAZ GT"
Roof	Structure type (materials, thickness…)	(m)	0.2 (Structural roof-deck + roofmate insulation (4cm) +

			+ roofmate insulation (4 cm) + gravel)
	U value	(W/m2K)	0.42
	Position of insulation	(text)	Outdoor. Between structural roof-Deck and gravel
	Window ratio	(-)	10
Ground floor	Structure type (materials, thickness…)	(m)	0.4 (Gravel + reinforced concrete + terrazzo flooring)
	U value	(W/m2K)	-
	Position of insulation	(text)	-

Finally, the construction material specifications were added to the walls, roof and ground floor, according to the information made available by the building owner. The physical model pictures can be seen in Figure 23.


a.


b.

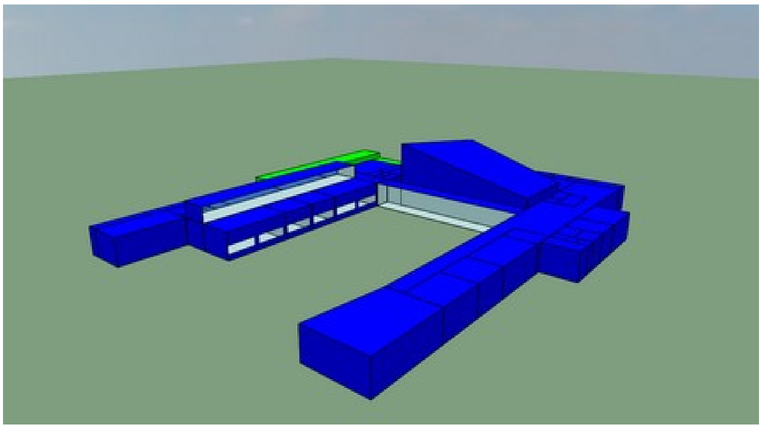

c.

Figure 23. Sant Cugat's building geometry included in the IESVE model

3.1.2.3 Definition of spaces and building use information

The nature of the activities hosted by Sant Cugat's demo building, as a multidisciplinary cultural center, makes that there is a wide variety of uses for the different physical spaces of the building. According to this, in a first version of the demo building model with the purpose of energy demand characterization, the following thermal zones were considered:

- Thermal zone 1 : Assembly Hall / Events Room
- Thermal zone 2 : Exhibition Room
- Thermal zone 3 : Dance and movement activities Room 1
- Thermal zone 4 : Music Classroom 1
- Thermal zone 5 : Music Classroom 2
- Thermal zone 6 : Current Warehouse. New training classroom for young people in 2020
- Thermal zone 7 : Dance and movement activities Room 2
- Thermal zone 8 : Civic center direction Office
- Thermal zone 9 : Local entities and collectives Room
- Thermal zone 10 : Workshop Room
- Thermal zone 11 : Main corridor
- Thermal zone 12 : Hall
- Thermal zone 13 : Connecting corridor
- Thermal zone 14 : Bathrooms

Additionally, as for Riga's demo case, the Thermal Template in IESVE was provided with the following input information for the specification of the building use in terms of occupancy patterns and temperature setpoints. During the operational phase of the building including SunHorizon solutions, this information will come from use predictions based on the user feedback and previous monitored data.

Overall occupancy of the building: between 40-150 people.

General occupancy schedule references considered within the model:

- 8-14h (from Monday to Friday): 40 people
- 16-22h (from Monday to Friday): 150 people
- 10-13:30h (Saturday): 60 people
- 16-20h (Saturday): 60 people
- 16-21h (Sunday): 60 people

Normative comfort air temperature requirement in winter: 21ºC. Real comfort air temperature in building: 22-23ºC, because some activities need higher comfort air temperature.

Normative comfort air temperature requirement in summer: 26ºC. Real comfort air temperature in building: 24-25ºC, because some activities need lower comfort air temperature.

3.1.2.4 Systems

The heating and cooling demands of the abovementioned spaces in Sant Cugat's demo building are currently covered by an independent HVAC installation for each area based on the following equipment:

- Reversible air-to-water heat pump (AWHP): 93.6 kW (cooling capacity); 96.3 kW (heating capacity)
- Air Handling Unit (AHU): 110 kW (cooling capacity); 67.8 kW (heating capacity)

For what concerns to this preliminary building model, no systems have been included in IESVE. As explained for Riga's demo case, the purpose of the building model within the controller workflow during the operational stage of the project is to obtain the energy demand that the systems (based on SunHorizon TPs) should satisfy. Therefore, modelling of energy systems will be performed in TRNSYS (see Section 3.2) and connected to the IESVE software thanks to a co-simulation approach.

3.1.2.5 Building energy demand preliminary characterization

For it what concerns Sant Cugat's demo site, there is no available historical demand or consumption data that could be useful for model calibration and first model tunning actions. Total annual electricity consumption (including lighting and appliances) is only available. Therefore, the IESVE building model has not been used in this stage of the project to conduct robust detailed simulation analyses on building energy demand characteristic.

During the second year of the project, a pre-monitoring phase at both Type A project demo sites will be conducted. From first measurements and more detailed registration of usage patterns, the building model currently presented will be adjusted and improved in order to provide more detailed characterization of the actual energy demand and preparing the ground for their final integration into the controller predictive workflow.

3.2 Models for the energy facilities

The purpose of this section is to present the simulation models for the energy systems of both project 'Type A' demo cases where the SunHorizon hybrid controller will be fully deployed for demonstration purposes. Such models have been developed using TRNSYS thanks to the robustness and versatility of this simulation environment to set up simulations of complex, innovative energy solutions including novel configurations and equipment (such as those being developed within this R&D project).

3.2.1 Riga demo site

Only heating demand of Riga's demo building (both for space heating and DHW) will be addressed within the scope of SunHorizon. Technology Package 2 (TP2) will be installed in parallel to the existing system to cover the entire heating demand. The existing system will remain, in case that the SunHorizon solution cannot properly cover the energy needs in certain moments as a back-up service (e.g. because of low solar availability, during first operational tests, etc.). Two different models were produced in TRNSYS 18 (32 bits): one for the existing system and one in which SunHorizon technologies were integrated. The second one will be taken as reference for its integration in the controller workflow for performance prediction.

The modelling of energy facilities was carried out following the gathered inputs from previous activities in the project within WP2 (T2.1), particularly related to existing HVAC facilities, sizes, connection schemes, etc. Although the general layout and sizing of main existing components is known, the controls management is an open issue yet and it will be revised and updated in further steps.

In this preliminary phase, a simplified building model was included for initial tests of the implemented system simulations. In Sunisi's demosite the heating system is centralized, with a gas-fired boiler that supplies 3 radiators and 3 underfloor heating circuits to heat up 96 m^2 in the main house. A playroom of $48m^2$ located in the adjacent garage building is heated up occasionally by an air-air heat pump and a wood burning fireplace. Figure 24 shows the existing system schematics, which consists of the following loops:

- 3 radiators loop
- 3 circuits of the underfloor heating
- Supply circuit (connected to the existing Junkers gas boiler).

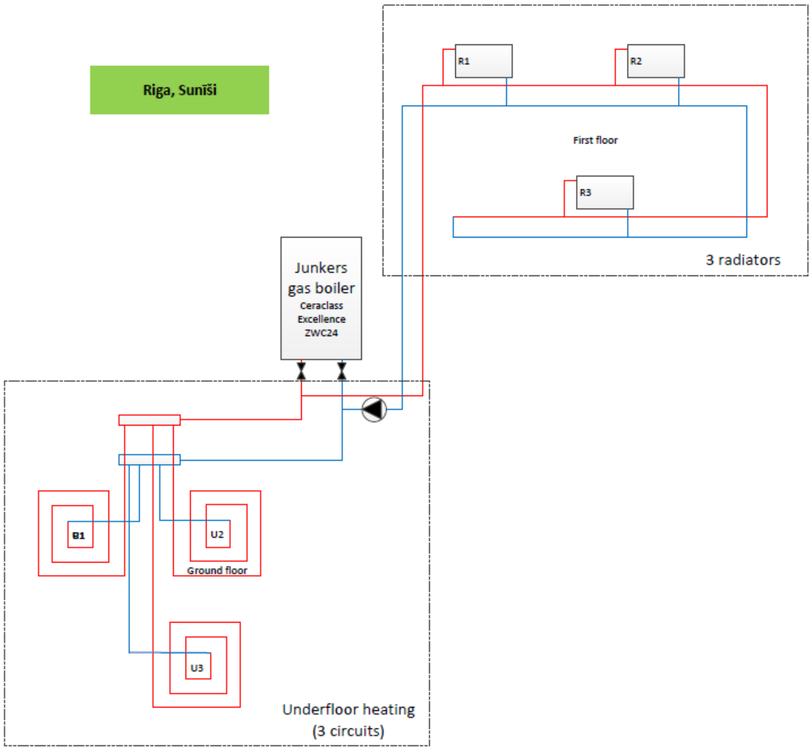


Figure 24. Existing system schematics

The existing system's TRNSYS layout is shown in Figure 26. It consists of a gas-fired boiler (Type 122), a DHW demand (Type 15 + assembled equations), a simplified building (Type 88), a radiator (Type 862), and hydraulic loops (diverters, mixer, heat exchangers, controllers, etc.).

The gas-fired boiler is modelled with Type 122 which is described in detail in Klein et al. (2018). The boiler is set with capacity restraints, characterized by its overall and boiler efficiencies[4]. When the inlet flow rate is greater than zero, the model will attempt to meet the user-specified outlet, when the desired outlet conditions cannot be met due to capacity limitations, the machine will run at its available capacity and the outlet state calculated.

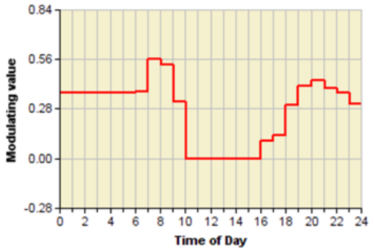
The underfloor heating and radiator loops are modelled in a simplified approach with one radiator connected to the building via internal gains (convective and radiative). Radiators are modelled using Type 862. It is a user type modified by CEA from former Type 262 source code (available from the original work by Holst (1993) within IEA SHC Task26[5] activity). It represents the dynamic first order model of a radiator, including a static model of a non-insulated pipe. This type includes proper management of multiple instances of Type862, making direct flow rate as input handier, and replacing a valve closure level combined with maximal flow rate parameter.

For these preliminary systems' models, the flow is controlled by a basic controller (Type 113) and a variable speed pump (Type 110). The number of radiators and the simplification of circuits will be revised in further steps.

