D5.2 Validated digital twins of prosumers based on socioeconomic factors

WP5 – Green Economy Models and Management Systems

Author: Bocconi University (UB)

March 2024

SMARTGYSUM project has been funded by the European Commission's Horizon 2020 Programme

SMARTGYsum has been funded by the European Union's Horizon 2020 Programme under the Grant Agreement GA 955614

The contents of this publication are the sole responsibility of UB (Bocconi University) and do not necessarily reflect the opinion of the European Union

Versions:

Version No.	Person in charge	Institution (acronym)	Date	Comments
1	Oleksandr Velihorskyi	CNUT	04.03.2024	First template of the deliverable report
2	Rafael Marentes Ortiz	SIEM	29.03.2024	Report by ESR
3	Edoardo Croci and Tania Molteni	UB	29.03.2024	Revision
4	Oleksandr Velihorskyi	CNUT	31.03.2024	Check of project's scientific coordinator and minor corrections
5	Rafael Marentes Ortiz, Edoardo Croci and Tania Molteni	SIEM and UB	02.04.2024	Revisions
6	Enrique Romero-Cadaval	UEX	05.04.2024	Final check before submission

SMARTGYSUM project has been funded by the European Commission's Horizon 2020 Programme

Technical References:

Project Acronym	**SmartGYsum**
Project Title	Research and Training Network for Smart and Green Energy Systems and Business Models
Project Coordinator (PC)	Enrique Romero (eromero@unex.es) Universidad de Extremadura (UEX)
Project Duration	1 October 2021 – 30 September 2025

Deliverable No.	D5.2
Dissemination Level	Confidential, only for members of the consortium (including the Commission Services)
Work Package	WP5 – Green Economy Models and Management Systems
Tasks	
Lead Beneficiary	13 - UB
Contributing beneficiary (ies)	SIEM
Data due of deliverable	01 April 2024
Actual submission date	05 April 2024

Table of Contents

List of abbreviations

BEN	Beneficiary
Dn	Deliverable (number)
DoA	Description of Action
DS	Doctoral School
EH	Energy Hubs
ESR	Early Stage Researcher
EST	Energy-Saving Techniques
ETN	European Training Network
HEMS	Home Energy Management Systems
GA	Grant Agreement
GWP	Global Warming Potential
IRP	Individual Research Project
ITN	Innovative Training Network
MSn	Milestone (number)
MSCA	Marie Sklodowska-Curie Actions
NZEB	Net Zero Energy Buildings
PC	Project Coordinator
PSD	Passive Sustainable Design
REC	Research Ethics Committee
RER	Renewable Energy Resources
RSC	Recruitment and Secondment Committee
SG	Smart Grid
SLR	Systematic Literature Review
WPn	Work Package (number)
ZEB	Zero-Emission Building

SMARTGYSUM project has been funded by the European Commission's Horizon 2020 Programme

1. Executive summary

The Work Package (WP5) focuses on supporting and coordinating research and application of business models in collaborative renewable energy systems, microgrids, and energy management. It aims to demonstrate the benefits of WP2, WP3, and WP4 technologies by designing synergic strategies and providing policy suggestions for transforming energy systems. Within the given scope, the present deliverable provides the report about the developed prototype, related with the implementation of IRP13 in Task 5.2 of the project. The work developed for this purpose consisted in the development on Digital Twins accounting for social, economic, environmental, and technical factors both in the development of the model and in the use of it.

A Digital Twin is a numerical model that is tuned to closely resemble a physical system for a practical purpose, like simulating or testing. It comes as a relatively inexpensive solution when compared to building a physical model and allows for the interaction between the real state of the physical system with proposed systems, to test their compatibility before implementation.

Within IRP 13, the work of ESR 13 has mainly focused on the development of tools and methods to account for multiple factors in digital models and simulations. It involved the research on modelling of social behaviour on residential buildings and their electric consumption, at the same time ways to incorporate these models into more technical simulations of prosumers and being able to include as well grid related solutions, like the power flow problem.

The creation of the digital twins presented the challenge of not only modelling the system but also other associated factors that interact with it, as such, a model of the operation of the device under different control strategies had to be developed in some cases, or even a complete model for the occupancy of the premises to properly account for its impact in other areas.

With the imperative importance of improving energy consumption patterns and behaviours, this document also presents some proposals and test where the models operate not only as their real counterparts but also in prospective scenarios that highlight potentials for energy savings, better use of available resources, cost savings or improved comfort.

All in all, the work developed in this document is expected to provide a guide of how to model and account for social factors that are influenced by the specific society that lives in a location, as well as their interaction with the environment and other systems in its surroundings.

1.1. Objectives of the deliverable

In line with IRP 13, the objectives of this work are:

- To develop a model that allows to test self-consumption and prediction scenarios with different social and economic factors and characteristics of renewable energy systems;
- To research on the possibilities to optimize resource-allocation of energy at the prosumer level;
- To gain insights on the importance of socioeconomical factors, in the consumption behaviour.
- To present a model that incorporates factors of all these categories and validate it as an accurate representation of a physical system, i.e. to present a Digital Twin

Specifically, this report intends to detail the components of a prosumer and the design of its digital twin, with steps that could be generalized in the development of the digital counterpart of any physical system but also in understanding that each one also has unique characteristics that require special attention.

It is expected to showcase as well how some of these characteristics can actually come not from the technical part of the system but from its social aspects, as a prosumer with the same equipment or technical description would behave completely differently with different occupants having different activities and schedules. Similarly, if the control implemented is coupled with economic signals, one would expect the behaviour of the system to change even when the technical characteristics are the same, as it can be inferred from the example scenario presented in the report.

SMARTGYSUM project has been funded by the European Commission's Horizon 2020 Programme

2. General progress of the action

2.1. WP5 Objectives and tasks

The deliverable is part of WP5 "Green Economy Models and Management Systems" which focuses on innovative energy management tools and business models for addressing the new challenges stated by the electric energy system. Four Individual Research Projects (IRPs) are involved in WP5 focusing on different research topics concerning innovative management solutions and business models. In detail, IRP12 focuses on sustainable strategies for Net Zero Energy Buildings and energy flexibility services, IRP13 focuses on digital twins for optimising energy self-production and self-consumption, IRP14 focuses on new integrated services for distributed electric energy systems, and IRP15 focuses on designing business models for Energy Communities. The research outputs will contribute to a better understanding and diffusion of technological and business solutions to foster the sustainable energy transition. In detail, WP5 has 3 goals, listed below:

1. Supporting and advancing the synergies between WP2, WP3, and WP4 in business model research, evaluation, and validation to facilitate cooperative and distributed renewable generation systems, microgrids, energy management, and consumption control systems.
2. Developing synergic strategies to display the benefits of systems and technologies developed in WP2, WP3 and WP4.
3. Suggesting policy recommendations to guide the transition of the energy system.

WP5 included 5 Tasks which involves different SmartGYsum partners:

- Task 5.1: Development of sustainable strategies for Net Zero Energy Buildings and Energy Awareness using Smart Appliances (UB, UNL).
- Task 5.2: Generation of digital twins of prosumers using socioeconomical factors and big data for Optimization of Customer's bill savings, (UB-SIEM-UNL).
- Task 5.3: Energy value chains and markets developed with the new paradigm of distributed EES (UB-UNL-CNR).
- Task 5.4: Identifying enablers and barriers to foster the replicability and transfer of business models for Green Energy Systems (UB, UNL, ECPE).
- Task 5.5: Elaboration of partial and final scientific reports (UB).

This deliverable is part of the Task 5.2 and reports the main findings of the IRP13 "Digital twins of prosumers using socioeconomical factors and big data for Optimization of Customer's bill savings, and the adoption of concepts of self-consumption and presumption".

2.2. WP5 – IRP progress

IRP13 aims to improve the understanding of the factors that affect the development of accurate models of prosumers, and integrate them in digital twins for optimising energy self-production and self-consumption.

The concept of Digital Twins are used for this purpose as they are numerical models that behave like a physical system to monitor its state and testing changes in the system before committing to them in real life. This approach brings many benefits but is prone to errors if the scope of the model is not clearly understood and if the limitations of the data available for the development of the model is not taken into consideration.

IRP13 involves ESR-13 who was recruited to the project in May 2022 (09/05/2022). His research activities have been conducted for twenty-two months since his recruitment by the Research and Training Development Department of Siemens Industry Software SAS in France (hosting institution). ESR-13 focuses on prosumers and his research regards the physical modelling of grids and the impact of social and economic aspects on the grid and its models. He performed his first secondment for two months at Universidade NOVA de Lisboa (2023-06) and one-month stay at UTBM in Belfort (2024-02).

The table below summarizes the status of ESR13 at the current stage:

ESR#	Starting date	General evaluation	Status
13	2022-May	Delay in the data availability and development of the second digital twin	1st model finished 2nd model in-progress

This deliverable is organized into sections addressing the description of the two Digital Twins developed on selected buildings and their model.

