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Prescient building Operation utilizing Real Time data for Energy Dynamic Optimization

WP7 – Demonstrations in operational environment

D7.1– Demo site #1 Switzerland

Version 1.0

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PRELUDE KEY FACTS

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	Participant organisation name	Country
1	AALBORG UNIVERSITET	DK
2	TAMPEREEN KORKEAKOULUSAATIO SR	FI
3	ASOCIACIÓN DE INVESTIGACIÓN METALÚRGICA DEL NOROESTE	ES
4	POLITECNICO DI TORINO	IT
5	FORSCHUNG BURGENLAND GMBH	AT
6	UNISMART - FONDAZIONE UNIVERSITÀ DEGLI STUDI DI PADOVA	IT
7	BRUNEL UNIVERSITY LONDON	UK
8	EMTECH DIASTIMIKI MONOPROSOPI IDIOTIKI ETAIREIA	EL
9	CORE INNOVATION AND TECHNOLOGY OE	EL
10	ESTIA SA	CH
11	EUROCORE CONSULTING	BE
12	IREN SMART SOLUTIONS SPA	IT
13	LIBRA AI TECHNOLOGIES PRIVATE IDIOTIKI KEFALAIOUCHIKI ETAIREIA	EL
14	STAM SRL	IT
15	LA SIA SRL	IT
16	TREE TECHNOLOGY SA	ES
17	1A INGENIEROS S.L.P	ES
18	DIMOS ATHINAION EPICHEIRISI MICHANOGRAFISIS	EL
19	BLOK ARCHITEKCI SPOLKA Z OGRANICZONA ODPOWIEDZIALNOSCIA	PL
20	CAISSE DE PREVOYANCE DE L'ETAT DE GENEVE	CH
21	INNOVACION Y CONSULTING TECNOLOGICOSL	ES
22	CORE INNOVATION CENTER NPO	GR

EXECUTIVE SUMMARY

In the present deliverable, the Swiss case study, located in Avenue de Wendt 35, is described. From its refurbishment project to the implementation of PRELUDE technologies and the performance of its technical installations. At first, the building refurbishment project and its objectives are described. The new technical installations are described, like the possibility to use the last two storeys floor-heating system as the heat source for the heat pump in summer. The extensive monitoring of the technical installations is then described. Limitations in the user engagement and failure to obtain GDPR consent for more than 2 appartements lead to a serious loss of data regarding indoor environment quality and heat consumption of individual apartments.

The compatibility with the different PRELUDE foreseen solutions is discussed and their implementation and results are described. Interesting results already available come from the indoor-outdoor corelation module of a selected appartement (82) and results regarding the PV system performed by TAU in the context of VRE community development.

In addition, the extensive monitoring of the building and of its technical installations allowed ESTIA to conduct some analysis of the overall performance of the building and of its technical installations. The refurbishment project itself is a success as final energy consumption for heating and Domestic hot water was reduced to 64 kWh/m^2. However, the energy dedicated to DHW is higher than expected. An extra monitoring device was used to corroborate the initial results. In addition, some systems can be further optimized, like the number of ignitions of the gas burner. Further results from implemented technologies are expected in the coming year and will be described in the Deliverable 7.7.

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ABBREVIATIONS

BESS	Battery energy storage system
DSS	Decision support system
ERA	Heated floor area. Used to normalize the building consumption by its size
CoV	Change of value
DHW	Domestic hot water
GDPR	General data protection regulation
GUI	Graphical user interface
HP	Heat pump
IEQ	Indoor environment quality
M&V	Measurement and verification
PV	Photovoltaic
RCP	Regroupement de consommation propre (self consumption regroupment)
RES	Renewable Energy Source
SH	Space Heating
VRE	Variable Renewable Energy

Introduction

In 2019 the European Union (EU) set the objectives of reducing its Greenhouse Gas (GHG) emissions by 50% by 2030 - compared with 1990 levels - and achieving carbon neutrality by 2050 [1]. Energy use in buildings accounts for approximately 17.5% of total GHG emissions [2]. In addition to the objective of reducing GHG emissions, the Russian invasion of Ukraine and its consequent spike in energy prices, have added to the economic and political motivations to improve the energy efficiency of buildings.

In 2019, buildings accounted for 43% of the EU final energy consumption and 25% was due to residential buildings [3]. There is , therefore, no doubt that buildings have to reduce their emissions in order to meet the objectives stated above. The market currently proposes several solutions to reduce energy consumption in buildings , which mainly consists of implementing Renewable Energy Sources (RES), improving the insulation, and upgrading technical installations. PRELUDE aims to develop and test new technologies to optimize the use of these solutions while taking into consideration the economic aspects as well as feedback from users. Therefore, the developed technologies span from choice and optimization of RES, models to predict a buildings' energy needs and behaviors, as well as solutions to assess the costs of refurbishments. Furthermore, it is necessary that the solutions provided are scalable to the EU's residential building stock as a whole [4].

The technologies developed by PRELUDE partners have to be tested in a real building environment. Several buildings throughout Europe have therefore been equipped with sensors to ensure adequate monitoring of the effects of the technologies developed by PRELUDE. One of these buildings is in Geneva, in Av. Wendt 35. This report aims to meet the goals of task 7.2 of PRELUDE which includes an assessment of the building performance and performance gap, a verification of the performance of the RES installation, the technical installation, as well as an assessment of the indoor environment quality. Finally, based on the discussions with other PRELUDE partners, the implementation of their technologies within Wendt 35 will be discussed.

1 Objectives of the building

The Wendt 35 building was built in the early sixties and had not been renovated before the recent works. The question of its energy footprint arose, provoking a general reflection on the building. The addition of an extra storey to the building was proposed but since Wendt 35 is part of a homogeneous block, contact with the neighbouring landowner was required to resolve objections to the increase of the buildings height.

In order to respect the quality of the original façade, it was decided to keep a plastered cladding over the rock wool insulation. Furthermore, the layout of Wendt Avenue did not call for an intervention that would create a decontextualized object. The elevation is therefore in keeping with the continuity of the existing building, but with a more contemporary variation of openings.

Additionally to the architectural aspect, the news of the PRELUDE project pushed the CPEG (the building owner) to implement innovative technologies regarding the technical installations. The idea was to be a test building regarding multiple technological installations and development:

- Installation of PV system
- HP with both exhaust air and floors as heat source
- Direct feed-back regulation

Within PRELUDE, the defined KPI's for the buildings are the following:

- Reduction of the Maintenance and Repair costs to 510€/a per occupant
- Final consumption of the building: 111.60 kWh/m^2·a
- Annual overheating hours < 3%
- Metabolic CO_2 <1000 ppm
- RES as example (PV dimension and battery associated)

1.1 State of the case study prior to the refurbishment

The buildings envelope was of low performance. The following table resumes the envelope's thermal performance prior and after refurbishment.

Envelope element	Performance before refurbishment [W/m^2·K]	Performance after refurbishment [W/m^2·K]
Wall	1.4	0.16
Roof	0.4	0.17
Floor	3.4	2.6
Window	3.0	1.0
Door	3.0	1.9

Table 1: Thermal performance of elements

The initial elements of the building envelop were dating from 1962 and were obsolete regarding their thermal resistance and U values.

Figure 1: Wendt 35 before its refurbishment

The building was heated with radiators by a gas heater dating from 1993 with nominal power of 250 kW. The average consumption of gas for the years 2017-2019 is 450'000 kWh meaning 172 kWh/m^2 of final energy for both space heating (SH) and domestic hot water (DHW).

2 Building characteristics and monitoring plan

2.1 Building's plans and refurbishment

The building is located on Av. Wendt 35, in Geneva's urban district. It's a multifamily housing with 56 apartments. The building was originally built in 1962 and its refurbishment was completed in 2021. During the refurbishment the following actions took place:

- raising the building of two floors
- insulation of the roof
- insulation of the walls
- installation of PV panels with a battery
- renovation of the technical installations
- change of the windows for triple glazing
- change of ventilation system

The building after the refurbishment has an Energy Reference Area (ERA) of 3502 m^2, 2717 m^2 corresponding to the renewed floors, and 785 m^2 to the new ones. In Figure 2, on the left, it is possible to observe the south-eastern facade of the building, where the entrance is located, while on the right, is the cadastral plan of the area where the building is located.

Refurbished floors have the same characteristics as in Figure 3, with the exception of the ground floor in Figure 4. The new floors (7th and 8th) are shown in Figure 5. It is important to observe that the apartment density on the refurbished floors is higher than on the new ones with seven apartments per floor versus five.

Figure 2: On the left: Picture of the south-eastern façade. On the right : Cadastral plan of the Wendt avenue

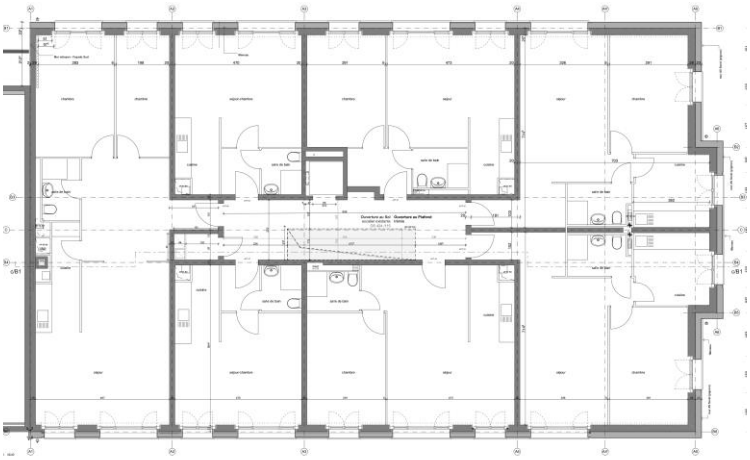

Figure 3: Plan of the 6th floor (refurbished)

Figure 4: Plan of the ground floor

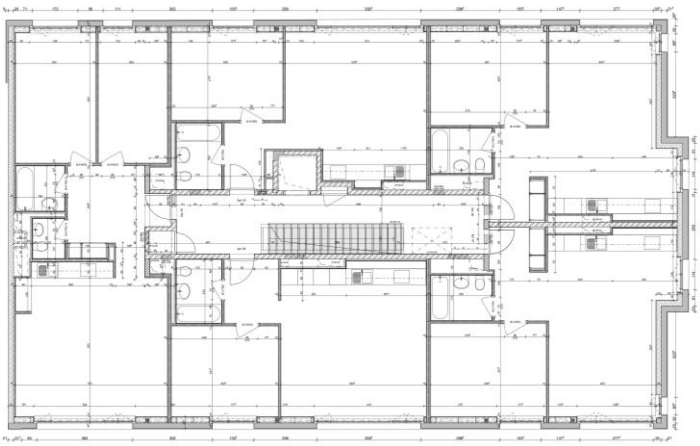

Figure 5: Plan of the 7th floor (new)

2.2 Description of technical installations

During the refurbishment, all technical installations have been updated with state of-the-art installations. Heat for domestic hot water (DHW) and space heating is produced by a water-water heat-pump (HP) and by a gas heater. In Figure 6 it is possible to observe a diagram of the heat fluxes from the heat sources to the utilities. The following sections will detail the technical installations.

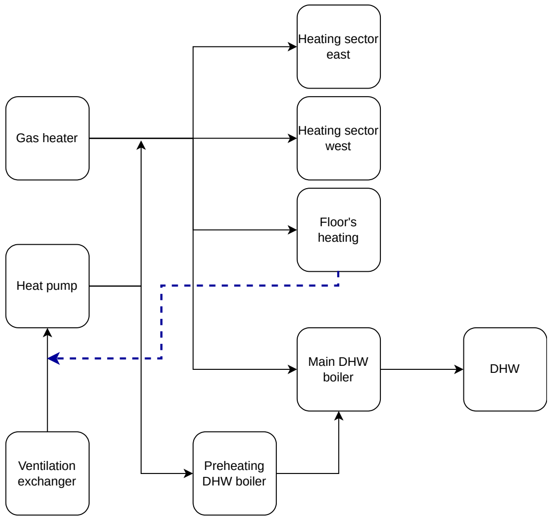

Figure 6: Diagram of the heat flux in Wendt 35 technical installations.