DHW profile is inserted by means of Type 14, derived from IESVE database. Figure 25 shows the typical input data for the building typology under investigation. In further iterations, the DHW profile should be replaced by a more realistic and detailed model that will be calibrated by pre-monitoring data.

[4] Boiler efficiency was introduced as based on ASHRAE's definition of boiler efficiencies as published in 2000 ASHRAE 'Systems and Equipment Handbook'

[5] IEA SHC Task 26 http://task26.iea-shc.org/



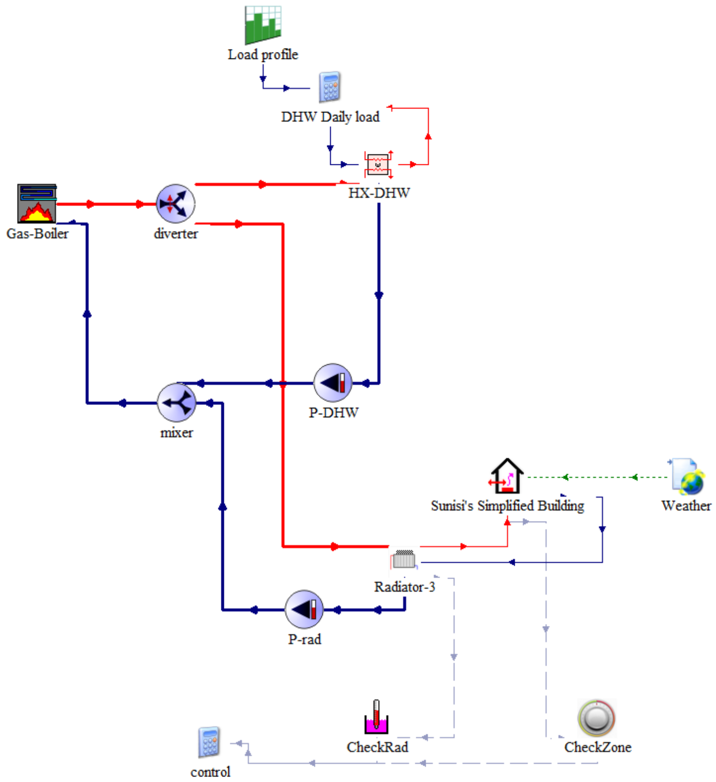


Figure 25 – DHW profile

Figure 26 – Existing energy system (Sunisi)

For the purpose of these initial activities concerning energy systems' model creation, the behavior of Sunisi's house is modelled using Type 88. Type 88 is a simple lumped capacitance single zone structure subject to internal gains that assumes an overall U-value for the entire structure and helps to measure the speed with which a building heating load can be added to a system simulation. In later iterations, this load will be substituted and connected with the Sunisi's IESVE model in a co-simulation approach.

A weather data file from *Meteonorm* (typical meteorological year) is taken into account for model testing with reasonable ambient temperature conditions representing typical weather in Riga, Latvia. This ambient temperature is connected to the building type.

Figure 27 shows the SunHorizon schematics to be integrated in parallel to the existing energy supply systems. Next, a description of the devised concept is presented:

PV/T panels from DS (1) can heat up the stratified tank from RT (10) through a direct heat exchanger (4) when the outlet temperature from DS panels is higher than the RT tank (S3). When the temperature is lower, V5 is switched to connect the PV/T panels to the glycol tank (3) in order to run the evaporator of the BoostHeat (BH) heat pump unit (5). PV production from DS (1) is mainly used to cover electricity demand from the building. When the electrical production exceeds the building's demand, then the smart energy electrical heater (2) can be used to heat up the RT tank (10). This way, electricity is always self-consumed. The evaporator of the BH unit can be driven by DS (1+3) or by an outdoor dry cooler (6). BH unit heats up the flow in two phases. First, the water is heated up in the condenser (up to 50º). Second, if the desired temperature is higher than the condenser outlet, a secondary burner heats up the flow up to 60 to 70ºC. DHW demand will be preheated by heat exchanger (7) with the RT tank and later will flow to the DHW tank inside the BH unit to be heated up by the BH unit (1). The radiator stream will be preheated first with the RT tank through a three-way valve (V4 – component (11)), and conditioned by the BH unit (5).

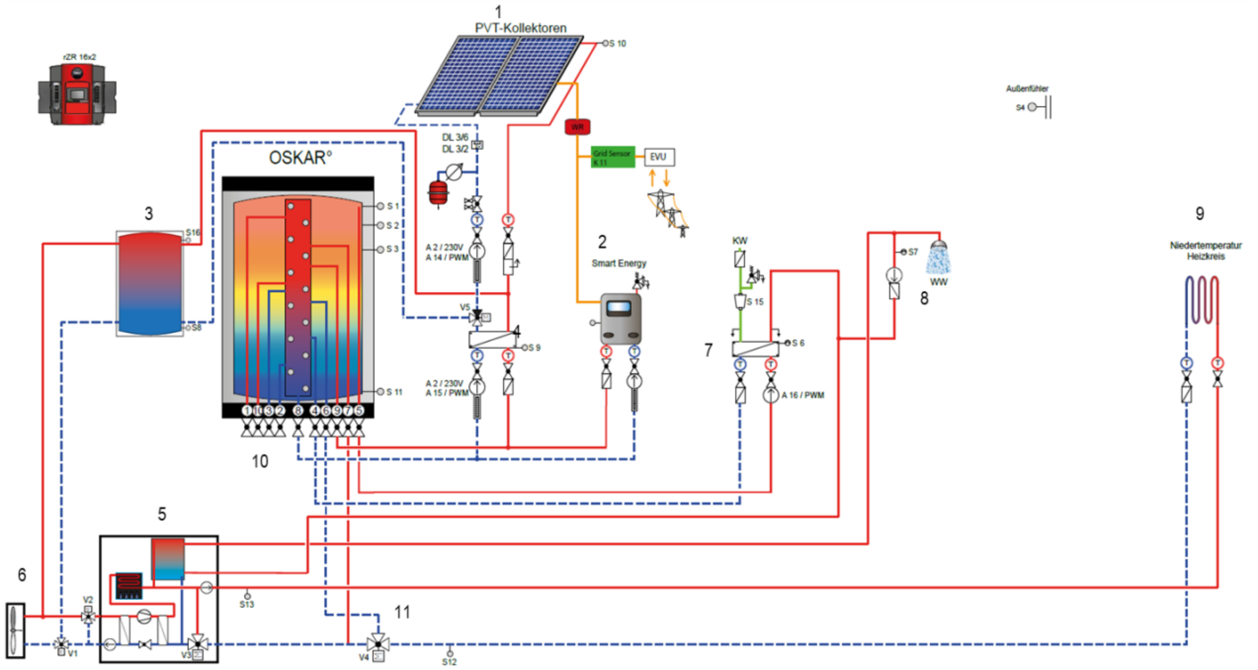


Figure 27 – TP2 Schematics for Riga Sunisi demosite (Performed by Ratiotherm). 1) PVT panels from DS 2) Smart Energy Electrical heater 3) Glycol Tank 4) Heat Exchanger between DS and RT 5) BoostHeat unit 6) Outdoor dry cooler of BH 7) Pre-heating of DHW through Heat Exchanger 8) DHW demand (showers, sinks) 9) Space heating connection (Radiators & underfloor heating circuits), 10) RT tank 11) 3-way Valve

The SunHorizon system is modelled in parallel to the existing system. Table 9 summarizes the TRNSYS types that have been used to create the model. The TRNSYS layout is shown in Figure 28.

Table 9. Component names and TRNSYS types summary of Sunisi's model

COMPONENT NAME	TRNSYS TYPE
Building envelope	Simplified in first iterations: Type 88
Radiators	Type 862 (user type modified by CEA)
Variable speed pump	Type 110
Low-level controls	Simple Room Thermostat (Type 166 standard) Aquastat (Type 1503 TESS,106 standard)
BH heat pump unit	Type 5837 (from CEA)
Ratiotherm tank	Type 340 (TRANSSOLAR)
Heat exchanger	Type 91 (standard)
DS PV/T panels	Type 816 (from DS)
Outdoor fan coil of the BH unit	Simplified with a HX - Type 91 (standard)
BH tank	Type 534 (TESS)

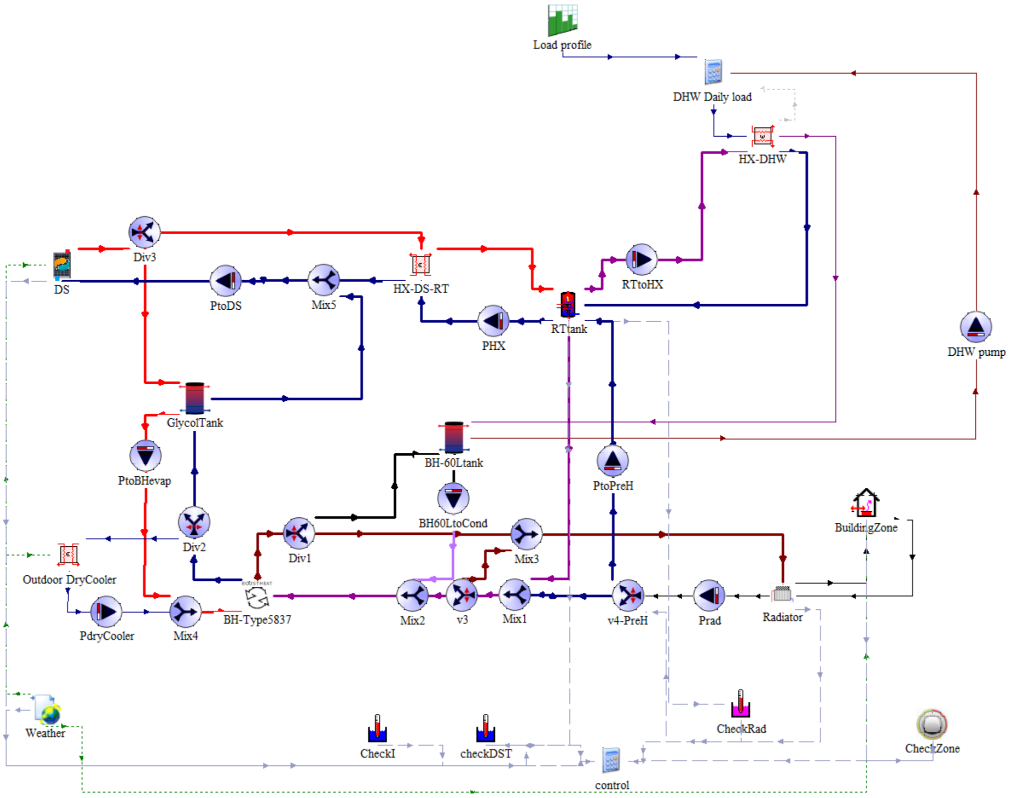


Figure 28. TRNSYS layout SH system in Sunisi's demosite

The BH unit TRNSYS type was developed by CEA and referred as Type 5837. It represents a combination of a compression heat pump and a gas boiler model, taking into account that the compressor is thermally driven by the gas boiler. The BH unit receives the load flow rate at the condenser side, and it is pre-heated until 50ºC. Afterwards, if desired temperature is higher than 50ºC, it is heated up to the setpoint temperature in a secondary boiler. As shown in Figure 30, inside the BH unit there is a small DHW tank (of 65L) which is modelled externally by Type 4a (*Stratified storage tank with uniform losses*). The BH unit is mainly managed by external sensors with basic control rules. To consider the losses of the BH unit the technical room air temperature is considered constant and set as 20ºC for the losses of the BH unit, as it will be placed in a container and protected by the freezing outdoor temperatures. The dry cooler (outdoor unit) is modelled externally and simplified by a heat exchanger (Type 91) and it does consider the variation of the outdoor temperature.