In subsection 3.2.1 the first Digital Twin is presented, a detailed description of the inputs, parameters and outputs is presented as well as the operation of the system. Going from the physical system to the model is then detailed, mentioning the simplifications made and how different spaces were considered. The parameters of the model were then tuned based on the validation data, leading to a model that behaved like the actual system and this was used to run some test to exemplify the usefulness of a digital twin in energy savings analysis, resource allocation and supporting decision making.

In subsection 3.2.2 the second Digital twin is introduced, this one at the moment mostly focused on the impact of occupancy. The purpose of the model is presented as well as the factors considered in its development. A detailed explanation of the occupancy model developed for this digital twin is presented and also the modelling and validation of some of the components of the renewable energy production and storage systems.

The last sections conclude what are the contributions of this work to the project and how they relate to the main objectives of the Work Package 5. Finally a short recap of the work done is presented along with the concluding statements.

SMARTGYSUM project has been funded by the European Commission's Horizon 2020 Programme

3. Deliverable description

3.1. Preliminary information about deliverable

The findings presented herein are the result of a collaborative effort involving three beneficiaries and partner institutions. This endeavour encompassed a two-month secondment at NOVA University in Lisbon, Portugal, a one-month stay at UTBM in Belfort, France, and intermittent engagement over twelve months at the main hosting institution, Siemens in Lyon, France.

At NOVA University, the Energy Efficiency Research Group efforts were concentrated on areas such as energy consumption reduction and offset, smart water heaters, and net-zero energy buildings. Leveraging their expertise and ongoing initiatives, a model of one of their buildings was developed.

The focus of research at UTBM primarily revolves around hydrogen fuel cell technology and digital twin technology for modern power electronics and energy systems. Drawing upon their proficiency in these domains and their sensor network, we constructed a Digital Twin of their laboratory and affiliated office space.

Lastly, at Siemens' Research and Technology Development team, the research emphasis lies in the advancement of modelling techniques and tools for rapid and precise computation of Multiphysics systems. This aligns seamlessly with our objective of creating the desired Digital Twins, thereby fostering a synergistic collaboration.

3.2. Prototype description

The Digital Twins developed consist of numerical models that represent physical entities. They have inputs, which represent the environmental, social, and economic factors, and vary over time; they have parameters, which describe the characteristics of the entity, its physical dimensions, and sensitivity to the inputs; they have the component Multiphysics models, which represent the building blocks of the entity as well as the interactions they have between themselves; and they have outputs, which show the values of interest as a result of the inputs to the system.

3.2.1. Nova digital twin

The first digital twin consists of a university building in the region of Caparica, Portugal. It is a long 70 by 20 meters structure of about 10 meters height above the ground that serves as a space for offices and laboratories connected by long open corridor in the middle. The building incorporates a climatization system which is thermally modelled and analysed, with the use of real measurements it is then validated, and some tests and proposals are showcased in it.

In the following sections, the different components of the digital twin will be detailed, the relevant data processing that was done and the model simplifications. For the operation of the control a simplified description is given as the specific mathematical implementation is not important and due to the caveats of each simulation tools. Each software has different ways to resolve the equations used to model the different components and different approaches to how signals interact with other components, as such it is only important to understand the relations used to determine the behaviour of the control and not so much how it was implemented in this specific tool, as if implemented in reality this would have to be redone on the specific architecture, the use of hardware in the loop could be used in these cases to validate a control system but such application is beyond the scope of this report.

3.2.1.1. Inputs

- Sun position

  The position of the sun in the sky is important to understand how the heat and energy from the sun affect each side of the system and to determine the efficiency of photovoltaic systems.

- Sun irradiance

  The cloud coverage, fog conditions and other factors affect how much energy from the sun reaches the surface. When a measurement of the sun irradiance is available it can work as average of all these considerations in the location.

- Temperature

  The external air temperature is an important factor to consider as it affects the heating and cooling cycle of the system and its ability to dissipate heat from its external surfaces.

- Wind Speed

SMARTGYSUM project has been funded by the European Commission's Horizon 2020 Programme

The average wind speed around the location is known to impact the thermal dissipation of a surface exposed to air due to the poor thermal conductance, therefore one would expect the wall to retain heat when there is slow wind speed.

- Electric Demand

  Humans produce heat by their presence as well as for their activities. It is hard to quantify this directly, especially if their presence in the building is not recorded, but the electric demand of the system can be a useful proxy for human activity as it would be expected to increase when it is occupied and in use and to decrease as humans leave. Similarly, the energy of electric equipment ultimately dissipates as heat.

- Electric tariff

  To be energised, the system needs to be connected to the grid and this is regulated by a contract that details the price that must be paid per unit of energy. Depending on the location and regulations this can vary but it is usually the case that it is either a fix price or a price depending on the time of the day, favouring consumption during low demand hours.

- Open-loop cooling demand

  The start of the cooling system can be triggered by many different conditions or systems but in the case of the building under study it seemed to be arbitrary and not dependent on the temperature or time. Therefore the original cooling schedule extracted from the observed electric consumption was used as input for the cooling demand of the building.

  The operation of the cooling system - mainly the chiller - was conspicuous in the electric consumption, so, after averaging out the values of its seemingly two stages, an algorithm was devised to separate both curves: the demand from the building from the demand from the chiller. The signal was derived, the activations of the chiller isolated, and then returned to the original domain.

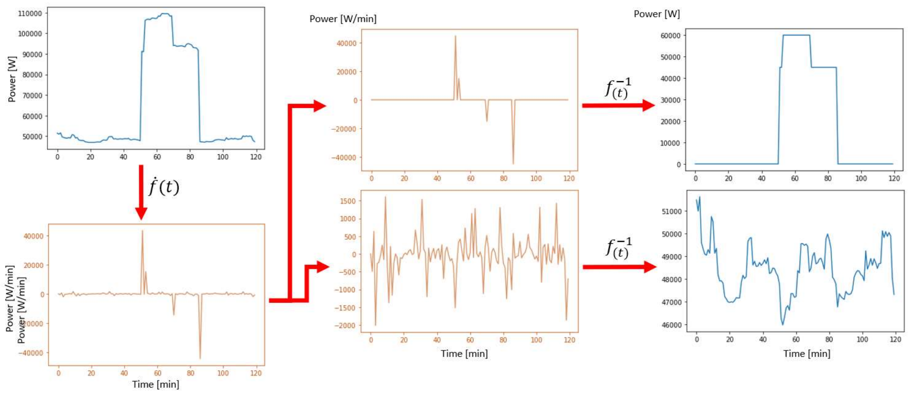

Figure 1 Separation from the consumption of the chiller operation

3.2.1.2. Operation Modes

- Off

  Despite its name, in the "Off" operation mode, the system is still modelled for the whole duration of the simulation with the consideration that the cooling is turned off. Basically, the cooling demand signal is ignored so the building's condition evolves depending only on the remaining inputs. This allows to understand the impact of the cooling system on the internal temperature and the building's temperature comfort.

- Normal

  This is the observed and expected operation of the system in its current configuration. The system is assumed to require cooling with the intensity specified by the observed energy consumption of the chiller and the temperature inside the building is observed as well as the price of energy and the comfort level inside the building

- Water-cooled

  Rather than provide the cooling fluid from the chiller, under this operation mode, the water comes from a water tank, or more precisely, flows through a water tank that exchanges heat with it. It is therefore only reasonable to use when the water in the tank is cold enough to actually provide some cooling to the building.

In any case, in this operation mode the water pumps are turned on but the chiller is not, the flow is instead diverted through the water tank mentioned.

- Storing

  This operation is the one that allows the water in the tank to be cold in the first place. This operation is the most flexible in terms of time, whereas Normal-cooling or Water-cooling both activate the hydraulic system when triggered by the cooling demand, the storing phase can be activated at any point. This could be between cycles or, perhaps most sensibly, during the periods of low demand when the tariff is low and the energy is the cheapest.

- Hybrid

  The final option considered is the hybrid operation, where the flow in the hydraulic system is enabled for all components and therefore the cooling liquid flows through the building, the tank, and the chiller. This operation could be useful if a control for the chiller is implemented to consider the temperature of the water input, as less energy is needed to cool down water that is already somewhat cold.

- Automatic

  Not an operation mode itself, it is the automatic implementation of the cooling system to benefit from the storing tank. It simply decides which operation mode to use depending on the conditions of the system, the tariff, the cooling demand, etcetera.

  For this model in its pure Digital Twin operation, only the normal mode is needed as this is the way the system behaves in reality, but to highlight the usefulness of digital twins, an automatic mode was implemented, along with the proposed modifications for the storage tank, to showcase the operation of the building under these new conditions.

  The automatic mode works as follows:

  Every time that there is cooling demand, the cooling system will activate to satisfy it. During normal and peak tariff periods, if the difference of temperature between the building (average) and the water in the tank is above the threshold (6°C by default) then the tank is used to satisfy the cooling need with the Water-cooled Mode, to compensate for the reduced cooling effect that results from not using the chiller the pump is left running for an additional amount of time (30 min by default). In case the temperature threshold is not achieved then the demand will be supplied with the Normal Mode, using the chiller as usual. During valley tariff periods, it will always supply the demand with the Normal Mode.