2.2.1 Heating and DHW

The heat produced by the heater and the HP flows into three different circuits for space heating. Two of them flow through the radiators of the refurbished floors, one on the west and one on the east side. Due to a lack of historical information, it is not possible to precisely determine which radiator is connected to which sector of the heating. The third circuit flows through the floor's heating in the new storeys.

The DHW is stored in two 1'500 liters boilers. The first one, the preheating boiler, is connected to the HP, while the other, the main boiler, is connected to the heater. The water flows from the main boiler through the building, then the circulation comes back to the main boiler. Cold water can be added to both boilers directly. In order to ensure temperature homogeneity between the two boilers, a pump is used to mix the water between the two.

2.2.2 Ventilation and heat-exchange for the heat pump

The building's ventilation system is hygro-regulated. The mechanical extraction on the roof, and the hygro-regulated outlets and inlets are the main components of the system. The inlets are in the window frames and autonomously open and close themselves in function of the difference of relative humidity between the room and outside. This reduces the need for the users to open the windows and ensures sufficient air quality. The outlets are placed in the wet rooms (bathrooms and kitchen) and are connected to the mechanical extraction that is installed on the roof. The extraction also serves as the HP cold source. An air-water heat exchanger is installed in the extraction system. This heat exchanger takes an important part of the roof space as seen in Figure 7.

Figure 7: Picture of the roof. The available space is shared between the ventilation extraction and the PV panels.

2.2.3 Free-cooling

During the warm season, it is possible to invert the heating system of the new apartments. The floor heating circuit can be used as the cold source for the HP for the DHW production. This allows the use of the apartments as a cold source instead of using ventilation. The process is represented by the blue dotted line in Figure 7. It will be determined if this system increases electricity consumption.

2.3 PV installations and expected performances

On the roof surface that is not used for the ventilation extraction are installed 62 PV panels. The installation is set to produce 21.1 kWp at its power picks. Furthermore, a battery is also installed in the basement to increase the self-consumption of the installation. It has a capacity of 20 kWh and a charging and discharging power of 5 kW. The simulations of the provider estimated a self-consumption of 80%.

It must be underlined that the PV installation does not power the whole building, but only the technical installations, the common areas, and the 2 new floors. The refurbished floors are connected only to the energy distribution network. The new floors form a self-consumption association (or "regroupement de consommation propre", RCP) [5].

In financial terms, the cost of the whole PV installation was about 50’000 CHF. The provider estimated that the investment would be profitable after 11 years. This included 8’000 CHF funding for the battery, 8’315 CHF of taxes reductions, and 600 CHF or yearly expenses for maintenance [10].

2.4 Sensors installation

As PRELUDE case study, several sensors have been installed in the building to monitor the Internal Environmental Quality (IEQ) and the performances of the technical installations.

2.4.1 IEQ monitoring

The IEQ monitoring is only available for the new 2 floors through FusiX.

The IEQ monitoring of the new floors is extensive and is operational since 2022 depending on the sensors. These sensors are provided by Service Plus Energies. The following measurement points are installed:

- 22 measures of temperature and relative humidity: Available since February 2022.
- 8 measures of CO_2: Available since April 2022.
- 10 measures of the apartment consumption for heating and cooling (one per apartment on the new floors): Available since February 2022.

Atthe same time as the 8 CO_2 sensors were installed on the new floor, 3 more were installed on the refurbished floors. Therefore, some CO_2 data was also measured in the older part of the building but cannot be recognized because of GDPR issues.

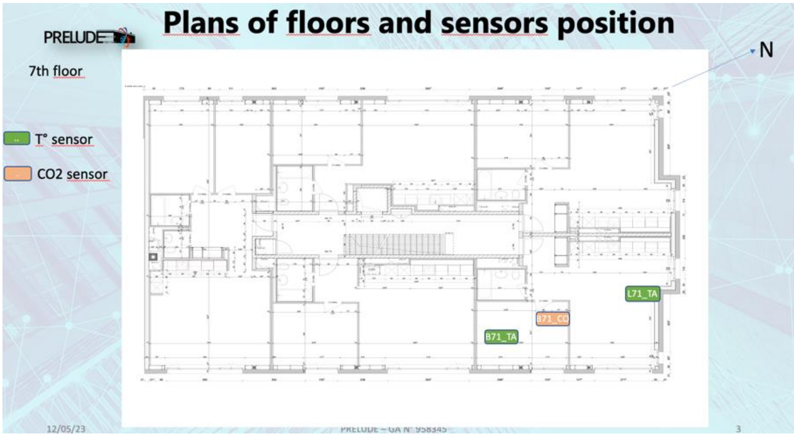

Figure 8: Monitoring plan of the 7th floor. Many more sensors are present but are anonymized due to GDPR constraints.

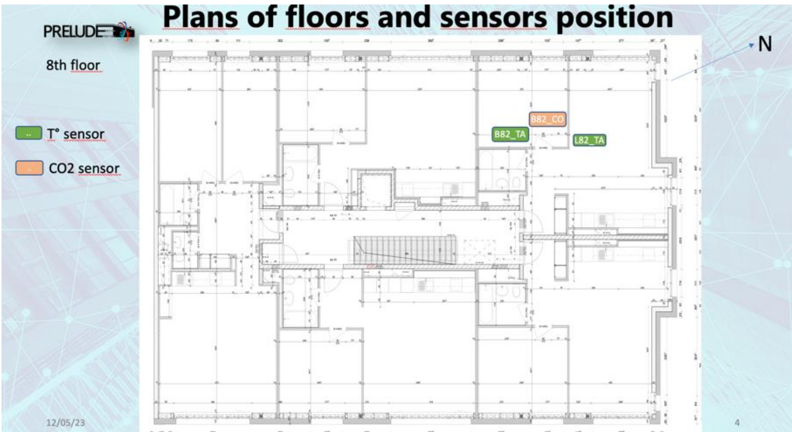

Figure 9: Monitoring plan of the 8th floor. Many more sensors are present but are anonymized due to GDPR constraints.

It is important to notice that a measure of temperature and relative humidity is available in all the rooms in the 2 last floors apartments. Due to GDPR constraints, only 2 apartments are available without anonymization of the data. These 2 apartments are number 71 and 82.

2.4.2 Monitoring of technical installations

The monitoring of the technical installation is composed of about 150 sensors, provided by Service Plus Energies, that monitor the following quantities:

- Heat flows
- Temperatures
- Pressure
- Electric consumption
- Electric flows
- Status of the HP and the burner
- Gas counter

In general, it is possible to monitor the energy flux between all sub-systems and the temperature of the main conduits. These data also allow computing the performance of the different sub-systems, such as the HP, the burner, and the DHW circuit.

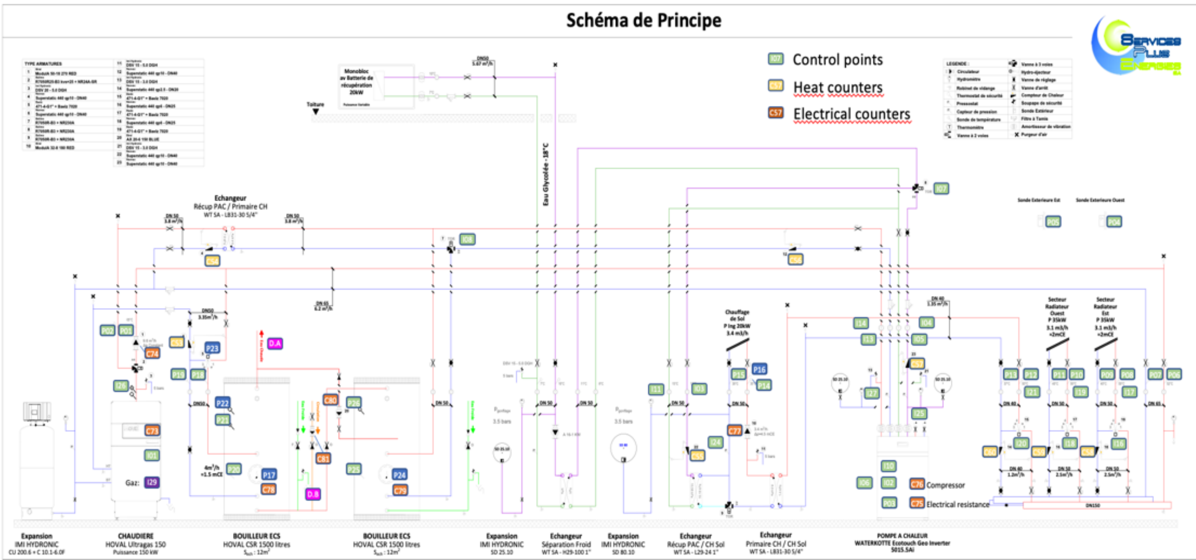

Figure 10: Monitoring points of the technical installations.

Regarding Heat counters, the coverage of the system is good and should allow the reconstruction of the heat fluxes. On Figure 11, the position of the heat counters on the heat fluxes scheme is represented.

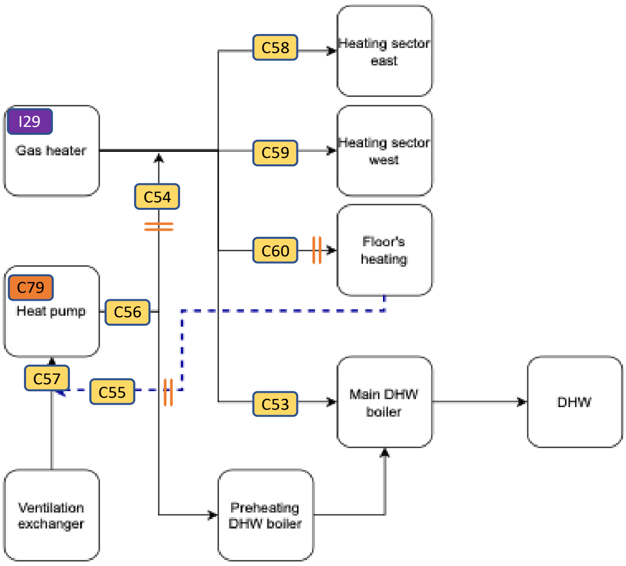

Figure 11: Heat counters position on the heat fluxes. C79 is the HP electrical counter and I29 is the gas counter.

2.5 Data availability

In this subsection, the position of the sensors has been described. Nevertheless, access to these data was not immediate. The main data provider, Service Plus Energies, made its readings available in different formats, which increases the complexity of the analysis. Indeed, before any analysis, it is necessary to standardize the format of the databases and merge them.

The data from Service Plus Energies, are accessible through the FusiX API. FusiX retrieves the data through the API of Service Plus Energie (EVOSPE system). Throughout the first year after commissioning of the case study, multiple problems with the Service Plus Energie's data were observed. Some of them are related to the complexity of the data access as two API are called. Whilst others are from the fact that FusiX is not a finished product, therefore the service is frequently interrupted for development and maintenance reasons. Finally, some problems were directly related to Service Plus Energie's installation. For example, one sensor wasn't correctly wired and reported the readings of another. Furthermore, there are some days when all sensors stopped working. For example, no data is available for five days at the end of June 2022.

In general, the problems with the different sensors have been manually spotted during the analysis of the data that they produced. Based on this experience, it is possible to estimate that between 5% and 10% of all sensors installed had a problem that has been spotted. If a monitoring plan is deployed for a whole building's stock, the reliability of the sensors must be much higher to allow the owner to make appropriate data-based decisions. To cover for this, it would be reasonable to ask the technology provider for a periodic check of both its data and the sensors.