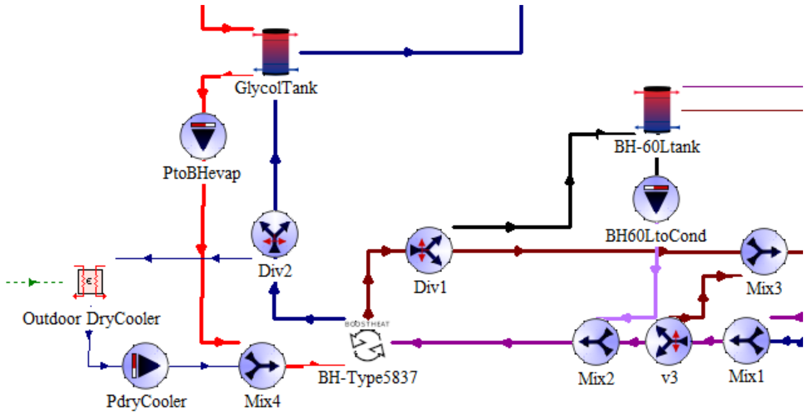
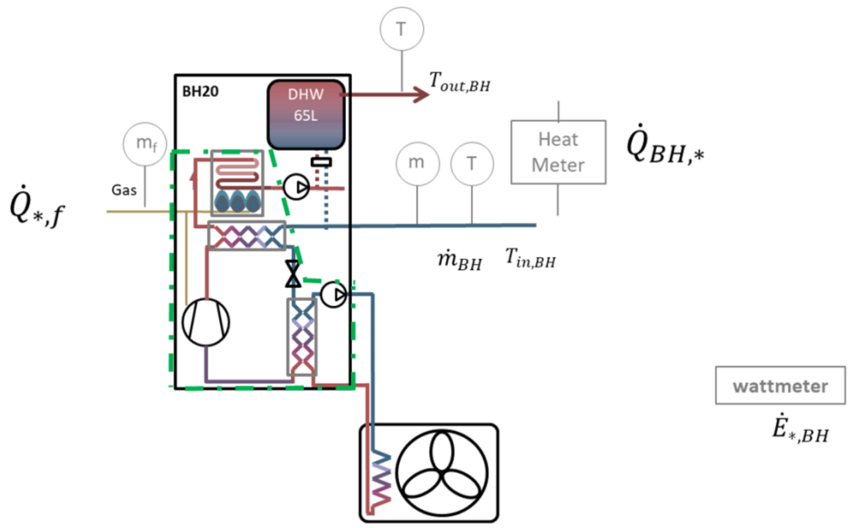


Figure 29. BH model in TRNSYS (Type 5837 + BHTank + Outdoor unit + Hydraulics)



Parameters	
Size	20 kW
$C_{p,ev}$	3900 J/kg·K
$C_{p,cond}$	4190 J/kg·K
Inputs	
Tº Technical room	20ºC
Mass flow evaporator	Inlet
Temperature evaporator	Inlet
Mass flow condenser	Inlet
Temperature condenser	Inlet
Desired temperature (outlet condenser)	50ºC

Figure 30. BH unit schematics (Type 5837 corresponds to the green square)

The Ratiotherm tank (RT) is modelled using Type 340 from TRNSSOLAR, which introduces more features to the Type 534 and improves the stratification modelling, thanks to the admission of more double-ports as well as the allowance of stratified charging and discharging of double ports. This effect allows the water to enter the storage in the exact water node where the storage temperature is equal to the temperature of the incoming water (Drück, 2006).

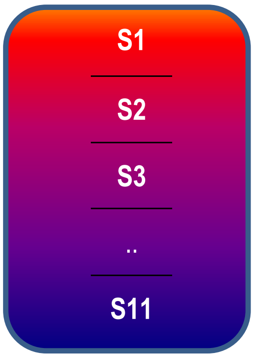


Figure 31 – RT tank, position of the sensors: S1 (Top = relative position 1, S2 (Center top = relative position 0.75), and S3 (center Bottom = relative position 0.5).

DualSun (DS) panels are modelled with an in-house developed model (Type 816), which constitute a dedicated simulation module for PV/T solar collectors. It considers power generation from embedded PV cells and simultaneously provides heat to a fluid stream flowing through tubes bonded to an absorber plate beneath the PV cells. The photovoltaic nominal power is 250W, and there are 4 module modes within the Type (See Table 10).

Table 10. DS modules (within Type 816)

Mode	Type module	Characteristics
Mode 1	Insulated DualSun PV/T module Wave	a0=51% a1=11,4W/K/m² a2=0W/K²/m² Area = 1.58m²
Mode 2	Insulated DualSun PV/T module spring	a0=47,2% a1= 9,1W/K/m² a2=0W/K²/m² Area = 1.654m²
Mode 3	Non-Insulated DualSun PV/T module Wave	a0=55,4% a1=14,84W/K/m² a2=0W/K²/m² Area = 1.58m²
Mode 4	Non-Insulated DualSun PV/T module Spring	a0=55,9% a1= 15,8W/K/m² a2=0W/K²/m² Area = 1.654m²

Linear factors relate the PV cell efficiency and the cell temperature, as well as the incident solar radiation. PV cells are assumed to operate under maximum power point conditions. Under stagnation conditions (1000 W/m^2 solar radiation but no liquid flow) the collector outlet temperature rises to 64.5C and the power generated by the PV is 200W indicating an electrical efficiency of 20%, which is reasonable for a PV panel. DualSun panels are connected to a direct heat exchanger (named HXGlycol/water in Figure 28) and a glycol tank (Type4a). A diverter valve (Type 11f) is controlled by an aquastat controller (type 113 named “CheckDST”), that verifies that the temperature at collector outlet is higher than the bottom of RT tank. When “CheckDST” is true, DS exchanges heat with the RT tank and when false DS will flow through a glycol tank to drive the evaporator of the BH unit.

The smart energy electrical heater is not modelled yet, but it can be simplified for now as the auxiliary heater integrated in Type 340. It would be modelled taken into account an electric demand profile and the PV output from DS panels. When there is a PV output excess, it would be used to heat up RT tank.

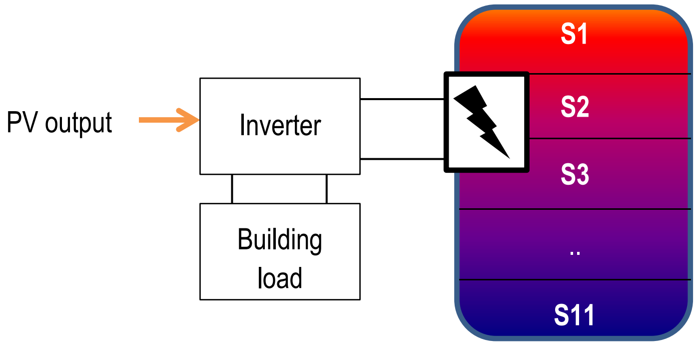


Figure 32. Possible integration of the Smart Energy electrical heater into TRNSYS.

The heating circuit loop is controlled by means of three-way mixing valves V4 and V3. A typical rule-based control (for equipment level operation) was defined and will be updated according to the technology development/improvement addressed by the project. When the temperature of the RT tank at the center-bottom position within the tank (S3) is higher than the temperature of the return heating circuit (S12), the water is preheated at the RT Tank. When S12>S3, water flows directly to the BH unit and V3 is used to control the supply temperature of the radiator according to the selected setpoint.

Regarding the DHW loop, first it is preheated with the RT through a HX and later, it is streamed to the BH tank. BH tank is maintained at a given temperature (e.g. 60ºC), in order to ensure the DHW supply temperature requested by the final users. To maintain it, the flow is mixed with the water coming from the radiators (at mix 2 in Figure 33) and it is heated up at the BH unit (first in the condenser up to a primary temperature setpoint –e.g. 50 ºC– and later in the secondary burner up to the final temperature setpoint –e.g. 70ºC–. Diverter valve (div1) separates the radiator and DHW flows.

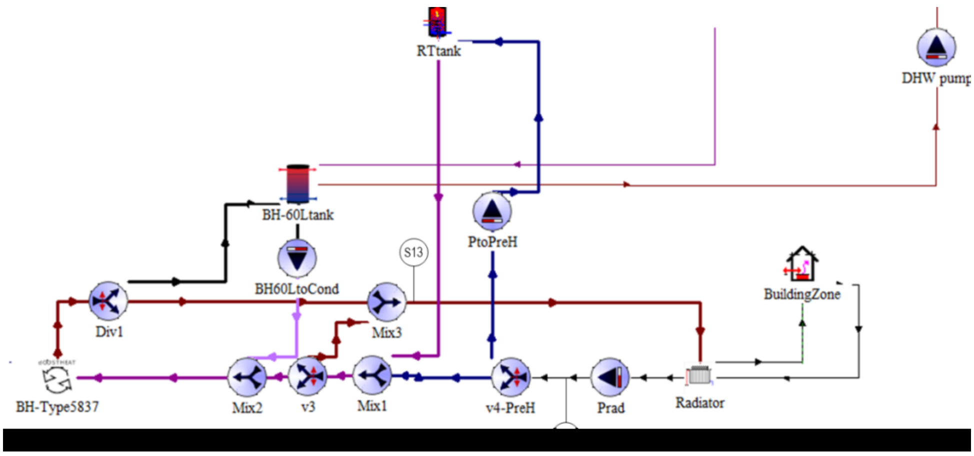


Figure 33. Heating circuit and DHW loops connected to BH and RT tank.