  During low-demand (valley) tariff periods, when energy is cheaper, the system will operate under Storing Mode to store thermal energy in the form of cold water in the tank, leaving a 1-hour resting period between activations.

  The following figure exemplifies the operation described. Four tariffs are shown in this figure but in the specific example of this digital twin the valley and low tariffs have the same price, so they are treated equally. In the figure it can be observed that the temperature change during assisted operation is indeed less prominent than the one driven by the chiller directly, which justifies the extended operation observed.

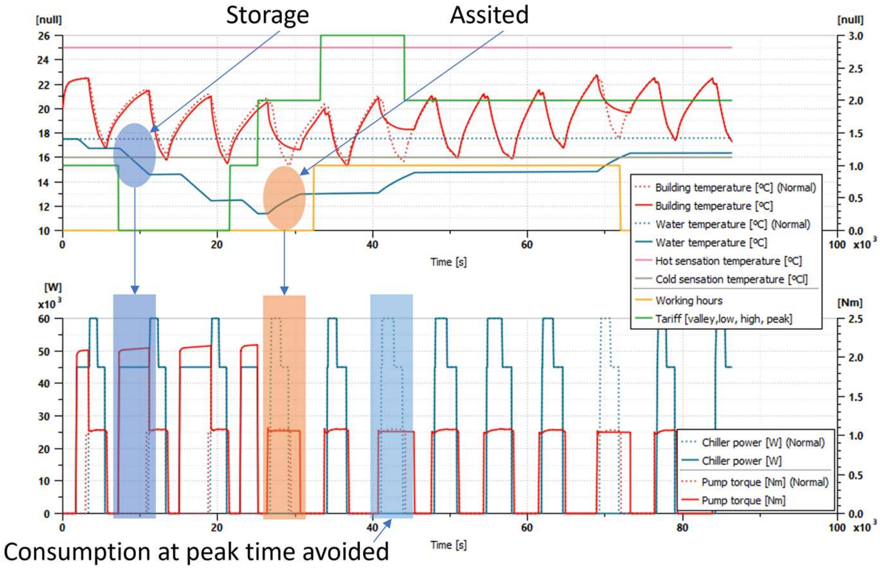

Figure 2 Example of how the automatic mode compared with the normal operation.

3.2.1.3. Parameters

- Time

  The initial date and time at which the system is being simulated. This is an important parameter to define as it affects the day and night cycle, activities inside the building being modelled, the trajectory of the sun in the sky, among other things.

- Location

  Geographical position of the modelled system. This parameter impacts the angle at which the sun is seen at a given time.

- Temperature difference

  The threshold required for the storage tank to be used for the cooling task instead of the chiller.

- Assisted extra-time

  Duration the water pump will continue being active after the cooling demand of the building has stopped to compensate for the reduced cooling effect of using the storage tank.

3.2.1.4. Outputs

- Internal temperatures

  The model's main physical output is that of the temperatures in each section of the building as modelled with the considered simplifications, this is considering all offices in the same floor to be on thermal equilibrium.

- Energy consumption

  Derived from the electric consumption from the building as well as the operation of the water pump and chiller which can be varied with the controls explained in the Operation Modes section, the energy consumed is calculated. A simple model for the grid to which the system is connected is added to show also the impact that the operation of the building has on the grid by causing drops in the tension at its point of connection. And though this voltage drops would naturally impact the loads connected to it, at the moment there is no measurement of this factor as the electric consumption is directly measured as a power, so the loads are modelled as power sinks instead of as impedance loads.

- Energy Price

  Considering the tariff and the power consumption at a given time it is possible to compute the final price of electricity per kilowatt-hour which is a good indicator of improvement of the operation of the system as well as of its environmental benefits as cheaper energy usually means that the consumption is distributed better throughout the day.

3.2.1.5. The model

- The cooling system

The cooling system consist of a water chiller and a pump that circulates the water through the building which has vents on the top of the inner walls and window bases into the laboratories and offices. As a separate system is the fire emergency water system which has 27 cubic meter water storage tank ready in case of need with its pumping and independent off-grid backup generator. For security reasons the water inside cannot be drained for other purposes, but its thermal capacity can be utilized for the purpose of storage.

The physical system, i.e. the building, does not have the modifications implemented to actually use this tank as a thermal storage solution, but to demonstrate the feasibility of the idea the necessary piping and valves are added to the digital twin.

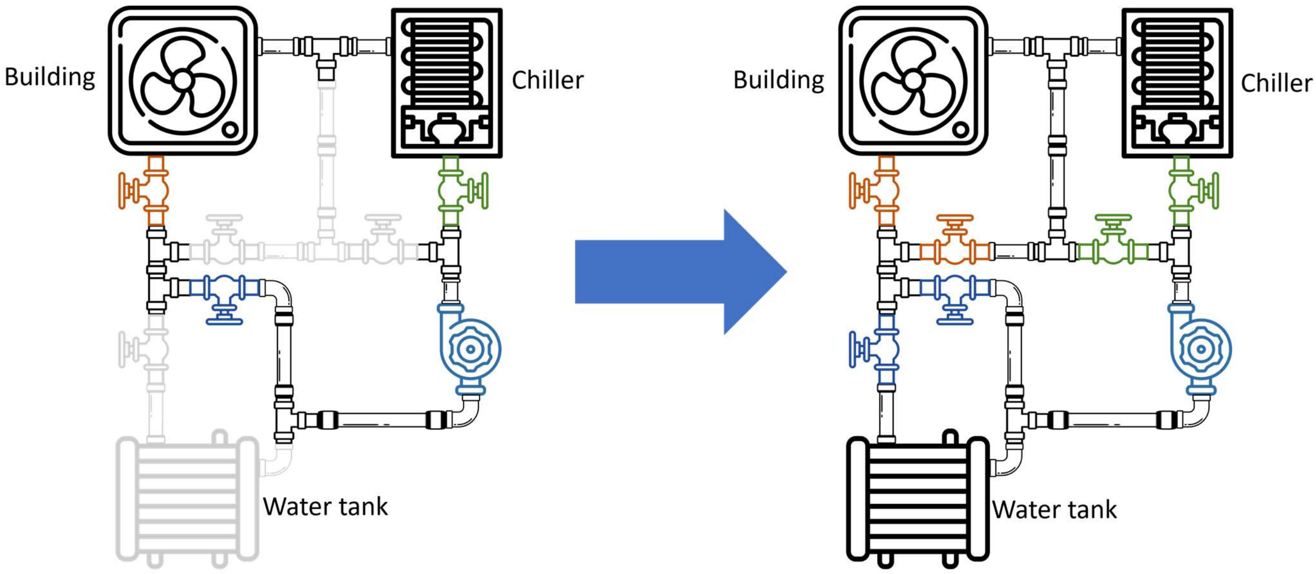

Figure 3 Diagram of cooling system connection on the left with the proposed modification on the right

Under its current configuration there is no need for hydraulic control of the valves during operation, but for an approach that involves the use of the thermal storage it would be necessary to direct the flow through the desired components. For the model thermal hydraulic components were used with the addition of a pump to convert the electric power into pressure and flow.

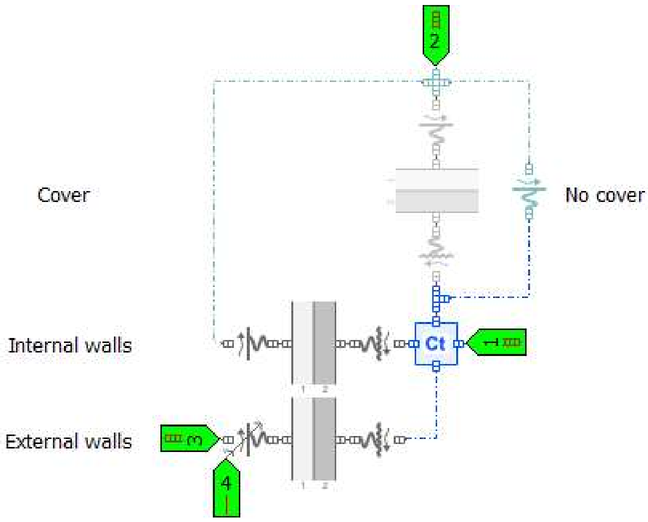

Figure 4 Water tank storage model

For the water tank the model considers its location in the basement and the fact that one of its walls contacts the exterior, a couple of models were placed as cover to simulate it having or not an insulation layer on top. The water is considered to be a thermal capacity block that interacts with its surrounding walls by convection.

- The grid

The modelling approach for the grid was described on a separate work in which the advantages of computing the power flow problem with the same solver that is used for the other components is presented. This research can be seen in the article referenced at the end of this document.