2.6 Data protection

Some of the data collected through the building's monitoring are considered personal data by the European General Data Protection Regulation (GDPR). Indeed, all data which are related to an identified or identifiable natural person are considered personal [11] [12]. This concerns all data on the room's temperature, relative humidity, CO_2, and the heat consumption of the new apartments. The monitoring of the technical installations is not related to any specific user, and therefore not considered as personal data.

The Swiss LPD is less restrictive than the European GDPR. To comply with the LPD it is indeed possible to inform the tenants on how their data will be used. If the tenant doesn't disagree, their data can be analyzed in Switzerland. Since all users have been informed and none opposed the use of their personal data, the IEQ monitoring of the building can be carried out by ESTIA S.A., located in Switzerland, and can be shared with the CPEG, also located in Switzerland.

In order to comply with the GDPR the tenants must give explicit consent, signing a document that details the usage and management of their data and another consent to that use. Therefore, it wasn't possible to share this data with the European partners of PRELUDE. For this reason, ESTIA S.A. visited three apartments to get the consent of the tenants to use their data. Two of them agreed. At the end of the process, the IEQ data of two new apartments are available to the PRELUDE partners, while all other data are anonymized.

It is important to underline that these data protection issues came up after the deployment of the building's monitoring and its connection to the FusiX API. Therefore, for about a year, all partners of PRELUDE had access to personal data in violation of the GDPR. Data protection issues must be anticipated and duly treated prior to the deployment of the monitoring. Since data protection regulations are unlikely to be weakened, future projects of a monitoring plan at the scale of a building's stock must carefully include data protection aspects.

3 Planning of project solutions

3.1 Implementation of PRELUDE technologies

The report describes activities carried out in the demonstration cases considering motivation and reasons to implement/not implement PRELUDE solutions. The PRELUDE solution is modular and therefore allows for application of only required and relevant technologies. The following list addresses each PRELUDE technology on whether it is suited for the Geneva case study or not.

FusiX integration – Implemented. Connection to FusiX middleware is essential for interoperability of the technologies and access to the buildings data for the different technology providers. Connection is however only one way. In fact, no technological solution on the demo site of Geneva is recovering information from FusiX. The use of a technology provider as intermediate for the implementation and communication of the sensor will make it difficult to implement communication from FusiX to the building at the time being.

Dynamic Free Running enhancement by PREDYCE – Not implemented. No dynamic EnergyPlus model was produced to allow for a PREDYCE integration.

Indoor-outdoor correlation module – Implemented. The indoor-outdoor correlation module predicts hourly internal environmental conditions from ambient climatic conditions by investigating the relationships between indoor and outdoor conditions in a building for its thermal comfort, indoor air quality and lighting. Even though Wendt is not naturally ventilated, the early availability of its data made it an interesting case study for the indoor-outdoor correlation model. The early results of BUL's work are available in Section 5.1.1.

Weather and insolation prediction model- Implemented. CORE's module depends on available weather data and not on the building's data. They developed a model for each case study location, including Geneva. The results are available in Deliverable D3.1.

Occupancy model – Not implemented. The lack of GDPR compliant tenants makes the occupancy model difficult to implement. In addition, no monitoring of the real occupation of the studied apartments is made. Therefore, Wendt is not prioritized as a demonstration site for this technology.

District heating integration module – Not implemented. No district heating data are available for the neighboring of the case study. The study will mainly focus on the Aalborg municipality and its district heating network.

VRE community – Implemented. The installation of PV panels with a battery on the building, prior to the start of the project, makes the Geneva case an interesting source of data to test TAU's model. The results of the research will be available in Deliverable D5.2.

Renovation roadmap and EPIQR analysis – Implemented. The refurbishment costs and optimization operations executed on the building are used as verification of the EPIQR cost database. In addition, the building will be used as a test for the renovation roadmap coming tool. The building will be coded in its state prior refurbishment and the tool's output will be analyzed in comparison with the refurbishment project and its performance.

Dynamic energy forecasting – Not implemented. The energy balance forecasting was developed using data from two other case studies. No integration in the present case study is foreseen.

Comfort and Energy Efficiency optimizer and customized GUI (STAM) and Data Predictive Control (FB/STAM) - Implementeds. The available data makes it possible to test the solution from STAM on the last two floors of the building. However, the presence of already existing energy efficiency and control measures designed by the building manager can make it difficult to implement the solution once available. This is a considered risk for implementation of the technology in the case study.

Predictive maintenance – Not implemented. No discussion was conducted to implement this technology in the Wendt case study.

Measurement and Verification (M&V) – Implemented. The M&V process focuses on evaluating the energy performance increase before and after refurbishment for the first seven floors of the building. This will allow us to assess the real energy savings of the refurbishment actions. In addition, historical data starting from 2022 would allow M&V verification of any PRELUDE technology implemented on the building in the near future.

Aggregation model (TREE) – Not implemented. The model needs historical data on district heating (DH) energy consumption and none is available for the Geneva district.

To summarize, the solutions implemented or tested on the Geneva case study are the following:

- FusiX integration by EMTECH
- Indoor outdoor correlation module by BUL
- Weather and insolation prediction model by CORE
- VRE community by TAU
- Renovation roadmap and EPIQR analysis by ESTIA
- Data predictive control by STAM
- Measurement and verification by LIBRA

3.2 Technology description and implementation plan

Each technology needs different services, data or access from the building. The needs for each technology, applied to the Geneva case study, are described here.

FusiX integration:

FusiX middleware allows for a centralization of the data processed through and to the building. It is the central point of the PRELUDE solution. Therefore, a connection to the service was a priority. To connect the building through Fusix, an API connection was necessary. Discussions took place with the technology provider of the whole building control and monitoring system to develop an API platform accessible for EMTECH to access the data from the building. Such development on the technology provider's side leads to extra costs that were not planned for in the initial budget. The storage and communication of the datapoints is billed 4'700 CHF per year by the technology provider. In addition, the development of the API for retrieval was billed 1'650 CHF by the technology provider.

Indoor-outdoor correlation module:

The indoor-outdoor correlation module predicts hourly internal environmental conditions from ambient climatic conditions by investigating the relationships between indoor and outdoor conditions in a building for its thermal comfort, indoor air quality and lighting. For this, BUL needs to precisely know the envelope elements of an appartement. In addition, they need to know the level of CO2 in the space, its temperature as well as its ventilation flow.

Weather and insolation prediction model:

The weather prediction model from CORE allows uses artificial neural network to predict different weather parameters for the following 24 to 48 hours. The main predicted parameters are the temperature and insolation. These are useful to simulate the energy needs for the following day. The model didn't need any information regarding the case study except its location. No weather station was installed on the building and therefore, METEOBLUE data was used for the development of the model.

VRE community:

The variable Renewable Energy community technology developed by TAU aims at developing methods to study the impacts of several factors of variable renewable energy (VRE) integration in multi-apartment buildings. The study mainly focuses on PV systems and electricity tariffs in Finland and Geneva in Switzerland. TAU needed data associated with the installed PV system of the case study and its battery. In addition, Overall consumption of the building was needed, as well as electricity tariffs from the electricity provider. Finally, the insolation was also needed for the simulation.

Renovation roadmap and EPIQR analysis:

The Renovation roadmap developed by ESTIA aims at providing guiding rules for refurbishment or optimization of a building to improve its energy efficiency. To do so, it needs a list of information from the building, mainly its envelope performance and its technical energy settings. The renovation roadmap will start from an EPIQR assessment. Such assessment must be performed on the building.

Data Predictive Control:

The DPC technology from STAM aims at controlling the energy input in the building by monitoring the indoor air quality and temperature. It uses a grey box model to train the system with historical data and find the optimum solution for the forecasted weather conditions. The technology is still under development, but the identified requirements are gathered in the following table:

Quantity	Need	Available ?
Space Heating: Measured energy/power	compulsory	Yes
Internal temperature - real	compulsory	Yes
DHW demand	compulsory	No, Standard are used
Energy input for space heating	compulsory	Yes
External temperature	compulsory	Yes, but not via API
PV Energy/power production	compulsory	Yes
Battery Capacity	compulsory	21 kWh according to invoice Min-max= 19kWh
Battery SOC	compulsory	Yes
Battery: Maximum power exchanged	compulsory	5kW from measurements
Energy tariffs	compulsory	Yes but change annually
PV: Maximum power retrievable from the grid	compulsory	35,2 kW
HP : Energy measures	compulsory	Yes
HP : Efficiency (-ies)	compulsory	Yes
HP : Temperature Input	compulsory	Yes
HP : Temperature Output	compulsory	Yes
Gas consumption	compulsory	Yes
Gas heater Efficiency (-ies)	compulsory	Yes
Energy cost	compulsory	0.0969 CHF/kWh
DHW storage : Internal Temperature	compulsory	Yes
DHW Storage Volume	compulsory	2x1'500l

Table 2: Data requirements for data predictive control

Measurement and Verification (M&V):

The M&V framework developed by LIBRA and presented in D4.3, encompasses the M&V methodology and its module. Their focus is to evaluate and quantify the energy savings resulting from the building renovations that took place in 2002, providing valuable insights for energy efficiency improvements. Hence, the M&V 1.0 approaches will be employed, and the module will develop an adjusted baseline model that can predict the energy consumption and track the energy savings on a monthly basis under normal operating conditions and facilitate the quantification and monitoring of the energy savings achieved. The output will be readily accessible upon request through the Graphic User Interface (GUI) environment of the PRELUDE Decision Support System (DSS).

Based on the M&V methodology, the data points selected for calculating the heating energy consumption are defined. Having understood the characteristics of Wendt 35, the available data sources have been analysed. For this to take place, the different sources (as datapoints) per apartment and the whole building (central) from Wendt 35 have been mapped (Figure 12 and Figure 13, respectively). By using the interactive tree map, the datapoints needed for the computation of the heating energy consumption have been identified.

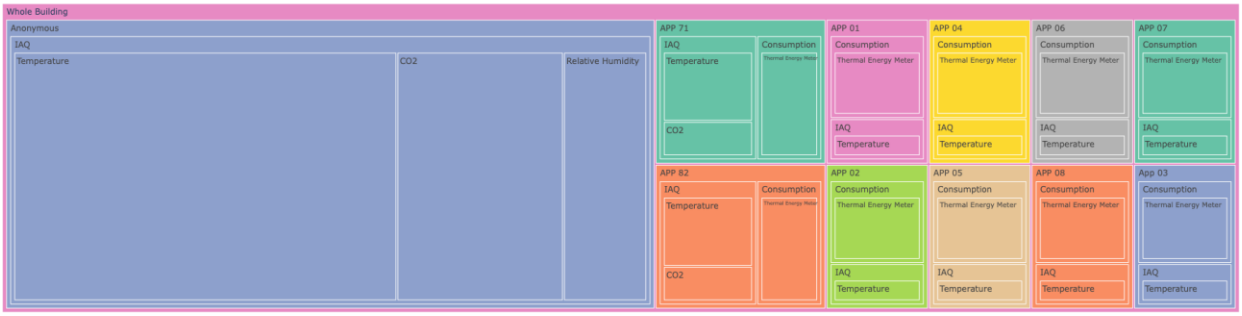

Figure 12: Mapping of the distribution of the devices per apartment in Wendt 35.