Finally, a first integrated model (including existing systems and SunHorizon TP2) was created. To that purpose, some assumptions, that will be validated in the project after completing those activities for system concept definition and TP schematics specification, were made. Particularly, the existing boiler was integrated within SunHorizon and connected to the RT tank as shown in Figure 34.

Preliminary results derived from simulation-based analysis using this model will be presented in D2.5, in order to refine the combination and sizing of SunHorizon technologies. Afterwards, final refinement of the model (also considering IESVE-TRNSYS coupling will be completed within the T5.4 scope in terms of the development and implementation of decision-making strategies).

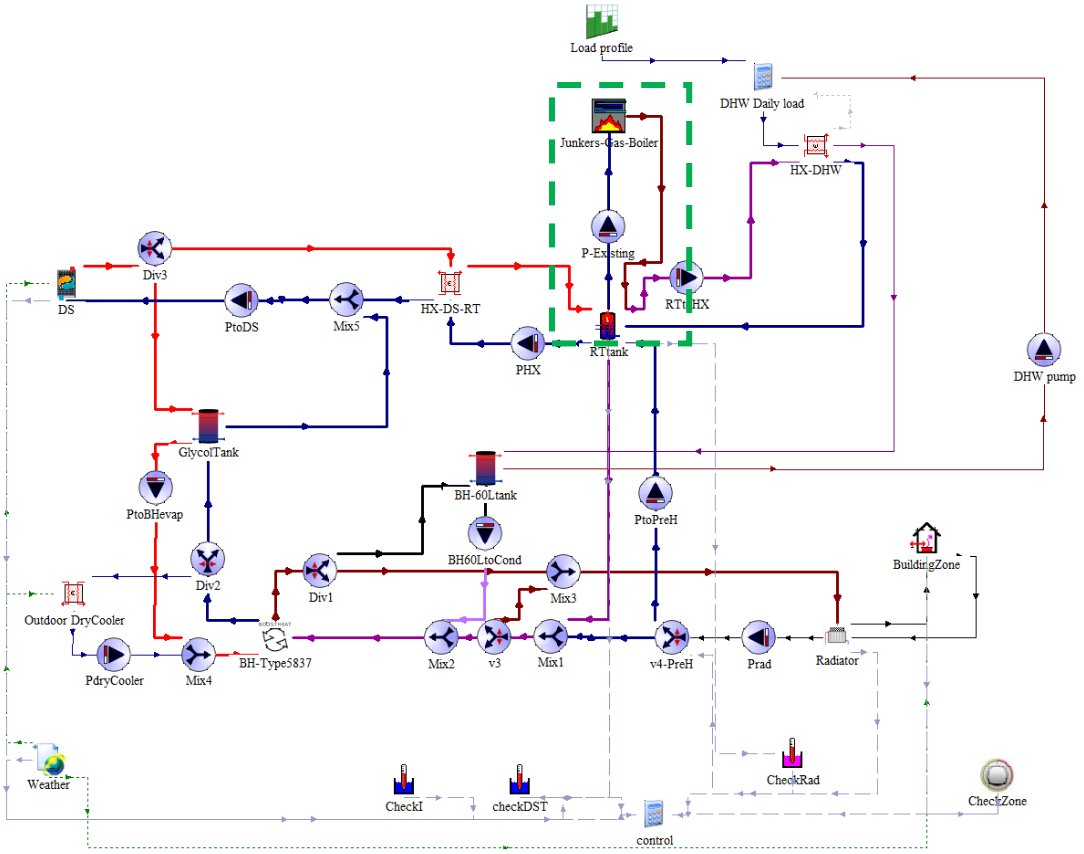


Figure 34. Integration of the existing system into SunHorizon TP layout

3.2.2 Sant Cugat demo site

The simulation models for the energy systems at Sant Cugat demo site were also implemented in TRNSYS 18. Two different models were produced: one for the existing system and one in which SunHorizon technologies were integrated.

The modelling of energy facilities was carried out following the technical documents provided by the municipality of Sant Cugat. Although the general layout and sizing of main existing components is known, the controls management is an open issue yet.

Heating and cooling demand that arises from building simulation is the main input for the energy system simulation. This data will be provided by the simulation described in 3.1.2; accordingly, the standard multi-zone building simulation Type 56 available in the TRNSYS libraries will not be needed. In this preliminary phase, however, a simple building model created as a TRNBuild model and was included to test the implemented system simulations, since a robust building simulation in IESVE is not completed yet.

The current layout of the model representing the installed system in the demo site, reported in Figure 35, is composed by the following loops: (i) building loop, (ii) hydraulic loop, (iii) AHU loop, (iv) controls, and (v) results output.

Moreover, in the SunHorizon model, a macro containing the novel project technologies is integrated in parallel to the hydraulic loop, as represented in Figure 36.

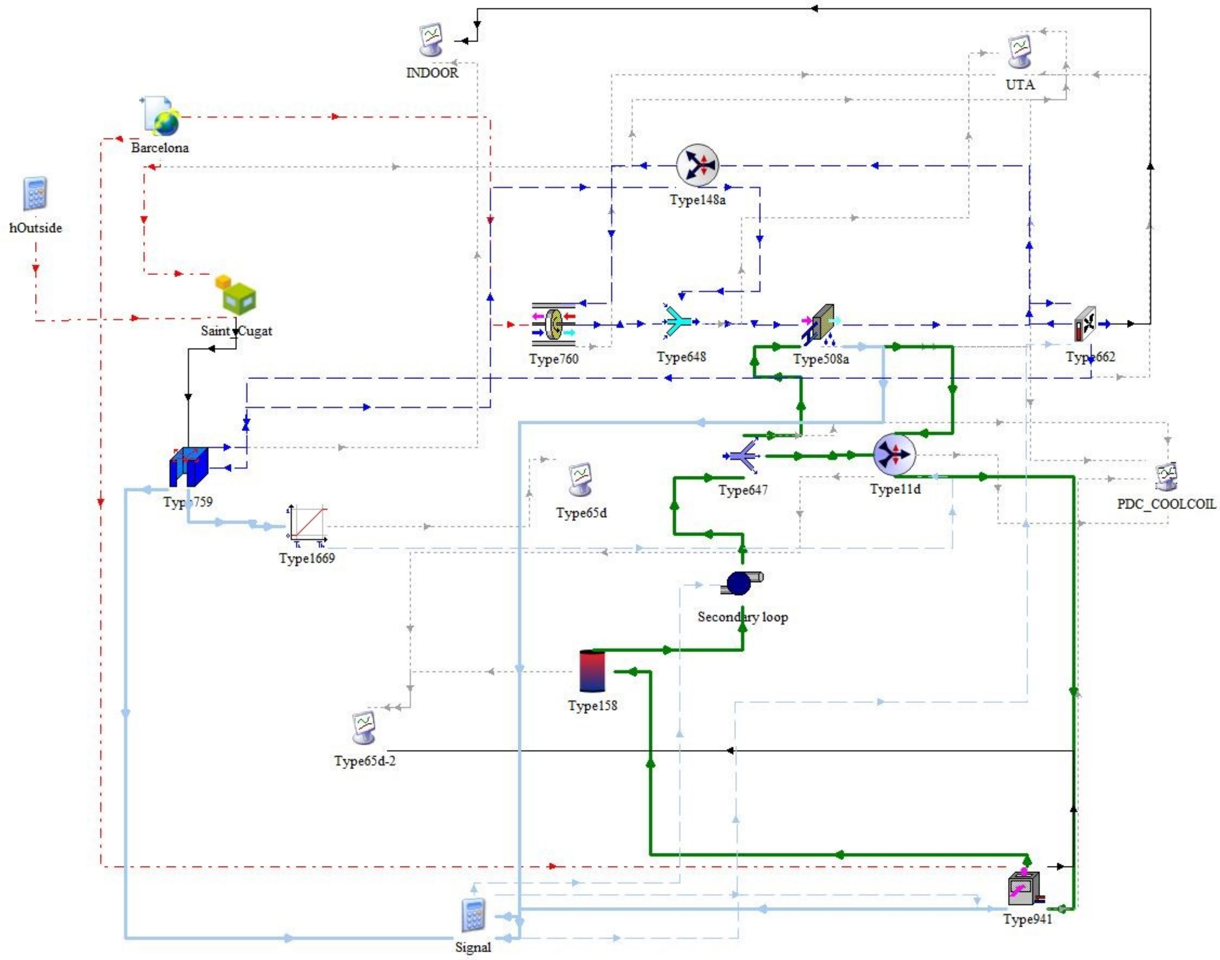


Figure 35: Overall simulation model of the existing HVAC system in Sant Cugat, implemented in TRNSYS environment.

In the **building loop**, type 759 was chosen as adiabatic box in order to simulate the balance between the external loads (heating or cooling from building simulation) and the conditioning gains (AHU loop). The exhaust indoor air temperature (EIAT) is used to control the main components belonging to AHU and water loop (light blue continuous line). Through a differential controller, the EIAT controls the mixing valve located at the outlet of AHU cooling coil in the hydraulic loop (Type 11d), then through an on/off signal it controls directly the AHU fan (Type 662). As explained previously, Type 56 was implemented only to simulate a building with real heating and cooling profiles, in the definitive model it will be replaced by data from building simulation (IESVE).

The **AHU loop**, in Figure 37, was introduced in place of type 151 available in the TRNSYS libraries, because the existing type is driven by energy loads and not by inlet conditions and control signal. Accordingly, it does not let the indoor air temperature and AHU components to be controlled, then its inputs and outputs must be directly linked to type 56 that we will not be available in the final simulation, as reported by the TRNSYS user manual: "…*the central air handler model is unlike many other TRNSYS HVAC component models in that it is driven by loads instead of being driven by inlet conditions and a control signal. It is therefore necessary to put the zones of the building being conditioned into energy rate control.*

This means that heating and cooling types are implemented in TRNBuild and that the sensible energy demands of each zone are set up as Type56 outputs that are passed to the AHU model."

For both models, the AHU loop is the same and it is composed by: (i) a static recovery section (Type 760), (ii) the mixing plenum (Type 648 and type 148a), (iii) a cooling coil (Type 508a), and (iv) the air delivery and recovery fan (Type 662).