The grid to which the system is connected is simply modelled as a rigid three-phase voltage source which feeds the building and chiller through a pi-type transmission line. Without measurements of the real system on this aspect it is not possible to validate the numerical output of the grid's condition, but at least it is possible to observe the impact on the grid that such systems can have. Additionally, a solar panel is present on the campus so its influence can also be modelled and considered.

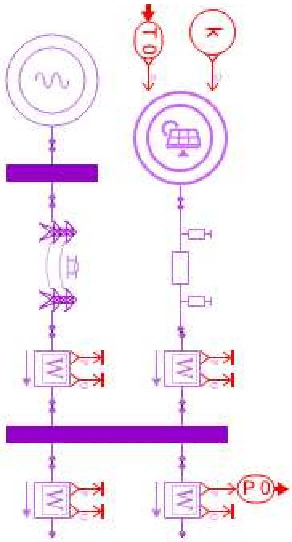

Figure 5 Simple grid model.

The model splits the measurement of the power consumed by the building from that consumed by the cooling system, viz. the chiller and the water pump to better observe the improvements the new operation has on operation costs.

- The building

The main element of the model is the building. The building consists of a rectangular prism with 3 storeys and a basement with a central corridor where a ramp connects the different floors, this corridor is connected among the three surface levels. The main entrance is on the north face and upon entering one finds offices on the left side and laboratories on the right side, where most courses and classes take place. In the basement is where the piping and plumbing are found as well as the emergency fire system which involves the large water tank.

SMARTGYSUM project has been funded by the European Commission's Horizon 2020 Programme

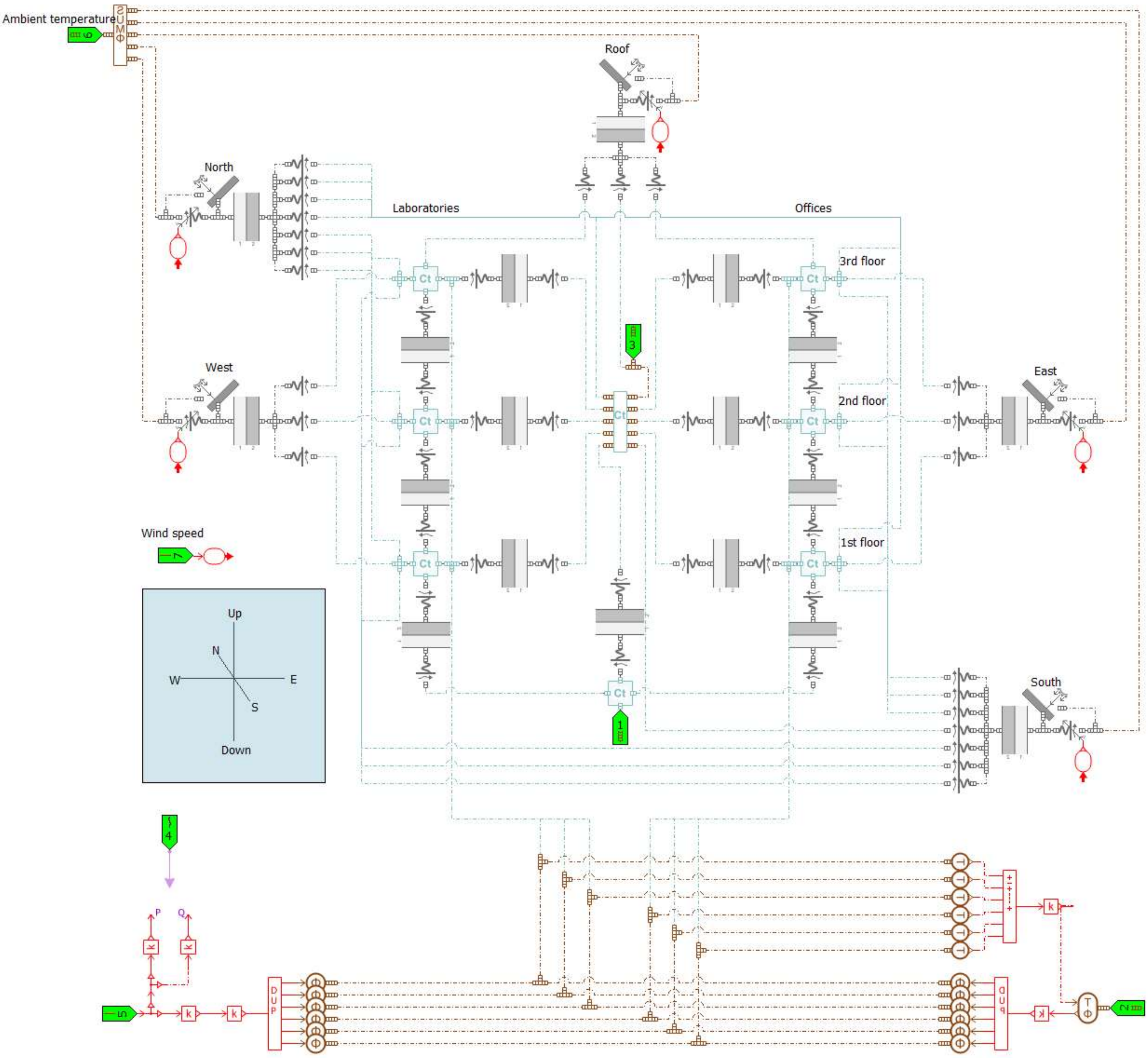

Figure 6 Model of the building

To model the building several elements were considered:

- External walls

These components are very important in properly modelling the system as they are directly in contact with the air outside, and therefore with the external temperature and the influence of the wind. They are also one of the most affected elements by the sun as they heat differently throughout the day depending on their orientation.

- Roof

This is the other element that directly interacts with the exterior conditions and the one that is most affected by the effects of the sun as it is almost always struck by it unobstructed.

- Internal walls

Similar to the external walls in both dimensions and composition, the internal walls separate the spaces inside the building and most importantly insulate the working spaces from the central non-cooled corridor. The main reason for which the internal walls are modelled with separate parameters to the external ones is that the external ones have windows which are not very efficient, while the internal walls are basically completely solid , other than the much needed doors.

- Floors

Between the levels the floors are considered to account for this evident division.

- Sections

For simplicity the spaces inside the building were not modelled for each laboratory and office but rather an average single space was used for all the offices on each floor, as well as for all the laboratories on each floor. This resulted in 3 laboratory spaces, 3 office spaces, 1 central corridor that spans the 3 floors, and the basement which thermally connects with the model of the storage tank. The sections of the offices and laboratories are connected thermally to the pipes of the cooling system as it is in these locations where the climatization has vents. The heat created by the machines which is assumed from the energy consumption of the building is also connected to these spaces as it is within the laboratories and offices that most of the devices are used. For the basement, a single section was considered. In the schematic of the sections of the building the big rooms are for the laboratories and the smaller one is for the offices.

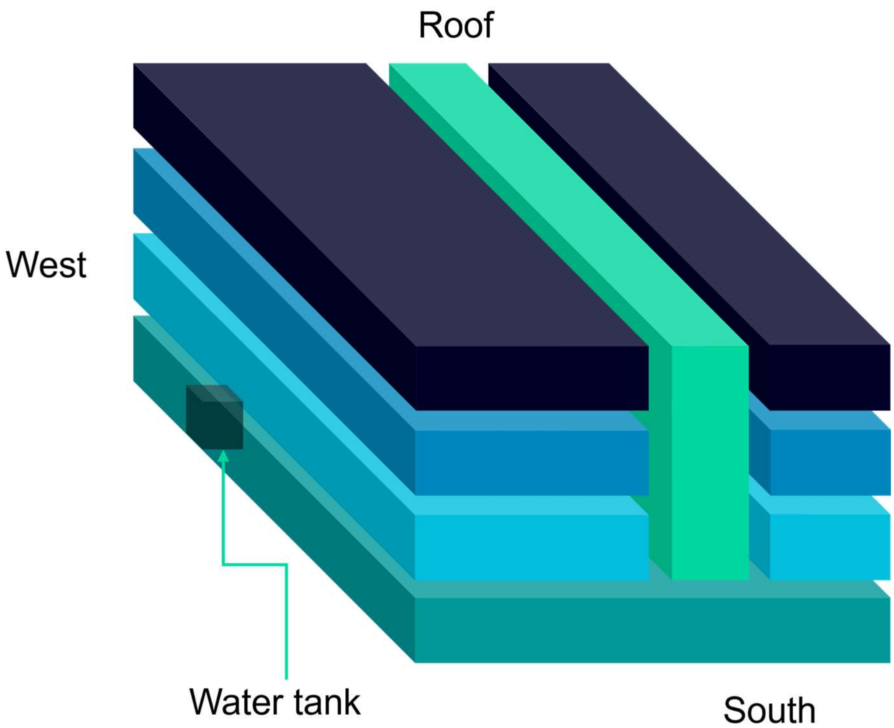

Figure 7 Segmentation used to model the building.