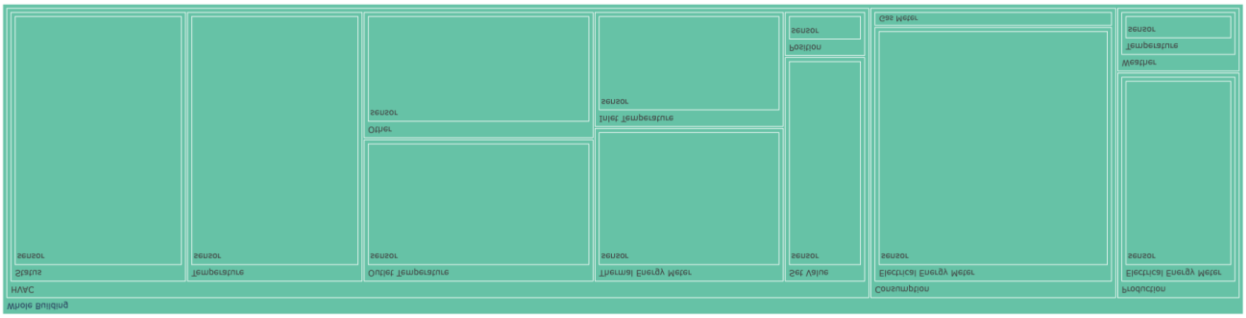

Figure 13: Mapping of the distribution of the central devices in Wendt 35.

The data for the computation of the heating energy consumption originate from the simulated data before the renovation and data from the sensors after the renovation. The calculation of the heating energy consumption before the renovation will be based on the typology of the apartments in the measurement boundary. For the heating energy consumption after the renovation, the input sources considered by the module are the central devices "HVAC thermal energy meters".

The measurement boundary for applying the M&V methodology will be the first 7 floors (old section), which existed prior to the renovation. Since there is no available data from before the renovation, simulation data for heat energy consumption per apartment type will be utilized to calculate the total energy requirements for the baseline and create a simulated adjusted baseline model. The reporting period will encompass the most recent 12 months of accessible monitoring data. This approach aligns with option D (simulation) of the IPMVP methodology. If any additional Energy Conservation Measures (ECMs) are implemented, the M&V methodology will be adjusted accordingly to assess the impact of both ECMs effectively.

Regarding the monitoring data, the datapoints of interest have been selected "*CPTR CHAUD RADIATEURS EST*" (*Existing Heat Radiators East*, **C58***, kWh*) and "*CPTR CHAUD RADIATEURS OUEST*" (*Existing Hot West Radiators*, **C59***, kWh*). The data for the weather conditions, which is used for forming the baseline, originates from Meteostat Python library [8].

4 Implementation of the technologies in the case study

4.1 Installation and integration of sensors and monitoring systems

Most of the technologies are using the monitoring system described in Section 2. However, some specific needs were to be addressed and are described in this subsection.

FusiX integration:

As discussed above, the integration of the existing sensor in FusiX took some effort on the technology provider side. The establishment of the API layer for data transmission took about 2 months to implement. Early June 2022, some defaults were detected in the data transmission. The sensor meant to count the DHW charge by the gas heater (C53) was detected to send the same data as another counter. This was pointed out to the technology provider and corrected. In addition, some misspelling of the original sensor names or abbreviations lead to loss of data.

Overall, the system began to be operative with close to no failure from October 2022.

FusiX connection is established, and the 146 datapoints of the building are accessible to all members of the consortium for their specific needs and developments.

Indoor outdoor correlation model:

The indoor-outdoor correlation module predicts hourly internal environmental conditions from ambient climatic conditions by investigating the relationships between indoor and outdoor conditions in a building for its thermal comfort, indoor air quality and lighting. In Deliverable 3.4 the development of the indoor-outdoor correlation module was presented on how the indoor operative temperature, airflow and illuminance can be predicted if the outdoor dry bulb temperature, wind speed and solar radiation are known. A specific model was developed for two apartments for the Geneva pilot building; these are apartment 71 (southeast facing) and apartment 82 (northwest facing). These apartments are equipped with temperature and CO2 sensors and therefore it is possible to compare the predictions of the climate correlation module with measurements. This section presents the correlation equations and some prediction results for apartment 82 (Figure 14). The scenarios investigated and the envelop properties used for the EnergyPlus simulations are presented in Table 3.

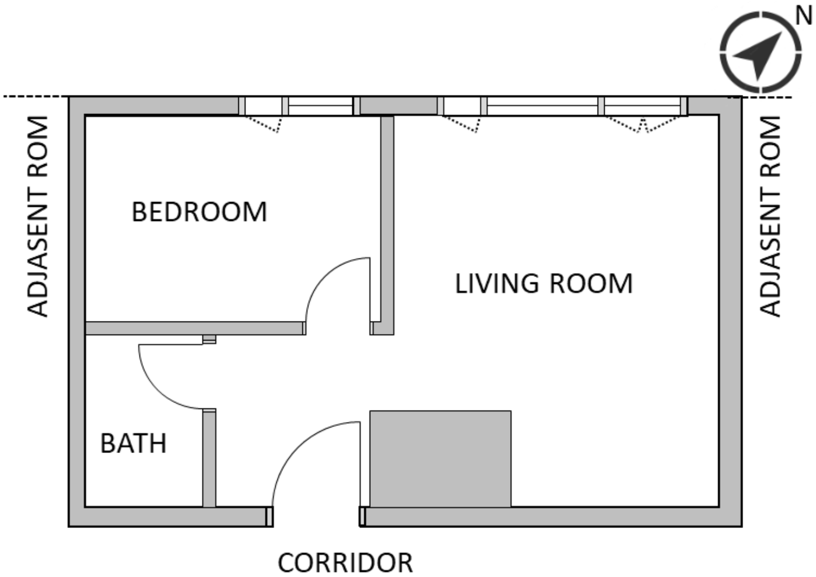

Figure 14: Floor plan of apartment 82 (Geneva pilot building)

Scenario			Category	U-value (W/m^2-K)
1	Window Close, Shading off, Trickle vent off		Roof	0.144
2	Window Close, Shading off, Trickle vent on		Ext. Wall	0.166
3	Window Close, Shading on, Trickle vent on		Party Wall	1.561
4	Window Open 2 hours, Shading on, Trickle vent on		Internal Floor	0.541
5	Window Open 5 hours summer, 2 hours winter, Shading on, Trickle vent on		Window	0.982
6	Window open: Winter 2 hours; Summer: 00:00 to 08:00 and 20:00 to 24:00, Shading on, Trickle vent on		N-W facing, Single Ventilation, 1 occupant Heating Setpoint: 20°C Cooling Setpoint: 26°C Window openable area: 20%	

Table 3: Scenarios simulated, building envelope properties and settings

Data Predictive Control:

A discussion is ongoing to leave control of the heating system to STAM for the Data Predictive Control once it has been developed for the specific case of Geneva. Difficulties might be encountered as the technology provider would need to be a full actor in the process and exchanges with them can be difficult. This will be addressed in the final deliverable of work-package 7 (D7.7).

Other technologies:

As of today, no other implementation needs to be carried out. The case study is generally used for its available data. The lack of end-user interest in the project makes it difficult to implement interactions with them. In addition, the anticipated, extensive and already existing monitoring system of the building allows for the different consortium members to access a vast diversity of data from the building.

4.2 Testing and calibration of systems

The testing and calibration of the monitoring system was performed by the technology provider. However, as described earlier, some sensors were detected to malfunction, sometimes almost 9 months later. In addition, the different sensors had change of value thresholds surprisingly high. As an example, temperature sensors in the rooms had CoV thresholds of 1°C. This exaggerated the stability of the indoor temperature in the apartments and resulted in constant values for long periods, not reflecting the variations of temperature with the presence of inhabitants. This was detected early in the project and corrected at the end of year 2021.

Another issue expressing the lack of verification from the technology providers is the lack of gas counter data during the September 2022 period. The gas counter was initially taped and on the 16th of August it fell off. A visit on site in September allowed us to realize the sensor wasn't in the right position and couldn't count anymore as it is a contact sensor. The counter was then re-installed on the 5th of October. This underlines the lack of surveillance of the overall monitoring system by the technology provider. This was not mentioned in its contract and therefore should be indicated if such monitoring by third parties was to be generalized.

4.3 User engagement strategies

CPEG and Estia worked together to communicate the project principles and implications to the tenants. Despite this communication, the project was not well received. Different reasons can explain this.

First, following the refurbishment commissioning, the tenants filed a complaint about indoor conditions (generally too cold in their perception) at the end of the year 2021. This mail was received by the building manager, and it took time to arrive at the desk of CPEG. By the time, other mails were sent by the tenants to the building manager, decreasing their patience regarding CPEG. A study about indoor comfort was carried out to establish the reason for such cold perception. The number of ventilation inlets per apartment was identified as a potential cause and some of them were shut to reduce the flow of cold air in the apartments.

Following this, the tenants were sensitively keen on exchanging with the owner and Estia. However, as the relationship was difficult, it was decided to only ask consent from tenants with whom Estia had already had close contact during past visits. Following this decision, 3 tenants were contacted personally by Estia during a visit to sign the GDPR consent form. Out of the 3, 2 tenants gave their consent and signed both GDPR form and the information letter.

In a future project involving multi-family housing, a discussion with the tenants should be engaged straight-forward as their implication is finally crucial for the well-being of the project. Luckily, in the present case study, the technical installations are the main interest, and their consent is not needed. However, in the future and seeing the increasing importance of tenant's participation, such assumption won't hold anymore and needs to be corrected.

5 Results and impacts

5.1 Performance of the installed solutions

In this section, the different results from the specific implemented technologies are displayed. As some of them are still under development or testing, results are not available for the whole set of technologies. The final results will be shared in D7.7 about the whole testing process in the case studies.

5.1.1 Indoor-outdoor correlation module

The correlations derived are shown in Table 4 and Table 5.

Scenarios	Correlation Parameters		Coefficient of determination (R^2)		Correlation Equation for Thermal Comfort and Ventilation	
	x = Outdoor	y = indoor	Window Close	Window Open	Window Close	Window Open
1	DBT	OT	0.7023	n/a	$y = -0.0033x^2 + 1.068x + 19.247$	n/a
	WS	ACH	0.7229		$y = 0.0009x^2 + 0.0005x + 0.0284$	
	IVT	ACH	n/a		n/a	
2	DBT	OT	0.7060	n/a	$y = -0.0012x^2 + 0.9594x + 18.896$	n/a
	WS	ACH	0.6426		$y = 0.0013x^2 - 0.0008x + 0.0697$	
	IVT	ACH	n/a		n/a	
3	DBT	OT	0.7083	n/a	$y = -0.0011x^2 + 0.9102x + 19.007$	n/a
	WS	ACH	0.6485		$y = 0.0013x^2 - 0.0008x + 0.0688$	
	IVT	ACH	n/a		n/a	
4	DBT	OT	0.6863	0.8405	$y = 0.0075x^2 + 0.4257x + 17.851$	$y = 0.0059x^2 + 0.5168x + 14.421$
	WS	ACH	0.6337	n/a	$y = 0.0013x^2 + 6E\text{-}05x + 0.0543$	n/a
	IVT	ACH	n/a	0.9749	n/a	$y = -4E+07x^2 + 25702x + 2.4964$
5	DBT	OT	0.6601	0.8832	$y = 0.0084x^2 + 0.2986x + 18.105$	$y = 0.0033x^2 + 0.4776x + 14.52$
	WS	ACH	0.6225	n/a	$y = 0.0014x^2 + 3E\text{-}05x + 0.0529$	n/a
	IVT	ACH	n/a	0.9774	n/a	$y = -8E+07x^2 + 37245x + 1.7477$
6	DBT	OT	0.3047	0.704	$y = 0.0047x^2 + 0.0899x + 20.214$	$y = -0.0043x^2 + 0.7202x + 11.764$
	WS	ACH	0.5978	n/a	$y = 0.0009x^2 + 0.0031x + 0.0277$	n/a
	IVT	ACH	n/a	0.9272	n/a	$y = -1E+08x^2 + 41261x + 1.6779$

DBT: Dry bulb temperature (C) ; WS = Wind speed (m/s); IVT = Invesed of indoor and outdoor temperature differences
OT = Indoor operative temperature (C); ACH = Air change per hour (ach)