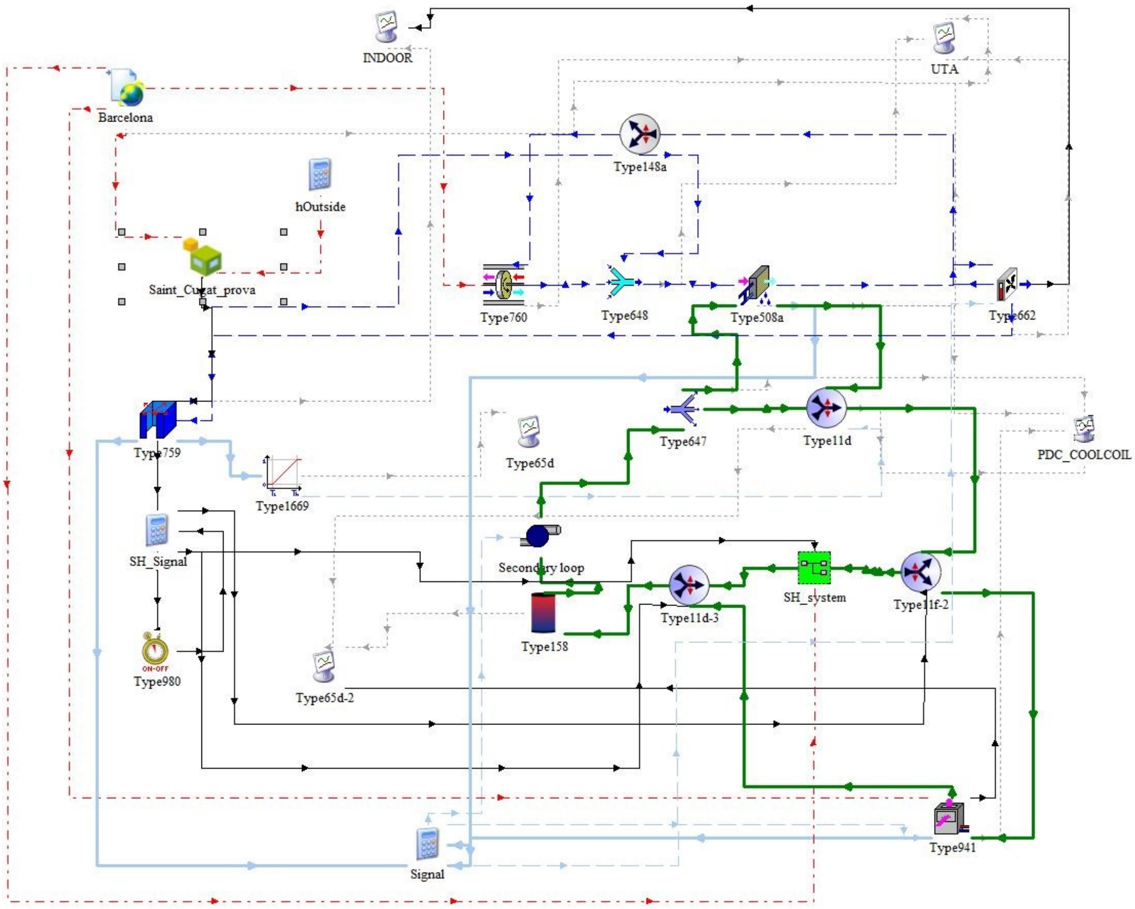


Figure 36: TRNSYS simulation model of the Sant Cugat system including the SunHorizon system in parallel.

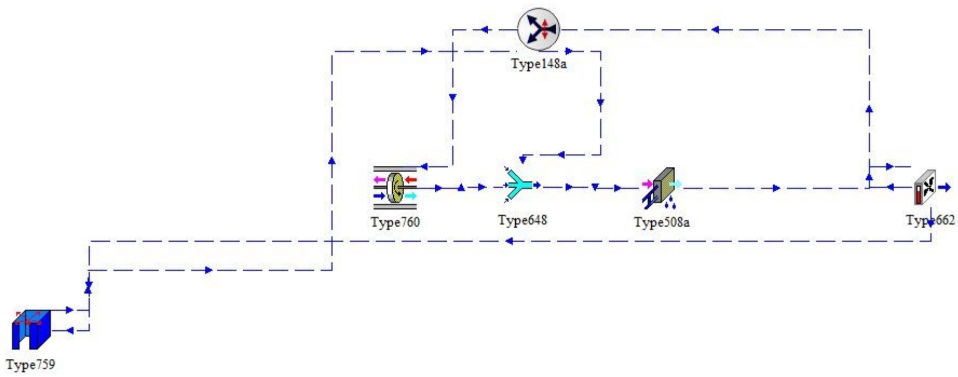


Figure 37: Air Handling Unit loop implemented in TRNSYS.

The **water loop** simulation, see Figure 38, follows the P&ID layout of the existing plant, while the SunHorizon system is installed in parallel to the existing system. From the SunHorizon macro there will be a chilled water outlet in summer and a hot water outlet in winter (produced by TVP solar panels) that will be delivered to the existing water storage tank. When chilled/hot water production from the SunHorizon system will be enough to maintain the set-point conditions, the existing chiller will be bypassed and only the SunHorizon system will be operated. Conversely, the existing system will be activated. The water loop is composed by the following types:

- Air to water heat pump - AWHP (Type 941). A specific performance map file was created from datasheet of existing heat pump
- Water storage tank (Type 158)
- Single Speed pump (Type 654)
- Fluid diverting valve (Type 647)
- Cooling coil (Type 508a)
- Controlled flow mixer (Type 11d)
- Controlled flow mixer and diverter. Only in SunHorizon model (Type 11d and 11f)

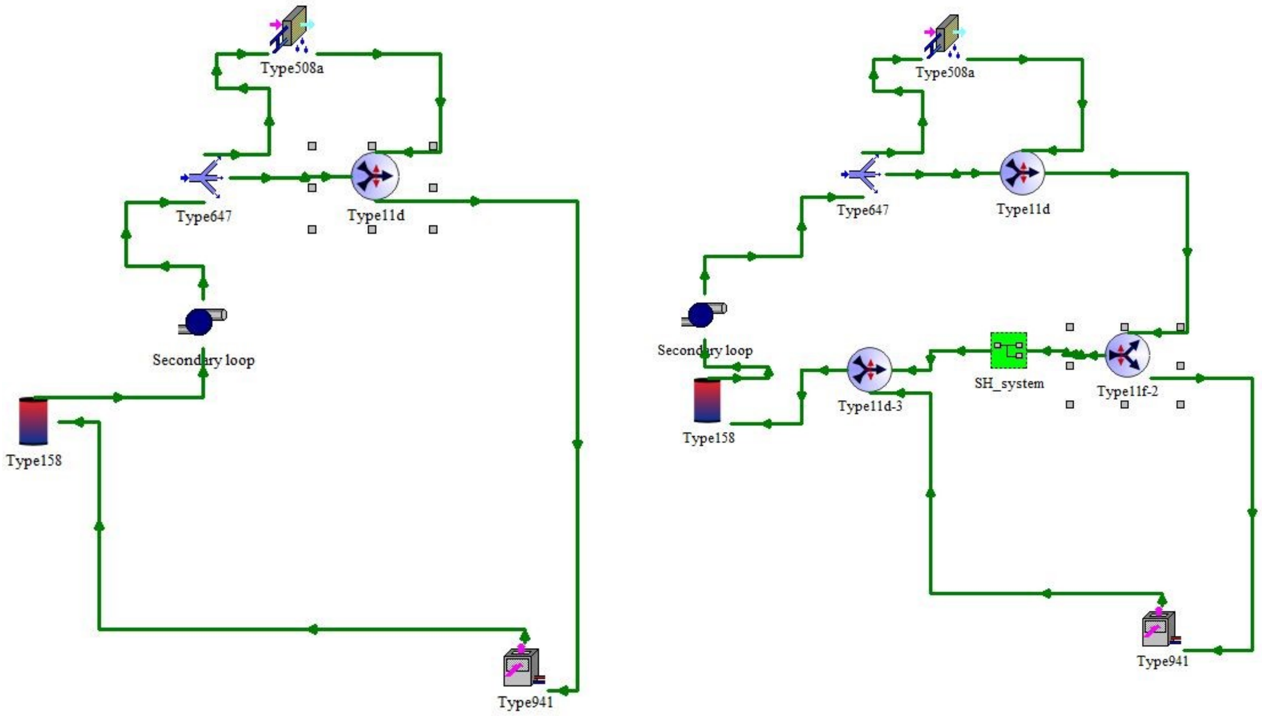


Figure 38: Hydraulic loop implemented in TRNSYS for the existing system, on the left-hand side, and the one representing the SunHorizon installation, on the right-hand side.

The **SunHorizon macro** in Figure 36 follows the design of the project Technology Package nr. 3 (TP3), as represented in Figure 39. In this TP, TVP panel, FAHR hybrid adsorption chiller and RT stratified tank will be integrated. During winter, the hot water produced by TVP panels will support the existing plant, in summer it will supply the FAHR thermally driven hybrid chiller. In this model, FAHR hybrid heat pump consists of two components: an adsorption chiller and a vapour compression chiller connected in a series circuit; water from cooling coil is firstly cooled down by the sorption module, then by the vapour compression chiller to achieve the fixed set point. TVP solar plant has a safety loop that, in case of water overheating, delivers hot water to a dry cooler to dump the excess heat to the environment. Both chilled water (in summer) and hot water (in winter) will be delivered to the existing storage tank (Type 151 in water loop). The heat exchanger separates the water/glycol mixture that flows in TVP loop and technical water that flows in RT tank loop. The SunHorizon macro is composed by the following types:

- Dynamic collector model (TVP Solar – Type 832_v500)
- Counter flow heat exchanger (Type 5b)
- Dry cooler (Type 511)
- Stratification tank (No standard types, Type 340)
- Adsorption heat pump (Type 909)
- Water to water chiller (Type 666)
- Controlled flow mixer and diverter (Type 11d and 11f)
- Single Speed pump (Type 654)