SMARTGYSUM project has been funded by the European Commission's Horizon 2020 Programme

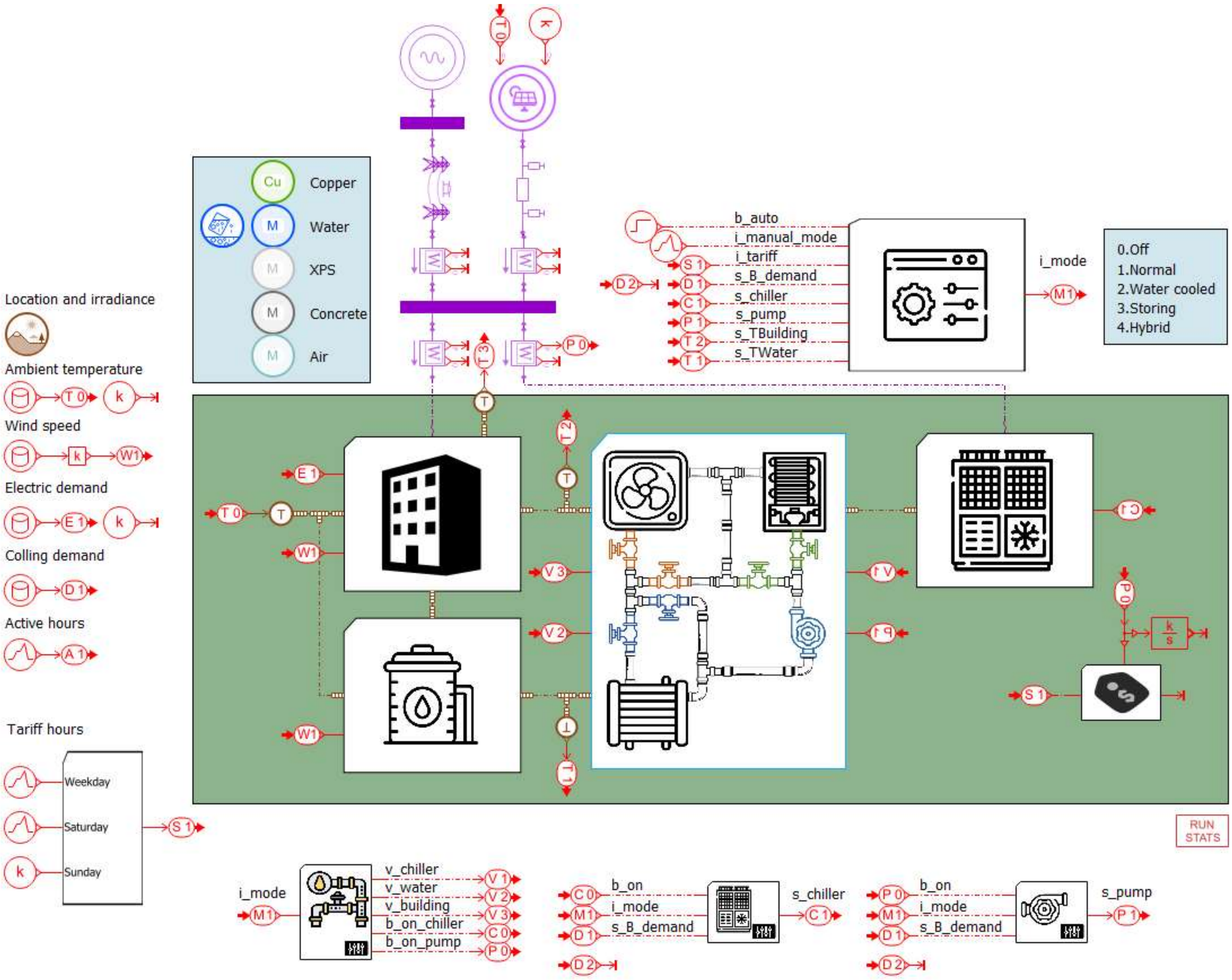

Figure 8 Final model for the digital twin implemented in Simcenter Amesim

3.2.1.6. Validation

To test new configurations and operations and be confident that the results from the simulations reflect what would be seen on a real scenario it is important to validate the model. This is the point when the model truly becomes a digital twin as the parameters get tuned to reflect as much as possible the behaviour of the physical system.
For this Digital twin this was done by gathering the input variables for a period of 10 days, as well as an output measurement that is not normally present but will in this case serve as the comparison variable to validate that the behaviour of the system follows the correct dynamics and is of the correct magnitude.

Validation data gathered in Autumn 2022

- Inputs
  Weather data: The National Information System for Hydric Resources through its weather station in Monte da Caparica served as a conveniently close high quality source of information for the temperature, wind speed, and irradiance. It also has the advantage that it has many other variables like pressure and humidity which are not considered in the current version of the Digital Twin but that could be used in future iterations of the model, and with the data gathered for this same dates it would still be possible to test and validate such model.
  Electric consumption: For the validation data unfortunately, there was no access to the consumption information so a previous measurement of it during a week was considered instead. In the consumption, a constant component could be observed with an increase during the active work hours in the weekdays and a flat constant consumption during the weekends.
- Parameters

SMARTGYSUM project has been funded by the European Commission's Horizon 2020 Programme

The dimensions of the building and the spaces inside of it are pretty much fixed so the parameters that could be tweakable relate to the characteristics of the materials in the walls and roofs, the amount of energy that the exterior surfaces absorb from the sun and the effect of the electric consumption inside of the building. These four characteristics were varied in search of a range of values where we effectively have a digital twin.

- Output

  For the output variable, the central corridor was chosen. A digital temperature and humidity sensor was connected in the middle of the space. The sensor had a +/- 2°C error with a 1°C resolution.

  With the system validated it is then possible to then test the other mentioned configurations with the confidence that the thermal dynamics of the building will be accurate and the results from the studies relevant.

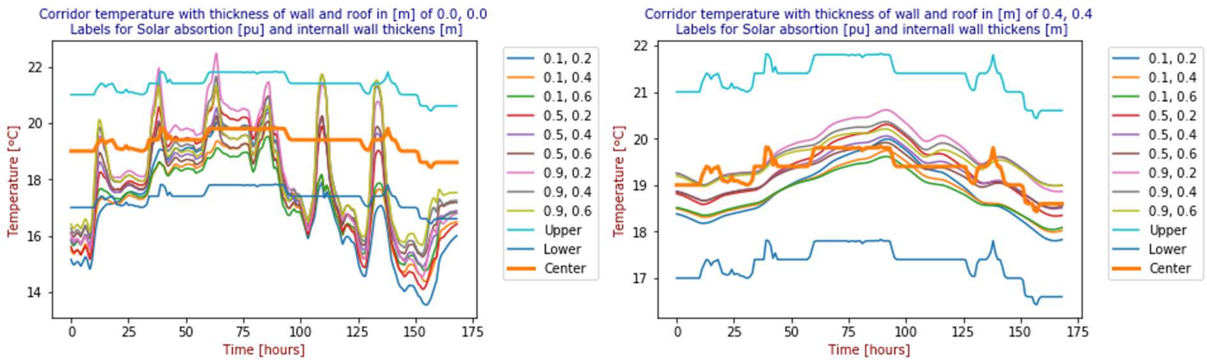

Figure 9 Bad fittings for the model as the output clearly exceeds the limits of the expected value (left), or fails to exhibit the dynamic of the phenomena (right)

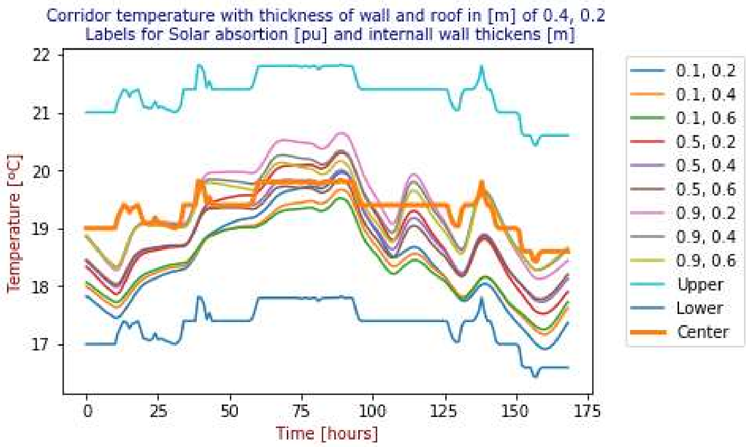

Figure 10 Fitting that is within the accuracy of the sensor while preserving the dynamics observed in the measurement.

In the previous figures it can be observed that it is possible to fit the model to the measured values by tweaking some parameters.