Table 4: Correlation Equations for Thermal Comfort and Ventilation

Time	**Coefficient of determination (R^2)**		**Correlation Equation for Daylighting (x = global solar radiation (W/m2); y = zone illuminance (lux))**	
	No Shading	**Blind shading**	**No Shading**	**Internal Blind shading**
05:00	0.9643	0.9513	$y = -0.0052x^2 + 0.9024x + 0.2757$	$y = -0.0004x^2 + 0.073x + 0.0271$
06:00	0.9000	0.8991	$y = -0.0009x^2 + 0.7794x + 2.7103$	$y = -7E\text{-}05x^2 + 0.0682x + 0.27$
07:00	0.8491	0.8709	$y = -0.001x^2 + 1.0157x + 6.7299$	$y = -7E\text{-}05x^2 + 0.0909x + 0.7525$
08:00	0.7883	0.8295	$y = -0.001x^2 + 1.1791x + 13.973$	$y = -6E\text{-}05x^2 + 0.1091x + 1.795$
09:00	0.7145	0.7894	$y = -0.0009x^2 + 1.1892x + 30.783$	$y = -6E\text{-}05x^2 + 0.1173x + 3.9481$
10:00	0.6651	0.7643	$y = -0.0008x^2 + 1.1214x + 70.815$	$y = -5E\text{-}05x^2 + 0.1169x + 8.6333$
11:00	0.7038	0.7954	$y = -0.0009x^2 + 1.3058x + 71.324$	$y = -7E\text{-}05x^2 + 0.1471x + 8.1462$
12:00	0.7031	0.7928	$y = -0.001x^2 + 1.4286x + 76.742$	$y = -8E\text{-}05x^2 + 0.1662x + 7.7365$
13:00	0.6502	0.7706	$y = -0.0012x^2 + 1.6007x + 69.735$	$y = -9E\text{-}05x^2 + 0.1812x + 6.9783$
14:00	0.5698	0.6914	$y = -0.0014x^2 + 1.8096x + 74.775$	$y = -9E\text{-}05x^2 + 0.1797x + 9.35$
15:00	0.5024	0.6273	$y = -0.0018x^2 + 2.1774x + 47.012$	$y = -0.0001x^2 + 0.191x + 7.6895$
16:00	0.5080	0.6721	$y = -0.0017x^2 + 2.2612x + 35.504$	$y = -6E\text{-}05x^2 + 0.1689x + 6.8556$
17:00	0.7397	0.8619	$y = -0.0017x^2 + 2.6811x + 4.9057$	$y = -4E\text{-}06x^2 + 0.1914x + 2.2608$
18:00	0.8854	0.9656	$y = -0.0021x^2 + 3.483x - 7.7118$	$y = 6E\text{-}05x^2 + 0.2329x + 0.226$
19:00	0.7615	0.9659	$y = 0.0158x^2 - 1.3305x + 42.751$	$y = 0.0001x^2 + 0.2488x - 0.3935$

Table 5: Correlation Equations for Daylighting

The predictions of the correlation equations for typical summer and winter days are shown in Figure 15 and Figure 16. It can be seen that internal conditions of thermal comfort and IAQ are affected by the operation of the windows and the presence of trickle ventilators. Opening windows at night during the summer improves thermal conditions during the day.

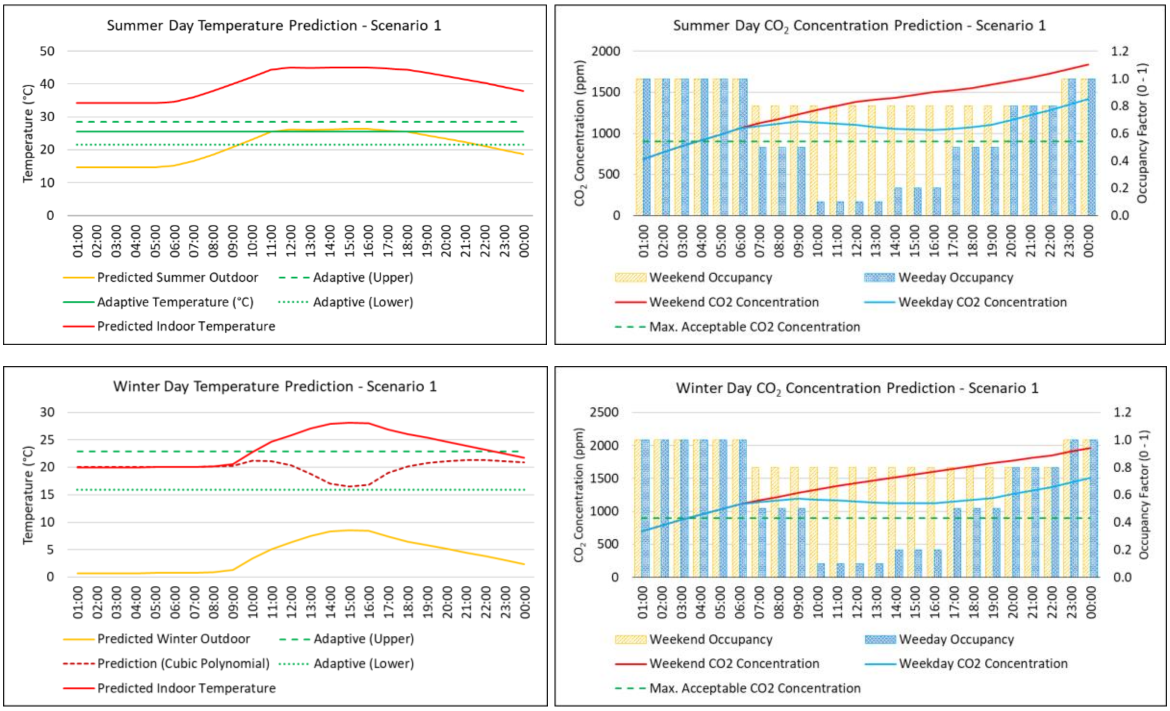

Figure 15: Scenario 1 - Window Close, Shading off, Trickle vent off, Heating on

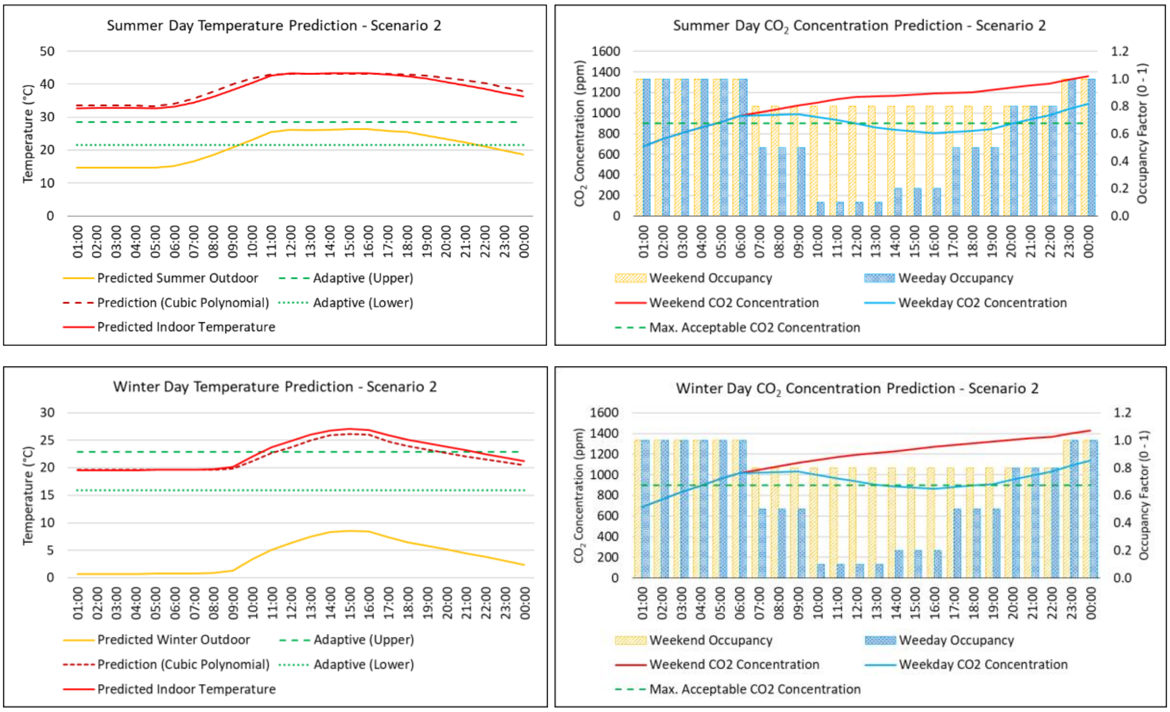

Figure 16: Scenario 2 - Window Close, Shading off, Trickle vent on, Heating on.

5.1.2 Weather and insolation prediction model

The following results were taken from D3.1. The Table 6 below, shows the performance metrics of the four key weather variables for the Geneva demo site. As we mentioned before, the results were derived from 1 year of test weather data ranging from 30-09-2020 to 30-09-2021. So, for the Temperature variable, our best model achieved R^2 equal to 93.6%, RMSE equal to 1.85°C and MAE equal to 1.4 3°C. These performance metrics are suitable for evaluating the Temperature's forecasting performance because Temperature has a few outliers and is characterized by normal distribution, and consequently the performance metrics are well defined. To better understand the performance of the best model for Geneva on the test set, we should see the statistics of the Temperature distribution shown in Table 4. We observe the mean and standard deviation values are 11.5°C and 7.5°C respectively and 75% of the values are below 16.9°C. So, from this observation we conclude that the MAE and RMSE values are optimal compared to these statistical values in units of °C. To continue with the three radiation variables, we observe from Table 5.3 that Diffuse radiation achieves the best performance metrics with R2 equal to 92.8%, compared to the other two radiations.

	Temperature (C)	Global Shortwave (W/m^2)	Direct (W/m^2)	Diffuse (W/m^2)
R^2	0.93603	0.86821	0.75389	0.92821
RMSE	1.8565	78.9643	70.905	22.9493
MAE	1.4378	42.322	34.9631	12.4543

Table 6: Performance Metrics for the Geneva demo site.

The worst metrics were obtained from Direct Radiation with R^2 equal to 75.4%. As we mentioned in our explanatory analysis, Direct radiation is a variable that is characterized by abrupt changes in the radiation especially in a location where sunshine is not the predominant weather condition, and with an average Cloud Cover close to 60%. So, there is difficulty to accurately forecast a quickly changing time series. Also, due to the nature of Direct Radiation, which means 50% of its values are below 1.76 W/m^2 and the standard deviation is very large compared to the mean value (Table 6), small changes in the radiation give very high errors especially in RMSE. This penalizes the high errors, while MAE is more robust to this phenomenon and that is why MAE is less than RMSE. By inspecting all performance metrics values from Table 3, for all radiation variables, we conclude that Diffuse and Global Radiation give the best forecasting results on a 24-hour basis.

Furthermore, in Figure 17 we present the distribution of prediction errors of the one-year test dataset. For all variables, we clearly observe that most errors are around zero and they follow normal distribution. For the Temperature variable, the prediction errors do not exceed 5°C and the mean value is around 1.4°C. In terms of Global and Direct Radiation, most prediction errors do not exceed 80W/m^2 with a maximum error around 200 W/m^2 where our best model fails to predict well. In terms of Diffuse Radiation, our model achieves extremely good results where the most values do not exceed the 20W/m^2.

Therefore, in Figure 17 we can visualise the performance accuracies of our best forecasting model for all variables and compare them with the statistical values of each variable's distribution shown in Table 7. From this Table, since most prediction errors are far lower than the mean value of the distributions, we conclude that the results that we achieved for Temperature, Diffuse and Global Shortwave Radiation are very good. In contrast, Direct Radiation prediction errors are close to the mean value of the distribution (85.77 W/m^2), so the forecasting accuracy of our model is as expected.