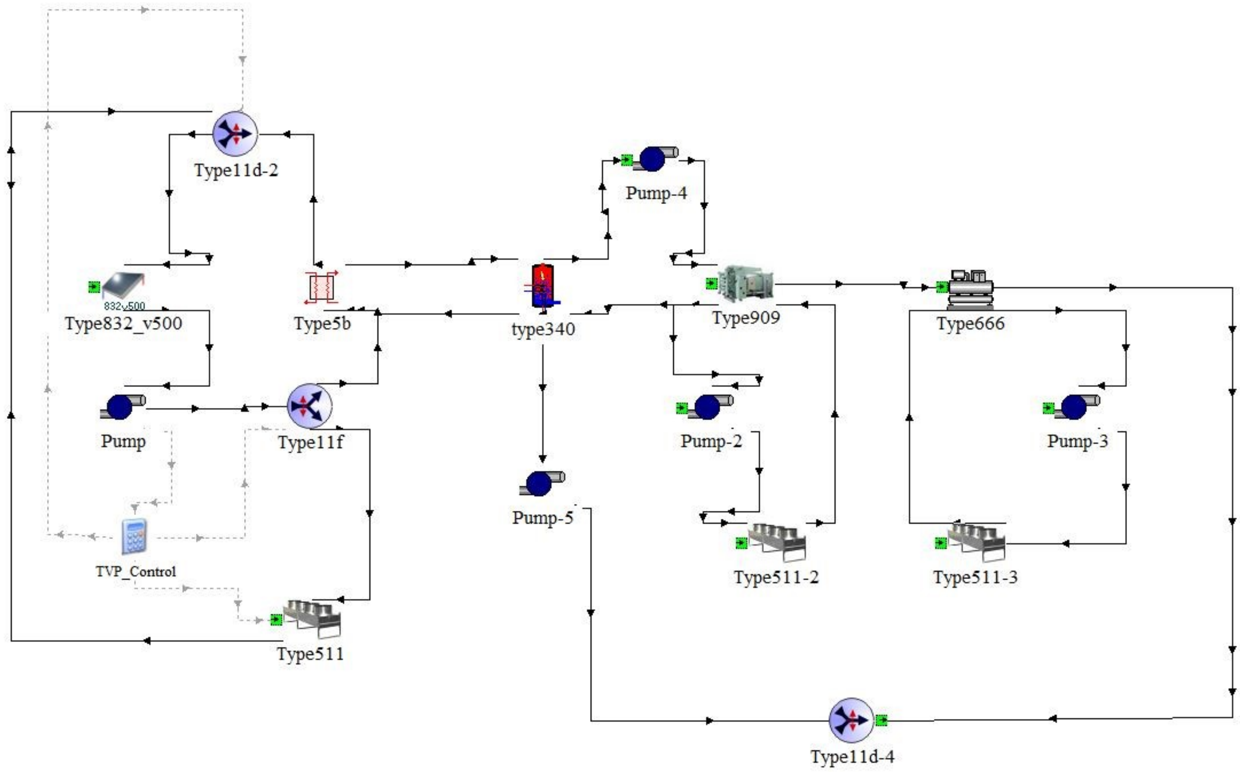


Figure 39: SunHorizon (SH) macro layout implemented in TRNSYS.

In the existing system model, both air and water loops are controlled by monitoring the exhaust indoor air:

- The mixing valve of cooling coil is controlled by a differential controller that tracks the indoor temperature set-point
- The AHU fan is controlled by an on/off logic that depends to indoor air temperature set-point

Air humidity ratio is not controlled as observed from data retrieved from existing monitoring sensors.

The water outlet temperature of cooling coil is used as input for an on/off controller in order to simulate the temperature set-point control installed on board to the heat pump. A further safety signal is sent to the circulation pump that is disabled when outlet water temperature from heat pump falls below the set-point temperature.

In the SH model, a further control on exhaust indoor air temperature is introduced in order to enable SH system or existing system during summer season. SH system is normally enabled, if exhaust indoor air temperature overcomes the set-point for a fixed time period, SH system is disabled and existing system is activated (Type 980, mixing and diverting valves connected to the SH macro).

TVP solar system has a safety loop in order to avoid superheating. When outlet temperature from solar panels rises over the safety temperature, the safety loop is activated and the dry-cooler is turned on.

3.2.3 Advanced control model

The control system should optimize the best operation of both demo sites. For that purpose, it should study and simulate different scenarios and choose the one that satisfies as much objectives as possible. Example considerations for the decision-making strategies (taking advantage of the prediction simulations) are mentioned in this subsection and will be developed and detailed within the second year of the project.

Expectations governing the proposed decision-making process may be:

- Less solar production in winter time. In Sunisi's the BH unit will mainly produce all heating demands, and in Sant Cugat, TVP technology will cover partially the heating demand, and the rest will be supplied by the existing system.
- High solar production in summer. DS collector up to 45ºC and TVP up to 90ºC. In Sunisi, both the thermal production and electrical production will mainly address the DHW demands, whereas in Sant cugat, the TVP output will help the adsorption unit to reduce the cooling demands from the compression chillers.

Different strategies would be studied within T2.4. For instance, in Sunisi's demosite one possible strategy may be to lower the thermal production of the BH unit by means of the Smart Energy electrical heater when the electrical demand in the building is low and there is PV production. In Sant Cugat, lower the electricity consumption by means of reducing the amount of heat coming from the existing HVAC using the TVP panel production, and in summer charge the cooling tank when there is sun (and no demand) using the adsorption unit.

Moreover, example objective functions may be:

- Avoiding waste energy: minimizing the primary energy used
- Identifying malfunctioning of equipment (it will be addressed in Task 4.2 and 5.5)
- Maximizing energy coming from renewables
- Increasing self-consumption
- Reducing local energy bills
- Cutting of CO2 emissions

3.3 Co-simulation methodology

Nowadays, it is desirable to use several simulation tools concurrently and make use of results generated by the different models, and this is the case of the SunHorizon project. Models and parametrization are usually provided by different specialists, and different programing languages and modelling approaches are used. Tools running transient simulation often needs results generated by other models at runtime. Pure integration of several existing models into a single simulation tool is very difficult. Co-simulation is a technique in which simulators are executed simultaneously while exchanging data during run-time. Each subsystem is modelled without taking into account the whole problem, and the coupled simulation is carried out by running each subsystem as a black-box.

In the scope of SunHorizon project, a simulation master is needed to instantiate and run the different simulators and orchestrate the information exchange between them. In particular, IESVE software is proposed to act as the co-simulation master tool using the Functional Mock-up Interface (FMI from now on) standard (FMI development group, 2019), and will orchestrate the TRNSYS models of the different subsystems.

FMI is a tool independent standard to support co-simulation of dynamic models using a combination of xml-files and compiled C-code. The first version, FMI 1.0, was published in 2010 with the goal of improving the exchange of simulation models between suppliers and Original Equipment Manufacturers. Nowadays, the development of the standard continues through the participation of 16 companies and research institutes.

FMI for co-simulation provides a standard interface for coupling two or more simulation tools in a co-simulation environment. The data exchange between subsystems is restricted to discrete communication points. Master algorithms control the data exchange between subsystems and the synchronization of all slave simulation solvers (slaves). All information about the slaves, which is relevant for the communication in the co-simulation environment is provided in a slave specific XML-file.

A Functional Mock-up Unit (FMU from now on) is a file (with extension .fmu) that contains a simulation model that adheres to the FMI standard. The FMI standard specifies two different kinds of FMUs: Model Exchange (ME) and Co-simulation (CS). ME FMUs represent the dynamical systems by differential equations so, to simulate the system, the importing tool needs to connect the FMU to a numerical solver. CS FMUs contain their own numerical solver.

SunHorizon's modelling approach (as it was done in (Vallée et al., 2019)) has decomposed the simulation problem into a collection of non-overlapping models, and each sub-model has been assigned to a simulation tool (IESVE for the building itself, and TRNSYS for the innovative SunHorizon HVAC equipment).

In this sense, several tests have been done during the first year of the project to evaluate the best option for model coupling and IESVE/TRNSYS tool communication. The decision of using FMU CS or ME options provided by the FMI standard is still open and will be refined in the upcoming project tasks depending on the more specific requirements for the decision-making strategies. Python scripting capability supported by IESVE (as proposed co-simulation master) has been successfully tested with simple models and will be further studied to accommodate the use of TRNSYS FMUs.

Figure 40 shows a preliminary co-simulation architecture that would integrate TRNSYS models for the energy equipment into IESVE simulations. Both TRNSYS FMU ME export as well as dedicated python-based developments in line with existing SimulatorToFMU capabilities (Nouidi and Wetter, 2018) will be further studied to implement this strategy within T5.4 project activity.

Finally, it should be reminded that this co-simulation approach fits in the proposed main optimization loop of the hybrid controller (see Figure 4)

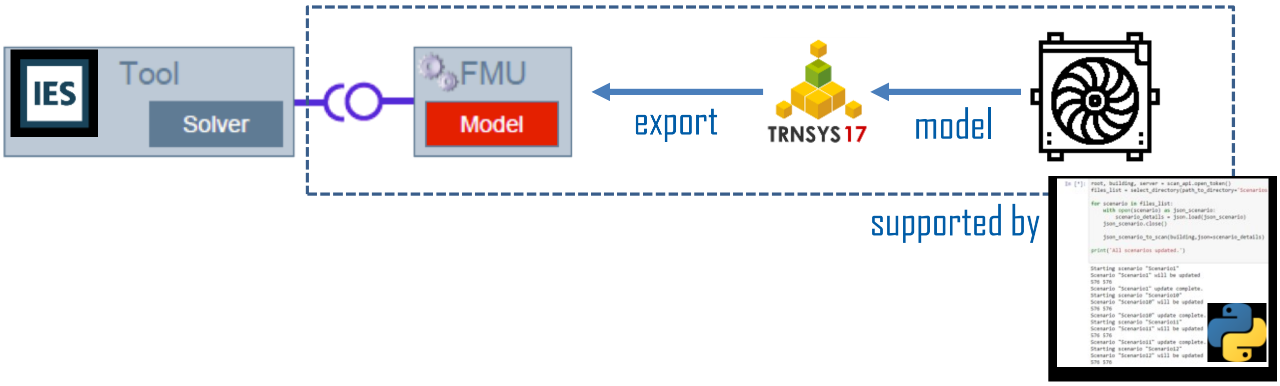


Figure 40. Conceptual scheme for the proposed co-simulation coupling between IESVE and TRNSYS

4 Weather forecast

Climate will clearly play a key role in the performance of any building so it is important to use the appropriate location settings for any demand and performance analysis. In particular, it is evident that dynamic simulations (either in IES VE or TRNSYS) require a weather file. These files should normally contain data for variables including dry bulb & wet bulb temperature, wind speed & direction, solar altitude & azimuth, cloud cover, etc. for each hour of the year.

As described in previous sections, a weather forecast service will be integrated in the advanced SunHorizon hybrid controller to be used as an input for the simulation-based predictions of the energy demand and systems' performance. This service will be developed in parallel to the main optimization algorithm in T5.4 based on the requirements and specific objectives defined in this document.

On one hand, SunHorizon will aim at integrating a modular service based on an open source solution to promote the replicability and adaptability of the service to future developments, also facilitating the integration with energy models of different nature (as those developed for Type A and Type B demo cases might be, or as those for the buildings –IESVE- and for the systems –TRNSYS-). On the other hand, as derived from the general controller requirements already exposed in this document, the weather forecast services should be able to provide predictions with at least hourly resolution for the considered prediction horizon (to be set between 6h and 24h after basic sensitivity analyses during the implementation phase). Moreover, another important aspect is the list of variables that the weather service can provide. Simple services with temperature and humidity values are not sufficient to feed the energy models and provide accurate enough predictions. For instance, solar radiation information is mandatory (even its availability is not a standard).