3.2.1.7. Example of prospective scenarios

Automatic mode during a summer week

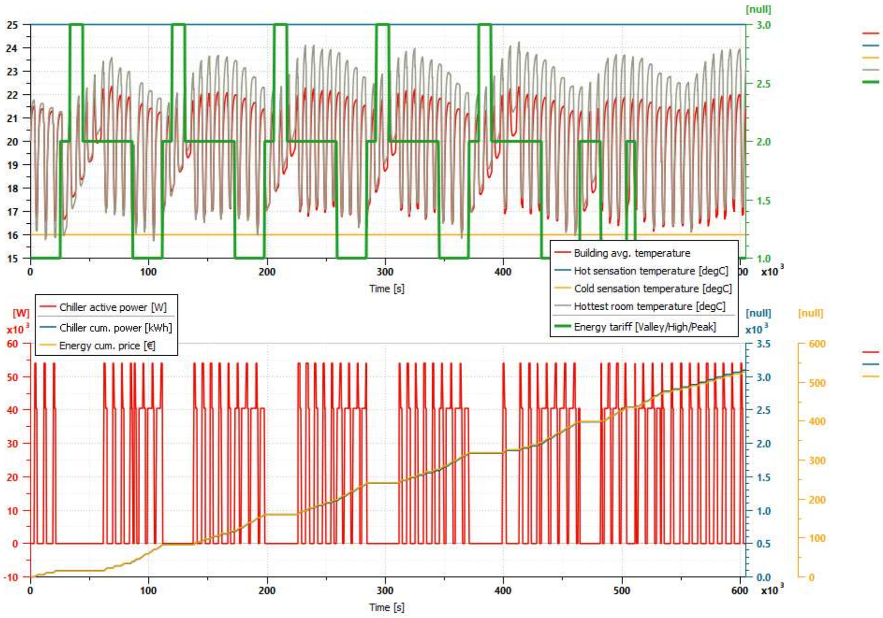

Figure 11 System performance during a summer week using the Automatic Mode

Using the developed control for the cooling system it is immediately noticeable that the activations of the chiller in the system has gaps that correspond to the high tariff. But the device has to now operate extra during the nights to restore its energy deposits which are noticeable. Another immediately noticeable effect of this operation is that the low temperature achieved with the operation of the system is not as prominent as when it is the chiller that provides the cooling directly, as during the water-cooled cycles the temperature decrease is smaller as the water in the tank heats. In any case, the results show that the temperature is consistently maintained below the heat discomfort level and the usefulness of the proposal would rely on the savings that can be obtained from such a modification in the structure of the cooling system and its operation.

The resulting increase in energy consumption with this modification is of 4.6% while the price reduction is of 6%. This means that less electricity was consumed during peak hours where at the same time solar energy production from the PV panel is greater. Operating on such a schedule would be directly beneficial to the system, economically but also to the energy utility company technically.

Improvement of thermal losses using a cover for the water deposit

Since in its current configuration the water deposit is exposed on the top to the air in the basement, one could wonder whether it makes sense to insulate it to improve its performance as a thermal storage. Once again, thanks to the Digital Twin, this can be done virtually to study its benefits before committing to an investment to get an idea of how it would improve and ultimately decide if it is worth the change or not.

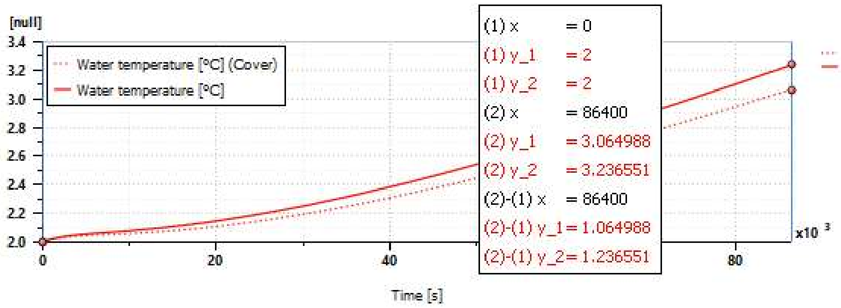

Figure 12 Change in water temperature in the tank after 1 day with and without a cover.

The result from the simulation shows that there is a 1.065 °C increase with the cover while there is a 1.237 °C increase without the cover, an improvement of 14%. This test was performed assuming standard concrete walls and a lid of expanded polystyrene.

3.2.2.UTBM Digital Twin

This time the model was based on a different building which is found in the region of Belfort, France. The space consists of a 3-storey building with offices and meeting spaces and a large testing laboratory which is connected through the ground floor. It has 2 main access points, the parking lot door and the main entrance, both of which open with a badge.
For the development of the second digital twin the focus is less around the thermal aspect of the prosumer under study and more around the energy production and storage devices present in the system as well as a more detailed understanding of the human impact. As such the occupancy of the building is recorded and statistical methods implemented to model the flow of people at any time. On the technical aspect, care is taken to accurately model the different devices, like the batteries and solar panels, with the objective of having a digital twin that is useful not only for offline testing of prospective scenarios but of real-time capabilities, running in parallel of its physical counterpart for the purpose of virtual sensing, insight in predictive maintenance or implementation of improved control mechanisms.

3.2.2.1. Final objective

The idea for this model is to accurately represent the impact different factors and devices have on a prosumer system, from conventional energy devices, like solar panels, to new technologies like hydrogen, to social interactions which are rarely considered in technical analysis but are ultimately what drives most of the activities in a system, and even if not all factors can be identified or be properly accounted for, at least it is possible to reduce the uncertainty caused by the presence of humans and contribute little steps into considering them as parts of the environments we live in and we model.

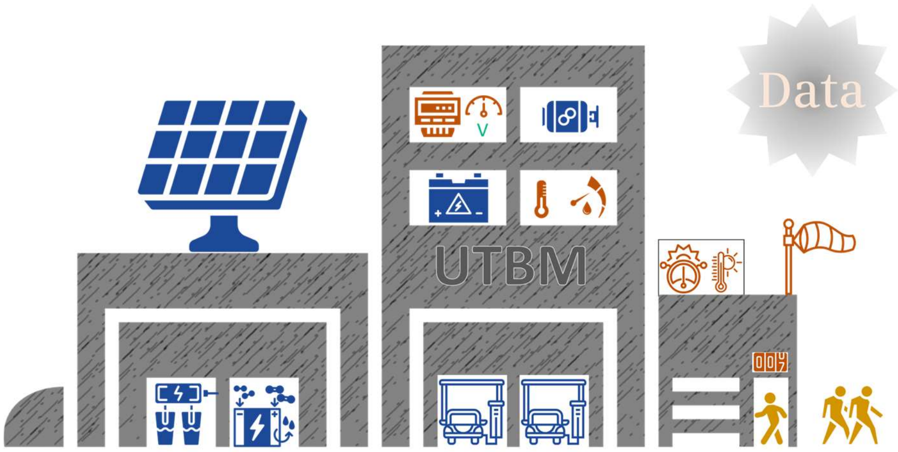

Figure 13 Diagram of considered devices and elements for the digital twin

3.2.2.2. Inputs

To ensure the availability and accuracy of the inputs used for this model, all data is gathered in situ. A weather station feeds the environmental conditions of the building's location every minute, and there is the access information for the entrance doors to the building which indicate the entrance of people into the building. There are also technical measurements on diverse equipment, like hydrogen production from the electrolyser and hydrogen drier as well as the energy production from the solar panel. For the final version of the model the electric consumption of these devices will be obtained as well as for the entire building and the electric vehicle charging stations.

- Building access information
  Every time someone uses its badge to enter the building a registry is created with the time of access and the door used, allowing to discriminate between entrance through the parking lot or from the street. The information gathered is completely anonymised and no personal information is gathered for this purpose.
  With the access information a schedule is created for each subject, since the badge is only needed at the entrance it is not possible to know the time of exit of any individual, but here is where social factors can be used to develop a strategy that provides the statistics needed to complement the occupancy model.
- Weather station information
  The weather station provides with high-quality, high-resolution measurements of the state of the weather at the location, as before variables like the temperature, heat index, wind chill, humidity, solar irradiance are gathered and processed to be used as inputs to the overall model.

- Hydrogen production data
  Despite the power measuring devices are yet to be activated, the hydrogen production devices have measurement of the variables of the hydrogen part, i.e. pressure, production, temperature, as well as of the electric consumption, i.e. voltage, current and power.
- PV panel energy output
  Not only is the environmental data available but now also the energy production measured by the panel as well. This has the benefit of allowing for the identification of problems if we notice that the efficiency has a sudden drop, possibly signalling a fault in the device. It will also allow to consider health monitoring and possibly even trigger a signal prompting the user to clean the panel or perform other maintenance tasks.