This is reasonable because as we mentioned earlier there is a difficulty to accurately forecast a quickly changing time series, by using of Deep Learning models only. Other models/methods like numerical which consider the physics of the atmosphere are more suitable to capture these multifactorial phenomena of Direct radiation.

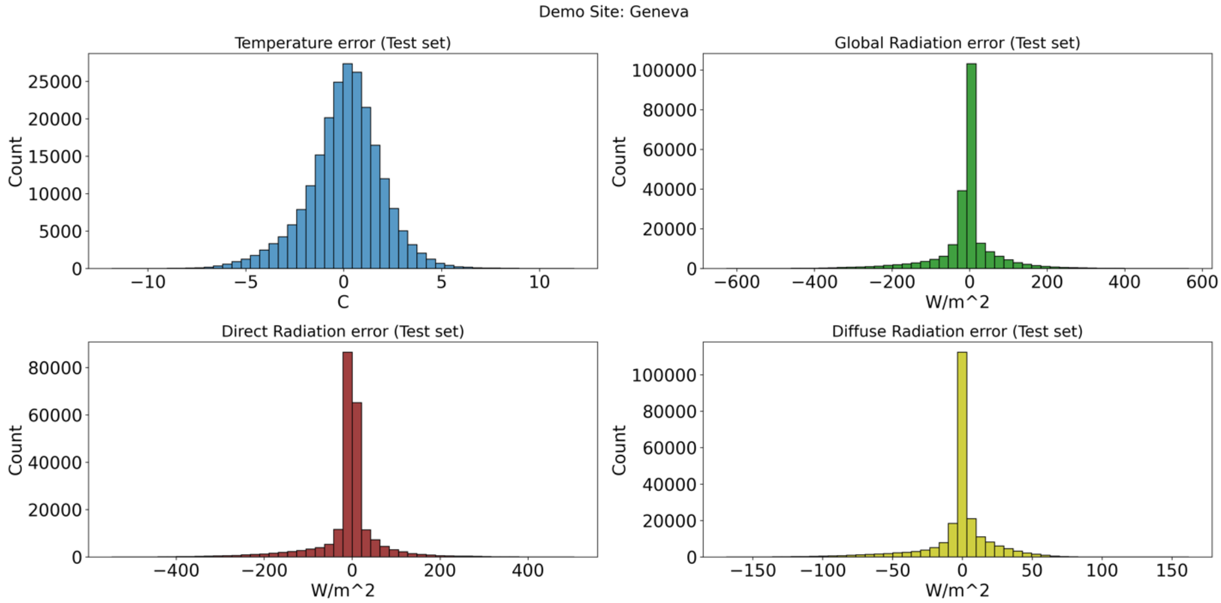

Figure 17: Distribution of Prediction errors for all variables in Geneva.

Statistics	Temperature [2 m elevation corrected] (°C)	Shortwave Radiation (W/m^2)	Direct Shortwave Radiation(W/m^2)	Diffuse Shortwave Radiation(W/m^2)
mean	11.5	150.991	85.77	65.220
std	7.54	220.181	144.36	86.076
50%	11.42	11.570	1.767	5.227
75%	16.92	242.970	120.14	126.122

Table 7: Statistics table of the target variables. Statistics were calculated only on the test dataset for evaluation.

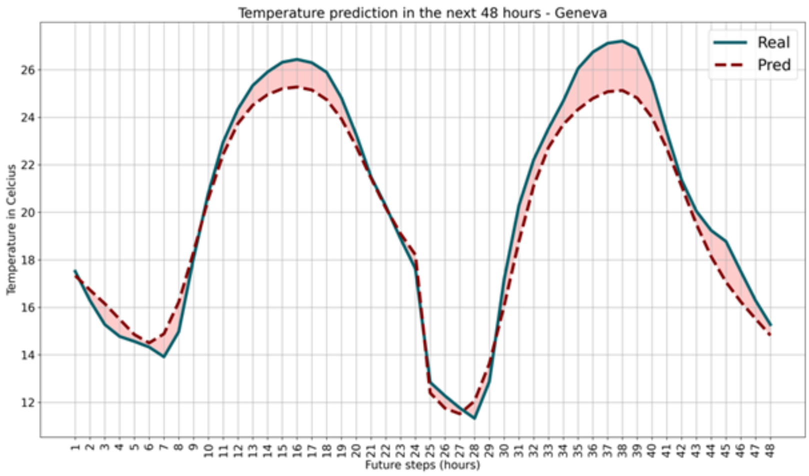

Figure 18: 48-hour Forecasting results of Temperature variable in Geneva.

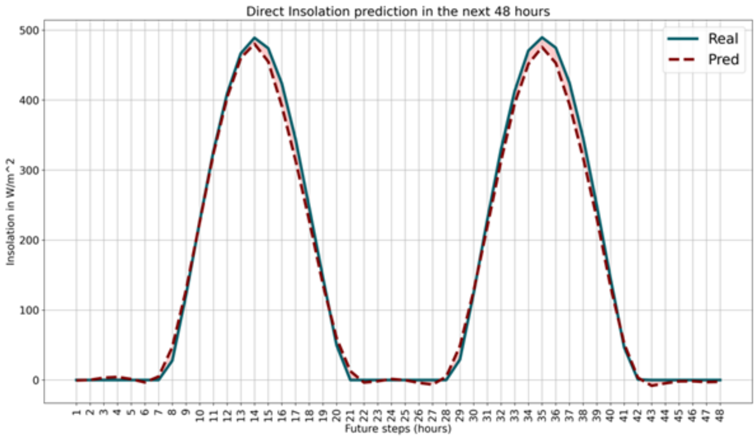

Figure 19: 48-hour Forecasting results of Direct Radiation variable in Geneva.

Finally, in Figure 18, Figure 19, Figure 20 and Figure 21 one can visualize the forecasting results for two randomly selected consecutive days (48 hours). Specifically, in Figure 18 we observe that the Temperature variable is very well predicted (Red line) with very small deviations from the true value (Blue line). The red shaded area depicts the difference between the predicted and the true values.

The same applies for the rest variables in Figure 19, Figure 20 and Figure 21 which depict the 48-hour forecasting of the three radiations. For all Radiation variables, we observe that the more difficult to predict the sunshine hours which are the hours of interest, compared to the night hours. As we mentioned before the results are very good except for the Direct radiation variable. It is also important to refer that these plots are the outputs of the deployment of the trained predictive models.

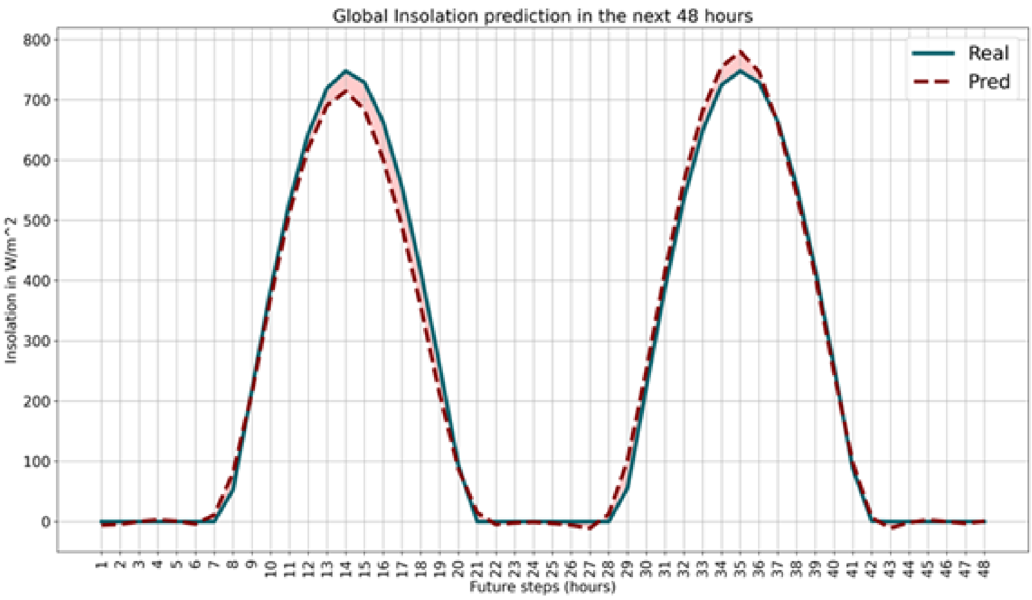

Figure 20: 48-hour Forecasting results of Diffuse Radiation variable in Geneva.

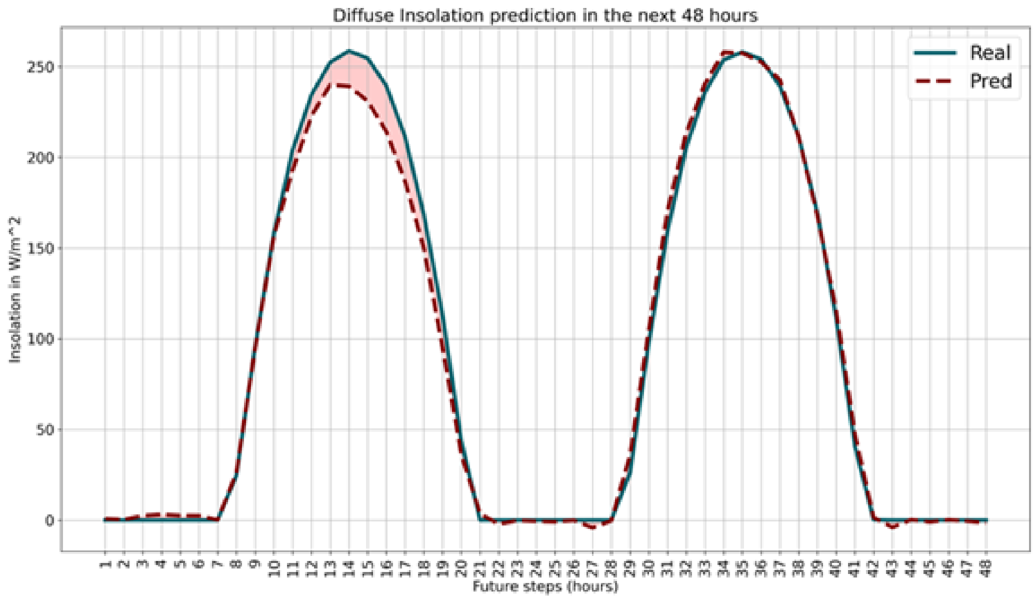

Figure 21: 48-hour Forecasting results of Global Shortwave Radiation variable in Geneva.

5.1.3 VRE community

Deliverable 5.2 is being submitted at the same time as the present deliverable. It contains interesting results concerning the swiss case study. Hereafter are quoted the main results and graphs regarding optimal PV sizing of the case study and impact of the battery energy service system (BESS).

For the Geneva demo case, the optimal solar PV system size can be determined based on the measured consumption and production data. The measured production for a 21 kWp solar PV system was scaled for system sizes ranging from 0 to 60 kWp with 2 kWp intervals. The results of the optimal sizing are shown in Figure 22. It is observed from the figure that the optimal system size for the Geneva demo case is approximately 12 kWp without BESS, which results in approximately 4,000€ in terms of annual cost savings. In the simulations, another case was studied where the feed-in tariff was set to 0 c/kWh to investigate the impacts of the feed-in tariff on the solar PV system sizing, and the results of those simulations are presented in Figure 23. It is observed that the optimal system size is similar to the previous case even though the upper linear regression is changed by the tariffs.