T5.1 conducted an investigation of several existing weather repositories supplying forecast services. Among them, Copernicus Climate Change Service (C3S) and the Global Forecast System (GFS) web service from Solar radiation data (SoDa) deserve mentioning.

- Copernicus Climate Change Service (C3S) provides a multi-system seasonal forecast service. Available data includes forecast created in real-time (since 2017) based on bias adjusted models. The data is grouped in several catalogue entries (CDS datasets) and defined by the type of variable (temperature, wind, solar radiation, etc.). Data are available after login in C3S website using gridded data at 1°x1° (approx. 100 km). The temporal resolution varies for the main selected variable and range from daily to sub-daily (6 hours). These data are useful to develop global and regional analysis due to their sparse gridded resolution, but do not provide the temporal resolution required for SunHorizon operational purposes.
- Solar radiation data (SoDa) provides the Global Forecast System (GFS) web service that is available worldwide, delivering time series of temperature, relative humidity, pressure, wind speed and direction, rainfall, snowfall, snow depth and short-wave irradiation (GHI). Time steps range from one minute to one month being original data every three hours. Forecast data are available up to three days. GFS is a weather forecast model produced by the National Centers of Environmental Prediction (NCEP) dependent on the United States Government and their punctual data are useful to develop local analysis taking into account that their spatial resolution is 0.25° (approx. 28 km). Data are open source and available by latitude and longitude coordinates using a web mapping service, however automatic access is not offered for free as an open source solution, which hampers its implementation within the SunHorizon control workflow.

Therefore, after discarding these options and accounting for the previously exposed requirements, the following web-based accessible option is proposed:

Weatherbit.io

Weatherbit.io offers high-quality weather forecasts (apart from observations and historical data) through a web-based system using global forecast models in combination with local short range high resolution models such as the HRRR (High-

Resolution Rapid Refresh[6]), the NAM (North American Mesoscale[7]), and the DWD ICON (Icosahedral Nonhydrostatic[8]) models to derive the most accurate forecast data possible. Weatherbit.io forecasts include world's premier weather data sources and packages them in an easy-to-use format. Additionally, when a weather forecast is requested via its API, the query is served by a hyperlocal 30 meter resolution forecast derived from the high resolution forecast models, location's elevation, and many other sources including: rainfall radar, and supervised machine learning techniques.

Different service packages can be considered. In particular, for SunHorizon purposes, 48h hourly forecasts can be freely accessed for any point on the globe using different access methods (postal code, latitude/longitude, city search, etc.). Additionally, over 20 weather parameters are included (see **Error! Reference source not found.**Figure 41).

As a back-up solution and with the purpose of developing the first proof of concepts and integration tests particularly with the building models, it should be noted that iSCAN can access a weather forecast service (by Athenium Analytics[9]) able to provide the required ambient variables for the energy demand characterization.

This capability was initially developed for FP7 funded project Energy IN TIME[10] and the plan is to re-use and enhance this service when needed for the SunHorizon Control Platform. Regarding the weather forecast, data is a proprietary blend of Global Forecast System (GFS) and European Center for Medium-range Weather Forecasts (ECMWF). Forecast is available for 7 days into the future and it is available globally for a 30km resolution for Europe region. This information is updated hourly in the AA service. Similar variables to those available in weatherbit.io are also accessible in iSCAN.

Field Decriptions:

- `lat:` Latitude (Degrees).
- `lon:` Longitude (Degrees).
- `timezone:` Local IANA Timezone.
- `city_name:` City name.
- `country_code:` Country abbreviation.
- `state_code:` State abbreviation/code.
- `data: [`
    - `ts:` Unix Timestamp at UTC time.
    - `timestamp_local:` Timestamp at local time.
    - `timestamp_utc:` Timestamp at UTC time.
    - `datetime:` [DEPRECATED] Forecast Valid hour UTC (YYYY-MM-DD:HH).
    - `wind_gust_spd:` Wind gust speed (Default m/s).
    - `wind_spd:` Wind speed (Default m/s).
    - `wind_dir:` Wind direction (degrees).
    - `wind_cdir:` Abbreviated wind direction.
    - `wind_cdir_full:` Verbal wind direction.
    - `temp:` Temperature (default Celcius).
    - `app_temp:` Apparent/"Feels Like" temperature (default Celcius).
    - `pop:` Probability of Precipitation (%).
    - `precip:` Accumulated liquid equivalent precipitation (default mm).
    - `snow:` Accumulated snowfall (default mm).
    - `snow_depth:` Snow Depth (default mm).
    - `slp:` Sea level pressure (mb).
    - `pres:` Pressure (mb).
    - `dewpt:` Dew point (default Celcius).
    - `rh:` Relative humidity (%).
    - `clouds_low:` Low-level (~0-3km AGL) cloud coverage (%).
    - `clouds_mid:` Mid-level (~3-5km AGL) cloud coverage (%).
    - `clouds_hi:` High-level (>5km AGL) cloud coverage (%).
    - `clouds:` Cloud coverage (%).
    - `weather: {`
        - `icon:` Weather icon code.
        - `code:` Weather code.
        - `description:` Text weather description.

    `}`
    - `pod:` Part of the day (d = day / n = night).
    - `uv:` UV Index (0-11+).
    - `dhi:` Diffuse horizontal solar irradiance (W/m^2) [Clear Sky]
    - `dni:` Direct normal solar irradiance (W/m^2) [Clear Sky]
    - `ghi:` Global horizontal solar irradiance (W/m^2) [Clear Sky]
    - `solar_rad:` Estimated Solar Radiation (W/m^2).
    - `vis:` Visibility (default KM).
    - `ozone:` Average Ozone (Dobson units).
- `... ]`

Figure 41. Available weather data from weatherbit forecast service

Finally, the methodological approach for **interfacing the simulation models and the weatherbit.io forecast** service will be based on the open API offered to get the forecasted data, in addition to the corresponding parsing routines to translate this information to the format accepted by the simulation software. Specific documentation is provided describing the weatherbit.io API features and required access methods[11].

[6] https://rapidrefresh.noaa.gov/hrrr/
[7] https://en.wikipedia.org/wiki/North_American_Mesoscale_Model
[8] https://www.dwd.de/EN/research/weatherforecasting/num_modelling/01_num_weather_prediction_modells/icon_description.html
[9] https://www.athenium.com/
[10] energyintime.eu
[11] Weatherbit API - https://www.weatherbit.io/api/weather-forecast-120-hour

Moreover, for IESVE building models, Apache simulation engine requires a weather file that is normally sourced directly from the EnergyPlus website, being .epw and .fwt (proprietary format) the weather file formats that VE can read. In this case, the weather data source will directly be the routine implemented into SunHorizon forecast service. The same situation applies for TRNSYS weather files, which, among others, can also accept .epw files. It should be noted that first integration tests have already demonstrated the feasibility to integrate weatherbit.io-based solution into energy simulations managed from iSCAN tool.

In the context of SunHorizon platform the planned weather data flow is described in Figure 42.

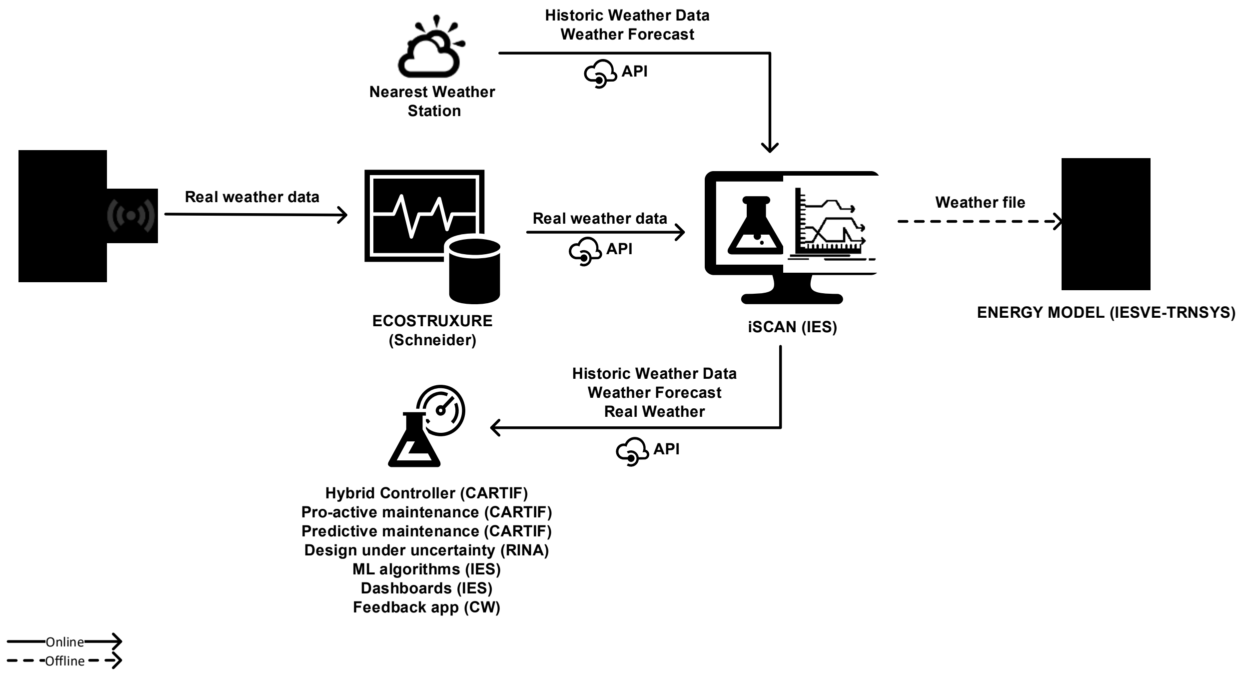


Figure 42. Weather Data flow in SunHorizon platform

Using the iSCAN-API, weather data can be easily accessed for further analysis and additional services in external algorithms such as the calculation of the KPIs, the predictive maintenance, the hybrid controller etc., as foreseen in WP4 and WP5. Moreover, as already described, data can be translated and packaged in weather files suitable for software performing for dynamic simulation such as IES Virtual Environment (IESVE) and TRNSYS. Using the same route backwards, processed data can return to iSCAN for storage, further analysis and display to the user.