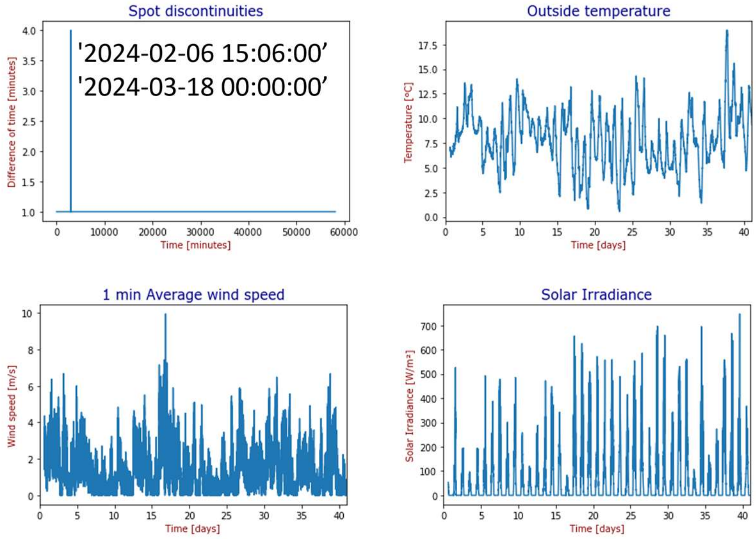

Figure 14 Processing of weather data with 4 min gap (interpolated)

3.2.2.3. Occupancy model

As mentioned before an occupancy model needs to be implemented to make sense of the data from the building access. For this the following tasks were done:

- The database was analysed to get the date range and the number of individuals recorded.
- For each individual a schedule was created marking the minutes in a day when an access through a door was recorded.
- A set of social factors influenced by the specific conditions of the system, e.g. opening and closing times, as well as by the behaviour of the society in that location, e.g. lunch time, lunch time duration, and variations in these times, are considered to synthesize and complete the schedule. The selected factors are:
  - Lunch time: hour at which lunch is usually had.
  - Lunch time duration.
  - Lunch time duration standard deviation.
  - Exit time: time at which people usually leave the office.
  - Exit time standard deviation.
  - Short exit duration: for how long people absent themselves when they leave the office during the day.
  - Short exit standard deviation.
  - Closing time on weekdays.
  - Closing time on Saturday.
- A set of tags are defined to characterize different patterns during a day. These are:
  - Morning entrance (before lunch)
  - Late entrance (after lunch)
  - Absent
- A secondary set of tags are defined to account for common characteristics like:
  - Lunch break: if there is an entrance recorded that fits with the characteristics of being a person returning to the office or laboratory after leaving for a lunch break.
  - Extra exits: if there are entrances recorded other than the lunch break or that do not match with a possible exit for a lunch break.
- For each person, for each day, the set of tags gets assigned.

- Based on the tags set, for each person, for each day an occupancy schedule is built. This is a binary record of the person being present in the building at any given minute is created. Access times are always respected as they are reliable input data, exits are stochastically modelled considering the tags and the social factors input before.
- Finally, all schedules are added to obtain the occupancy of the building.

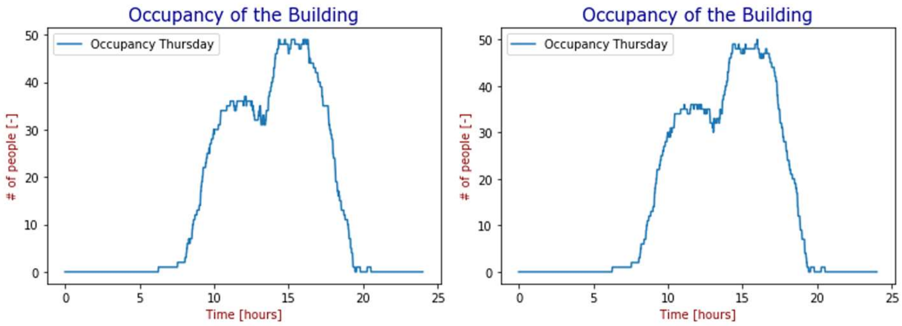

Figure 15 Impact of the randomness in the simulation.

Not having the real exit data could be seen as a problem but as shown above the overall behaviour is greatly preserved which is a good sign that the information that will be input to the system represent the ground truth.

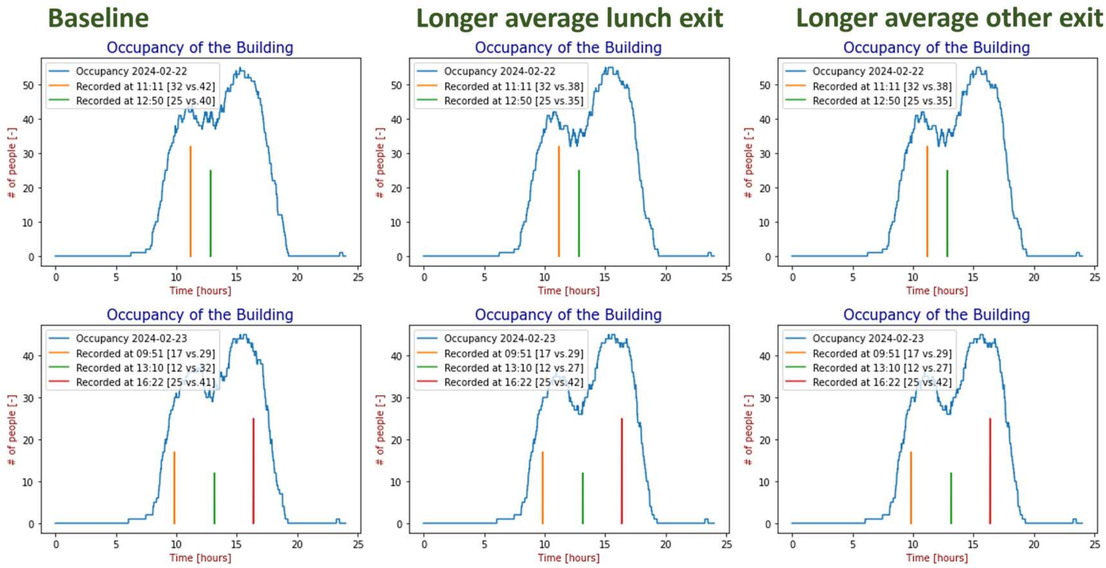

Figure 16 Modelled occupancy with different parameters vs. subjective observations

To get an idea of the accuracy of the model developed with the building access data some quick visual inspections of the apparent occupancy of the building were performed and what can be observed by varying the assumed social factors is that some have a larger impact than others, for example considering a larger lunch break lead to an occupancy that most closely resembled that which was observed in person, on the other hand a variation in the intermediate exits had little effect.

3.2.2.4. Device models

- Solar Photovoltaic
  An LG solar panel is installed on the site so a model of the device was developed to be part of the digital twin, using the techniques studied during the doctoral schools of the SMARTGYSUM programme. The model is based on the specification sheet of the device and will serve as a baseline to estimate the health of the physical system and determine the consistency in its operation

SMARTGYSUM project has been funded by the European Commission's Horizon 2020 Programme

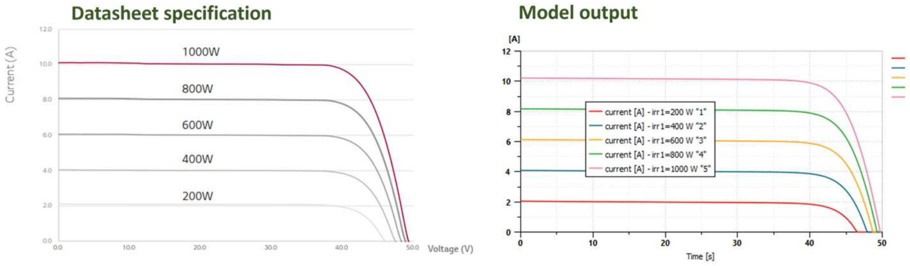

Figure 17 Simcenter Amesim model of the PV system

The specified Maximum Power Point voltage is of 41.5 [V] with a current of 9.65 [A], one of 41.65 [V] and 9.62 [A] was achieved. As for the thermal characteristics a power output of 493 [W] and 306 [W] is expected for a temperature of -40 [°C] and 90 [°C] respectively and it was achieved to be 488 [W] and 313 [W].
A possible next step on this aspect could be the characterization of the solar panel based on its measured output, but since losses from the inverter are part of the measurements the model would not really end up being of the PV panel but of the whole system itself.

- Battery
  Similarly for the battery system a model based on its specification was created and its behaviour was matched to the one described for the maximum discharge rate and the open circuit voltage of the battery when discharged. By using Simcenter Amesim Precalibrated model for a lithium iron phosphate battery this task was straightforward, and the result matches the one defined by the datasheet.

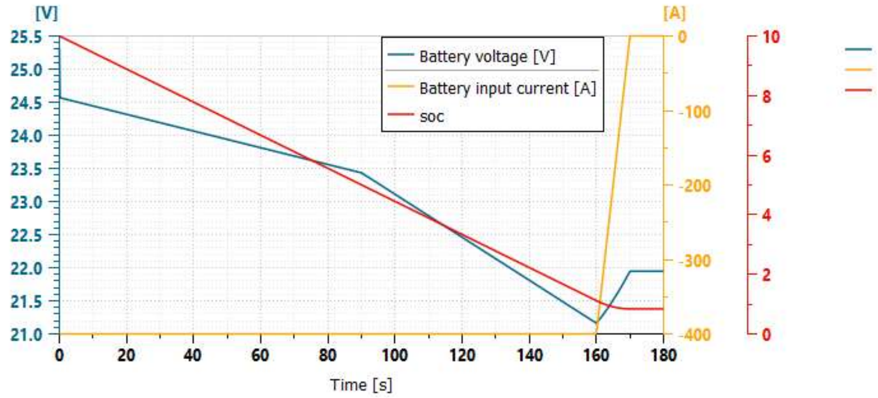

Figure 18 Behaviour of the battery model discharging and discharged.