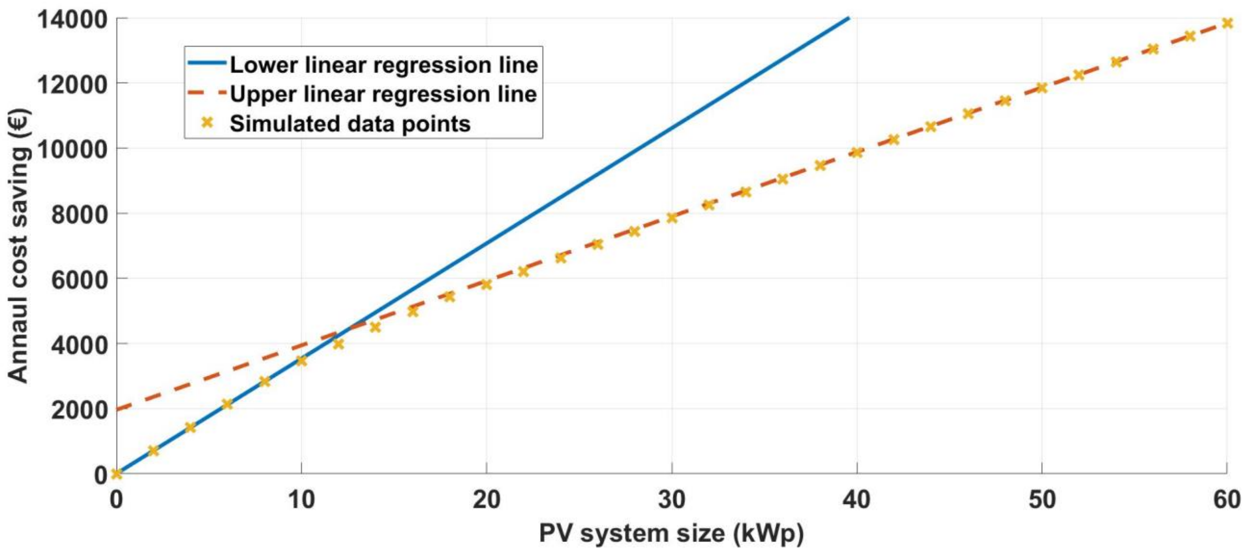

Figure 22: PV size optimization for Geneva demo case without battery (surplus PV energy feed-in tariff is 0.155 c/kWh)

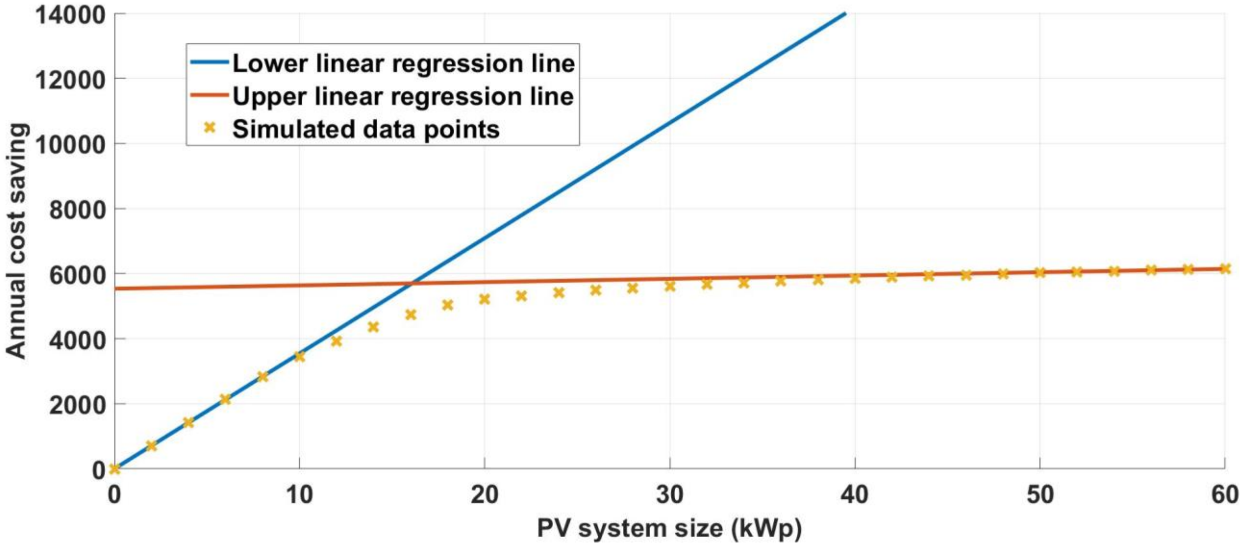

Figure 23: PV size optimization for Geneva demo case without battery, but in case when surplus PV energy feed-in tariff is zero.

Impact of Battery storage systems

In the Geneva demo case, there is a 20 kWh BESS, which increases the solar PV self-consumption rate. The control system in the demo case system was programmed by the manufacturer, and the exact control algorithm of the system is not known. From the measured data, a C-rate of approximately 0.23 can be evaluated for the battery, which means a maximum power of 5 kW. The battery control algorithm seems to be based on charging the battery with the available energy produced with the solar PV system whenever possible and using that energy later, e.g., during the evening.

The sizing of the solar PV system for the Geneva demo case simulations that include a BESS is shown in Figure 24. According to the simulations, the BESS in this case has no significant impact on the sizing of the solar PV system. It is observed from Figure 25 that the area from which the optimal solar PV system size can be found is wider with the BESS than without it. From the simulated data points, two turning points can be located. The first turning point occurs between the values 6 and 8 kWp, and the second turning point occurs when the value is approximately 20 kWp. Thus, it is difficult to use the typical sizing method, which provides a value that is between those two turning points. By comparing Figure 22 and Figure 24, it is observed that the solar PV system together with a BESS provides just slightly higher annual cost savings than if a solar PV system is used without BESS. The differences in the cost savings in those two cases are shown in Figure 25. It is observed that the differences in savings are low when the size of the solar PV system is small. However, as the size of the solar PV system increases, the impact of a BESS on the difference in savings becomes more significant.

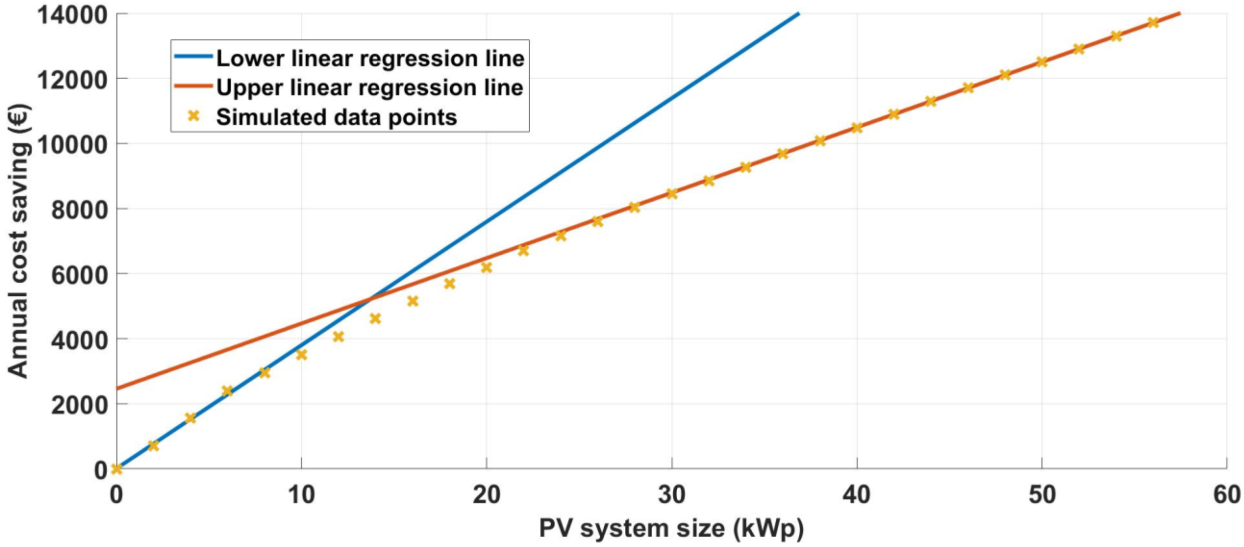

Figure 24: PV size optimization for Geneva demo case with BESS

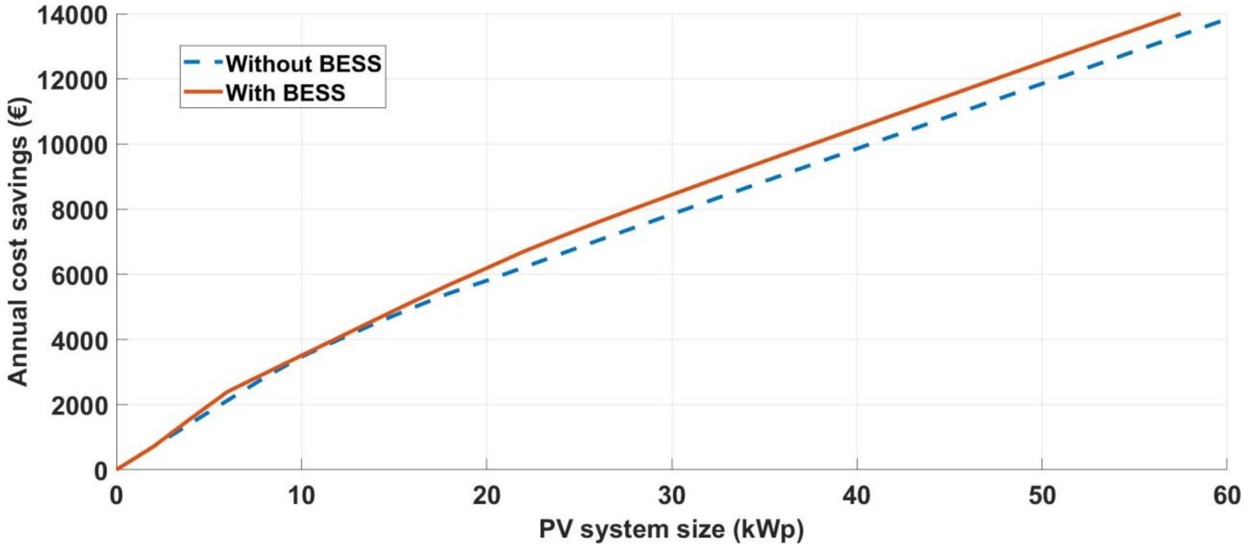

Figure 25: Annual cost savings in Geneva demo case by using different size of PV systems with and without BESS.

The annual cost savings vary with small solar PV system sizes with a BESS as shown by the difference between the curves depicted in Figure 25. In addition to the impacts of solar PV systems of different sizes, the differences in the annual cost savings achieved with different BESS sizes can be investigated as well, and those differences are shown in Figure 26.

The results of this study show that in the Geneva demo case, where a 21 kWp solar PV system and a 20 kWh BESS are installed, the theoretical annual cost savings are only approximately 100€ higher than what could be reached with a 4 kWh BESS. If the size of the solar PV system was to increase to 30 kWp, the difference in savings would be approximately 300€. In that case, the profitability of a smaller BESS would be higher when the investments costs are compared to the annual cost savings. The use of a BESS significantly decreases the costs that ensue from the demand charges when compared to the case where BESS is not used and the size of the solar PV system is in the range of 4-8 kWp, or larger than 22 kWp. With sizes that are in the range of 10-20 kWp, the BESS does not provide any extra benefits for decreasing the maximum demand. The cause for this phenomenon is in the load profile in the Geneva demo case. The results indicate that the ratio between the solar PV system size and the size of the BESS is not optimal, albeit the load profile is well-suited for the solar PV production profile. Thus, from an economic perspective, the Geneva demo case is not the best in the case of BESS. In the electricity tariff, the demand charge is relatively high, and the use of a smarter, compared to the one used at present, control system for peak-shaving could provide higher profitability for the BESS.