Furthermore, since the weather stations are usually not located near the demo sites, weather data obtained from the nearest weather stations are not representing the real weather conditions of the building mostly due to microclimate effects. Therefore, to improve the accuracy of the weather data and predictions, local weather services will be installed on the demo sites as part of WP4-6 activity, and then iSCAN will connect, store and replace the chosen weather service with real weather data coming directly from the monitoring devices installed on the demo sites. Additionally, the real weather data collected on site will create an accurate historic weather database, that will be stored and available for SunHorizon services. This way, maximum accuracy will be achieved in order to reduce the performance gap between the reality and predictions.

5 Other parameters for interaction of smart services

The aim of this section is to outline first considerations discussed within T5.1 definition of the SunHorizon prediction services in correlation to the model parameters affected by the rest of the proposed smart services (i.e. the integration of the end-user feedback in the control loop –T5.2-, and the implementation of self-learning algorithms for model calibration and comfort-related user perception and expected behaviour –T5.3-).

5.1 End-user feedback

Some parameters of the simulation models for demand and performance predictions should be affected or directly defined thanks to the information provided by the end-user feedback app, in order to provide reliable and accurate forecast of the building and systems operation.

Basically, the app will allow the users to report their occupancy patterns (e.g. when they are at home), their behaviour in relation with HVAC systems (e.g. when they switch the heating on, which setpoint they prefer) and how they feel about their thermal environment. This will be used to predict probable use patterns thanks to T5.3 developments (see Section 5.2 of this document) in the next hours and tell the models which occupancy schedules to use in the simulations, and tell the optimization algorithms whether any particular constraint concerning comfort should be considered.

Simulation models already accounts for these specific model inputs in the form of **occupancy/use schedules** that must be provide to determine internal gains and systems' operation. Moreover, **simulation-based comfort evaluation** is also provided as simulation output in order to be used within the cost function of the optimization algorithms. Then, model parameters do not need relevant modifications to incorporate end-user feedback information. The challenge is to get useful user feedback through the app and monitoring devices, and to be able to improve the prediction of comfort preferences of the individual users instead of using traditional comfort models (developed with a universal purpose). This will be specifically addressed within the scope of T5.2 and T5.3.

5.2 Self-learning algorithms

Self-learning algorithms will be applied for model recalibration. This can be achieved considering the problem of shortening the gap between simulation and real building performance as an optimisation task. In this description, a cost function based on the error defined as the difference between building measurements and simulation, should be minimised by searching the best model parameters in the parameter space until a minimum is reached. The comparison of online measurements from building sensor and predicted values from simulation can be used as an indication of the actual calibration error. Monitoring the calibration error over time allows to keep track of the quality of the energy model and to trigger recalibration when the error exceeds a certain threshold. As the optimisation task could be computationally expensive, machine learning models can be employed as proxy of the energy model allowing for a faster solution of the mathematical problem.

No specific model adaptations have to be considered to accommodate the use of these techniques for model calibration. The process itself will perform a diagnosis of the most influencing model parameters (among those originally defined in the energy model) and search for their best values for a minimized deviation between simulation results and real data.

On the other hand, machine learning techniques are being under study for thermal comfort and occupant preference prediction. The aim of this activity (within project task T5.3) is the implementation of a machine learning (ML) algorithm able to forecast current and future thermal comfort levels in a building and estimate possible occupant feedback based on environmental sensor measurement, previous comfort feedback and other occupant information (such as activity, clothing level etc.). The forecasting approach is foreseen to be directly used as input for the predictive control (particularly for the main optimization algorithm of the SunHorizon hybrid controller) with the intent of identify comfort constraints while optimising energy use and costs in the building. A series of benchmark/literature data have been used for the initial training of the ML algorithm. These should be progressively substituted by actual measurements from the buildings provided by two main sources of information: environmental sensor measurements (such as internal temperature or relative humidity) and occupant related information (such as: comfort feedback, activity, clothing level, window opening, etc.). Comfort level can be expressed as well know indexes/KPIs (e.g., PMV: predicted mean vote) or elaborating innovative KPIs tailored for the specific application. The output of the machine learning method will be included as constraints and informative input in the control algorithm to forecast the most acceptable future HVAC/zone settings of the building. This reinforces the idea of considering ML outputs as inputs for already existing parameters within the simulation models, namely: occupancy/use schedules (which in this case will be predicted by T5.3 developments).

6 Conclusions

This report D5.1 describes those project achievements accomplished in the framework of SunHorizon WP5, particularly in what concerns the definition and development of predictive capabilities for the SunHorizon hybrid controller.

Predictive algorithms for the estimation of the energy demand and renewable energy contribution as an integrated capability in an energy control loop does not comprise an independent direct development. It is, however, subject to an iterative development process (define-develop-test-refine) with a strong link with relevant amount of information coming from other project activities (e.g. data collection from demo building and energy systems characteristics as well as the definition of SunHorizon Technology Packages). For this reason, D5.1 presents some unclosed developments that require the consolidation of ongoing project tasks and, thus, will reported in upcoming project deliverables already identified.

Three main topics have been addressed within this report, leading to the following summary of conclusions:

First, **a development/demonstration strategy for the SunHorizon controller has been defined** based on the reasoned selection of two representative demo sites ('Type A') for the full deployment of the control system, together with the simulation-based validation of the controller in the other demo sites ('Type B'). Moreover, the general concept and **architecture for the optimization-based control concept** including co-simulation for model-based prediction has been also outlined. Final version of this architecture, according to the requirements coming from ongoing WP5 tasks will be implemented in T5.4 and reported in D5.5.

In addition, **the main simulation models required for the prediction of SunHorizon energy demand and systems' performance in the 'Type A' demo sites have been created** using IESVE and TRNSYS simulation tools. On one hand, IESVE building models will be refined and provided with the final adaptations for auto-calibration features within T5.3 (reported in D5.3). On the other hand, complete simulation-based characterization of the energy demand based on such IESVE models are to be reported in D2.5 together with extended preliminary results from TRNSYS models of the energy supply systems that will be completed after D2.5 is finished.

Finally, this report presents the **methodological approach** defined within the project in order to feed the core predictive components (i.e. the simulation models) with **additional forecasted information** and other required dataflows relevant for the overall controller implementation. Particularly, different options for the implementation of a suitable weather forecast service were analysed and the intended conceptual approach, data sources and tools have been described. Its final implementation will be addressed in T5.4 and reported in D2.5. Requirements for the interaction between the energy models and end-user feedback (through Machine Learning prediction techniques) have been identified. Adaptations of the energy models and parameters to make this integration feasible will be reported in D5.2 and D5.3.

A. ANNEXES

A.1 – Example weather design conditions for Riga demosite (located in Latvia)

Meaning of acronyms:
DB: Dry bulb temperature, °C
WB: Wet bulb temperature, °C
MCWB: Mean coincident wet bulb temperature, °C
Lat: Latitude, °
DP: Dew point temperature, °C
MCDB: Mean coincident dry bulb temperature, °C

Station	Lat	Long	Elev	Heating DB		Cooling DB/MCWB					
						0.4%		1%		2%	
				99.6%	99%	DB	MCWB	DB	MCWB	DB	MCWB
Latvia											
RIGA	56.92N	23.97E	10	-18.9	-14.2	28.9	20.3	27.0	19.7	25.1	18.3

Long: Longitude, °
Elev: Elevation, m
HR: Humidity ratio, g of moisture per kg of dry air
WS: Wind speed, m/s
HDD and CDD 18.3: Annual heating and cooling degree-days, base 18.3°C, °C-day

Evaporation WB/MCDB				Dehumidification DP/HR/MCDB						Extreme Annual WS			Heat./Cool. Degree-Days	
0.4%		1%		0.4%			1%							
WB	MCDB	WB	MCDB	DP	HR	MCDB	DP	HR	MCDB	1%	2.5%	5%	HDD	CDD 18.3
21.8	26.8	20.5	25.1	20.0	14.7	24.4	18.9	13.7	23.1	9.1	8.1	7.3	4098	93

Figure 43 Design data for the city of Riga

Extreme Annual Design Conditions

Extreme Annual WS			Extreme Max WB	Extreme Annual DB				n-Year Return Period Values of Extreme DB							
				Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years	
1%	2.5%	5%	WB	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
14a	*14b*	*14c*	*15*	*16a*	*16b*	*16c*	*16d*	*17a*	*17b*	*17c*	*17d*	*17e*	*17f*	*17g*	*17h*
10.3	**8.7**	**7.8**	**24.8**	**30.1**	**-20.0**	**2.0**	**6.3**	**31.5**	**-24.5**	**32.7**	**-28.2**	**33.8**	**-31.8**	**35.3**	**-36.3**

Figure 44 Extreme design conditions

A. Bibliography

Doty, S., & Turner, W. C. (2004). *Energy management handbook.* Crc Press.

Drück, H. (2006). *Type 340 MULTIPORT Store - Model.* Sttutgart: Institut für Thermodynamik und Wärmetechnik (ITW).

European Technology Platform SmartGrids. (2012). *SmartGrids SRA 2035: Strategic Agenda Update of the SmartGrids SRA 2007 for the needs by the year 2035.* SmartGrids Strategic Research Agenda 2035.

Fleiter, T., Elsland, R., Rehfeldt, M., Steinbach, J., Reiter, U., Catenazzi, G., . . . Stabat, P. (2017). *Profile of heating and cooling demand in 2015.* Heat Roadmap Europe .

FMI development group. (22 de August de 2019). *Functional Mock-up Interface for Model Exchange and Co-Simulation 2014.* Obtenido de https://fmi-standard.org/docs/2.0.1-develop/

IDAE. (2011). *Guía práctica sobre instalaciones individuales de calefacción y ACS en edificios de viviendas .* Obtenido de IDAE: https://www.idae.es/uploads/documentos/documentos_11821_GPInstalIndividualesACS_2011_A_efbd9f43.pdf

Klein, S., Beckman, W., Mitchell, J., Duffie, J., Duffie, N., Freeman, T., . . . M.J. (2018). *TRNSYS 18 – Mathematical Reference.* Madison: Solar Energy Laboratory, University of Wisconsin-Madison and Thermal Energy System Specialists, LLC.

Vallée, M., Bavière, R., Seguin, V., Vuillerme, V., Lamaison, N., Descamps, M., & Aurousseau, A. (2019). An efficient co-simulation and control approach to tackle complex multi-domain energetic systems: concepts and applications of the PEGASE platform. *32nd International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems.* Wroclaw, Poland.

White, J., & Reichmuth, R. (1996). Simplified method for predicting building energy consumption using average monthly temperatures. *Proceedings of the 31st intersociety energy conversion engineering conference, 3*, 1834-1839.

Zhao, H.-X., & Magoulès, F. (2012). A review on the prediction of building energy consumption. *Renewable and Sustainable Energy Reviews , 16*, 3586-3592.