The datasheet specifies for this model of a 25.6 [V] / 200 [Ah] Smart Victron LFP battery a maximum discharge current of 400 [A] with a discharged voltage of 22 [V], which is what was observed in the simulation.

3.2.2.5. Preliminary tests

Initial models have been implemented to see the interactions between the different components, especially on the electric side tests have been developed and the structure of the network considered.
As more devices and their data come online the model will grow larger and more complex and complete with the intention of observing the state of the system in its current state but also as shown below to test prospective configurations that could provide new research opportunities in the laboratory like, connecting the fuel cell into the electric grid so that the energy produced gets used to offset the building's consumption, or to install a DC bus for the components that actually require or produce electricity in DC to avoid the redundant inverters and replace them for a single inverter at the point where it connects to the AC grid.

SMARTGYSUM project has been funded by the European Commission's Horizon 2020 Programme

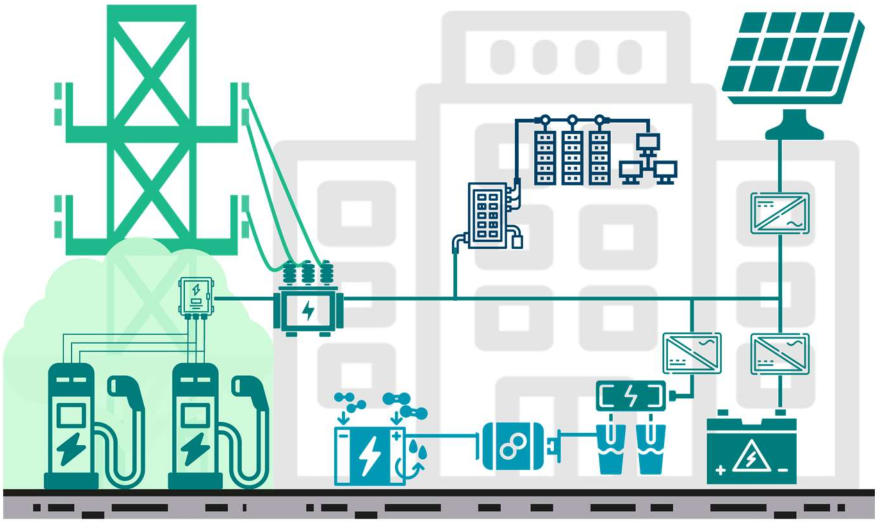

Figure 19 Electric and Hydrogen topology of the system in its current state

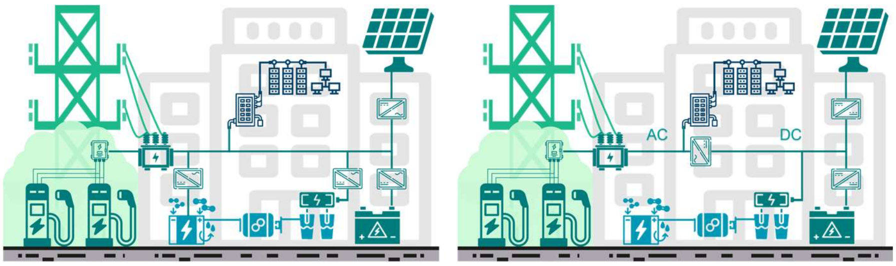

Figure 20 Prospective changes to use hydrogen as energy storage or implement a DC Grid

3.3. Contribution to the WP objectives

WP5 is dedicated to facilitating and coordinating research and the application of business models within collaborative renewable energy systems, microgrids, and energy management. Its primary goal is to showcase the advantages of technologies developed in WP2, WP3, and WP4 by devising cohesive strategies and offering policy recommendations aimed at transforming energy systems. This document contains a report focusing on "Generation of digital twins of prosumers using socioeconomical factors and big data for Optimization of Customer's bill savings" under Task 5.2.

The digital twins developed for this task directly contribute to improving the set of tools and techniques available to model Multiphysics systems taking into consideration multiple factors which is useful when complex decision have to be made regarding energy projects, so having the ability to prove the economic viability of a proposal can quickly improve the savings from developers while guarantying clients of the expected performance of the final system.

Therefore, the key contribution of this deliverable to Smartgysum's WP5 and other WPs can be summarised into the following three main areas:

- Design synergic strategies
  Through the development of models that interconnect different devices from different fields the work developed in this project serves as an aggregator of the work and research from areas like power electronics, renewable energy systems, hydrogen production and energy generation from it and sensor data manipulation.
  It also considers non-technical inputs like social and economic factors and parameters that allow to analyse not only the technical performance of these devices but also their economic performance and their impact in comfort for people and inversely the impact people have on the technical behaviour of the system. Therefore, Digital Twins can effectively support investment decisions and business models design, consistently with the main objectives of WP5.
- Collaborative operation of renewable systems
  It also integrates well with the work developed by other ESR's as it modelling prosumers relates to End-user energy from Work Package 4. The small-scale structure of the energy grids formed by the devices that form

SMARTGYSUM project has been funded by the European Commission's Horizon 2020 Programme

part of the system also relate to the work on Microgrids from Work Package 3 and finally, some of the proposed scenarios tested involve the use of renewable energy systems and storage methods including the innovative fire-emergency tank as thermal storage which goes in line with the objective from Work Package 2 on Green Generation and Storage.

- Connection with ESRs
  The most direct connection of this work with that of other ESRs from the project is probably with the topic of Strategy testing toward NZEB developed by ESR 12. All the models developed go in line with reduction and offset of energy consumption and allow for NZEB strategies to be tested and validated before deployment.

SMARTGYSUM project has been funded by the European Commission's Horizon 2020 Programme

4. Conclusions

Within IRP 13, two digital twins were developed for prosumer buildings and validated with data measured directly at the site. This deliverable shows the steps and methods used for the development of the model and describes the different elements of the physical system and its digital counterpart. Work had been carried out beforehand in the development of the necessary elements to incorporate other factors like the interactions with the grid and occupancy and were incorporated successfully in these models with a promising outlook for their usefulness in making our simulations and tests completer and more accurate.

The work developed for this deliverable contributes to the field of physical modelling of energy related systems by incorporating in the same tool power flow analysis capabilities, environmental inputs, economic signals, technical characteristics of Multiphysics systems and the complex interactions between heterogeneous components and perhaps most importantly techniques and hints on how to better account for the impact of all these factors on people and the impact of people's behaviour in the system itself, helping in this way to reduce uncertainties.

The models presented will allow the readers of these and its derived materials to have a systematic method of digital twin designing and some background information of the challenges they may face when developing one. The work developed here also opens multiple research paths, like for example the implementation of a synthesiser for occupancy on different building types based on the statistics derived from observations, the input parameters, and social factors.

The development and validation of digital twins is a useful tool to streamline the testing of novel ideas without the burden of cost and implementation of the idea to prove its feasibility. With a Digital Twin one is able to prove the economic benefit, the social acceptability and technical soundness of an idea before any change is done to a system. It is important to consider that a Model like the ones developed here is only as good as the quality of the data used to create it and validate it which highlights the importance of recollecting and organizing properly the operation information of a system. Data remains important outside the fields of social networks and machine learning, more traditional modelling methods still benefit and require plentiful and accurate data.

Though technically relevant or even environmentally beneficial, some proposals find themselves shelved indefinitely due to a lack of economic incentives or evidence of economic improvements in its operation or lifetime cycle costs. By implementing digital twins and including in its design social and economic factors and account for them as inputs of the system, it is possible to construct convincing scenarios that demonstrate the profitability of certain actions and the conditions under which they work. They also allow to develop in parallel ancillary services, like the control that would be required as it can be tested with the digital twin and be improved just as the real system is being constructed.

5. References

1. Weather station 22B/01C data for Monte da Caparica, Tejo, Sistema Nacional de Informação de Recursos Hídricos, available trough: https://snirh.apambiente.pt
2. Regulamento Geral de Higiene e Segurança do Trabalho nos Estabelecimentos Comerciais, de Escritório e Serviços, CAPÍTULO III - Condições especiais dos locais de trabalho, SECÇÃO II - Condições de temperatura e humidade, Artigo 11.° - (Temperatura e humidade)
3. Temperature in the Workplace, Temperature Guidance, Health and Safety Executive, consulted 2024-04, https://www.hse.gov.uk/temperature/employer/index.htm
4. "Multi-factor modelling of electric grids for social and technical impact studies," R. Marentes-Ortiz, F. Sellier, F. Gao, J. Martins and Y. Curci, 2023 IEEE 17th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG), Tallinn, Estonia, 2023, pp. 1-6, doi: 10.1109/CPE-POWERENG58103.2023.10227407