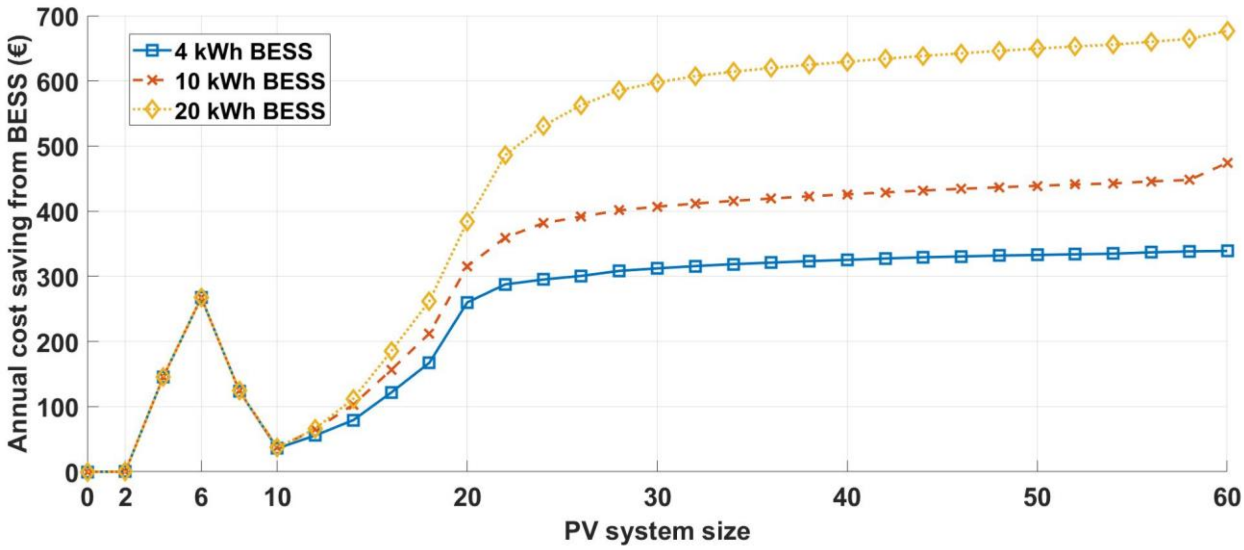

Figure 26: Annual cost saving from BESS (in addition to PV) in Geneva demo case with different PV sizes and three sizes of BESS

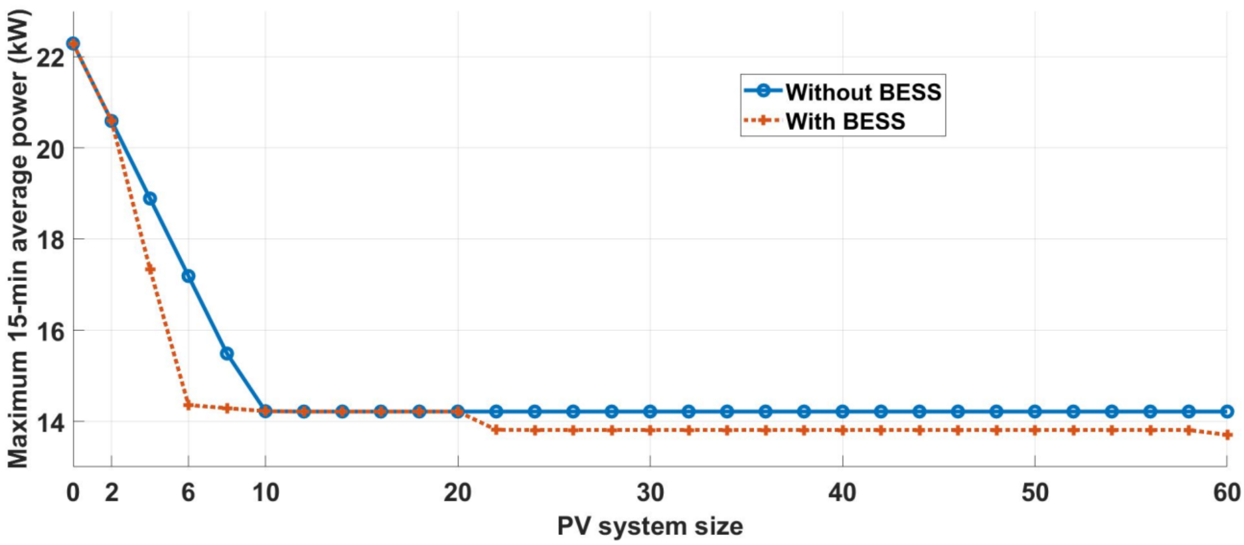

Figure 27: Impact of PV system size for maximum 15-minute average power in Geneva demo case with and without BESS

5.1.4 Measurement and Verification module

To ensure precision in both the model and the results of the methodology, the M&V methodology is customized to suit the characteristics of the case study and involves applying statistical models to develop a suitable adjusted baseline model. To identify the most accurate model, two metrics have been selected: the Coefficient of Variation of Root Mean Square Error (CV-RMSE) and the Normalized Mean Bias Error (NMBE). The CV-RMSE value is employed to assess the introduced uncertainty, with lower values indicating better performance of the model. The NMBE serves as an additional metric to aid in model evaluation; however, it is not utilized for model selection since positive and negative biases can offset each other. The primary objective remains the minimization of uncertainty throughout the modelling process.

The M&V module will generate two main outputs: (i) monthly time series data representing estimated energy consumption and (ii) monthly time series data indicating energy savings. The energy savings data will be presented in both absolute values (kWh) and relative percentage values, accompanied by information about the uncertainty of the estimations, including errors and confidence levels. The M&V module will be scheduled to retrieve the necessary input data from FusiX on a monthly basis, allowing it to generate a time series of estimated energy consumption and savings. It is important to note that the output is provided on a monthly basis and covers the period up until the previous month. Therefore, it does not provide predictions for future energy consumption, but rather offers a retrospective estimate, enabling end-users to evaluate the effectiveness of the implemented intervention.

5.2 Global performance of the building: Energy performances and performance gaps

The first step in understanding and analyzing the performance of this building is to compute the energy consumption for heating and DHW. These results must be compared with those given by static simulations carried out prior to building refurbishment. The overall goal is to establish if the building complies with the Swiss high energy performance standard (HPE) and to target possible performance gaps.

5.2.1 Heating requirement index

The heating requirement index is computed by adding the electric consumption of the HP and the gas consumption of the burner in terms of heat energy. The calorific power of the natural gas is set to 38.5 MJ/m^3. For the heat pump, the performance coefficient is set to 3.25 and gives 11.7 MJ of heat for one kWh of electricity.

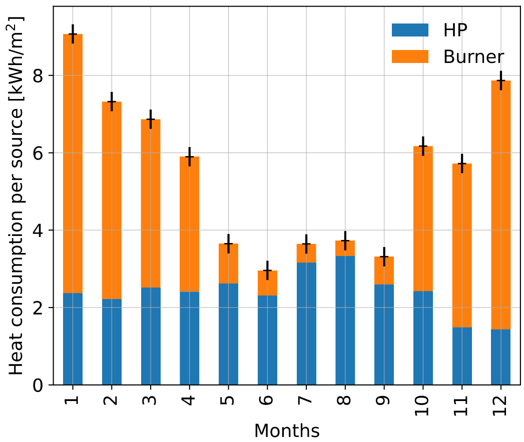

Figure 28: Monthly heat consumption index from the different sources.

Figure 28 shows the heating requirement index for a year (between March 2022 and March 2023) by energy source. This computation has been carried out with measures of gas consumption going from January 2022 to August 2022. The gas sensor malfunctioned from mid-August to mid-October 2022 due to installation problems. Therefore, the gas consumption has been modeled in function of the following known variables: the heat brought to the heating circuits, the heat produced by the HP, the heat produced by the HP that is used for heating, and the heat for DHW that is assumed constant through the year.

This computation gives a heating requirement index of 64±1 kWh/m^2 or of 240±4 MJ/m^2.

The filling of the missing gas consumption also allows evaluating CO_2 emissions per ERA. This is computed by multiplying the final energy by the greenhouse gas (GHG) ponderation coefficient given by SIA 380 standard. This coefficient is equal to 0.249 kg/kWh for the gas, 0.125 kg/kWh for the electricity imported from the network, and 0.042 kg/kWh for the electricity produced on site. The results of this computation are shown in Figure 5.17 for the year 2022. Over a whole year, the building produces 9.6±0.3 kg/m^2 of CO_2.

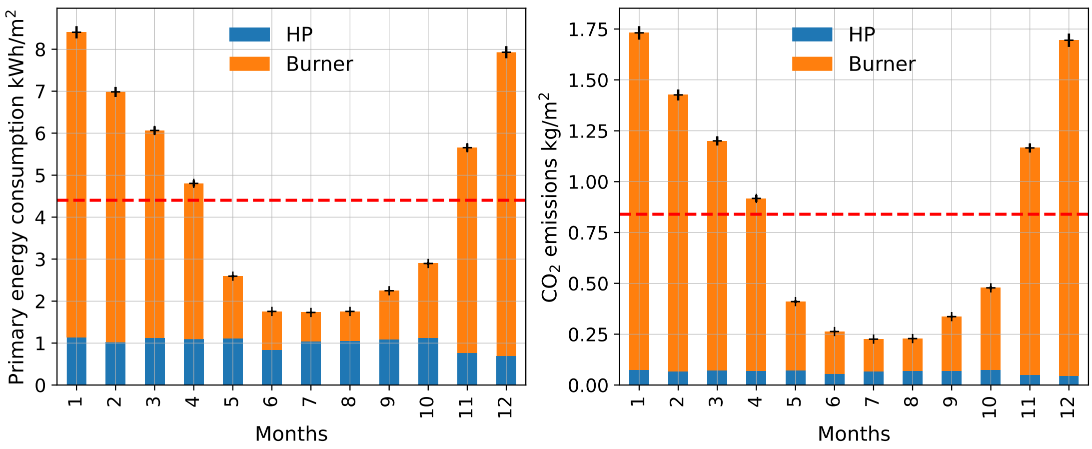

Figure 29: Monthly primary energy consumption of both Heat Pump and gas burner together with CO2 emission by heat source.

5.2.2 Performance gaps

The possible performance gaps are computed by comparing the results of two static EPCs made by two different offices to the actual measures of heat consumption of the building. The first simulation is a LESOSAI that has been carried out by ESTIA S.A. in 2022. The second one is the CECB (Le Certificat énergétique cantonal des bâtiments) certification carried out in November 2021 by CNergie Conseil Sàrl. The energy needs for heating, DHW, and global energy efficiency are compared to the measures and the results are shown in Table 8:

	LESOSAI	CECB	Measures
Energy needs for heating [kWh m–2 y–1]	19.1	16	17±1
Energy needs for DHW [kWh m–2 y–1]	26	26	45±3
Global energy efficiency [kWh m–2 y–1]	-	67	63±2

Table 8: Evaluation of performance gaps in Wendt 35 comparing the static simulations to the measures.

In Table 8 it is possible to observe that the performance gap for the energy needs for heating is small. Considering the error on the measures, the error with the LESOSAI simulation is negative and it's about 5% with the CECB. This corresponds to a zero performance gap for heating. However, we observe a consequent performance gap on DHW. The LESOSAI and CECB simulations estimate the energy needs for DHW using the value of 100 MJ/m^2y (26 kWh/m^2y) defined in the Swiss standard SIA 380/1. The measured value is about 65% higher than expected. The computation for DHW heat consumption has been carried out using the data through a period of 3 months between Mai and July 2022 and approximating the DHW heat consumption constant throughout the year. Since this result strongly deviates from the simulations, a supplementary energy meter has been installed on the DHW output by ESTIA S.A. for four weeks in November 2022 to corroborate the initial results. The results of this experience are detailed in the next section.

Finally, global energy efficiency is lower than estimated by the CECB. This is because of the PV installation, which reduces the need for electricity import from the network.

5.2.3 DHW consumption

To validate the results of the previous section an ultrasonic flowmeter has been installed on the output of the DHW boilers and on the return of the DHW circulation. The flowmeter measures the flow and the temperature of each circuit.

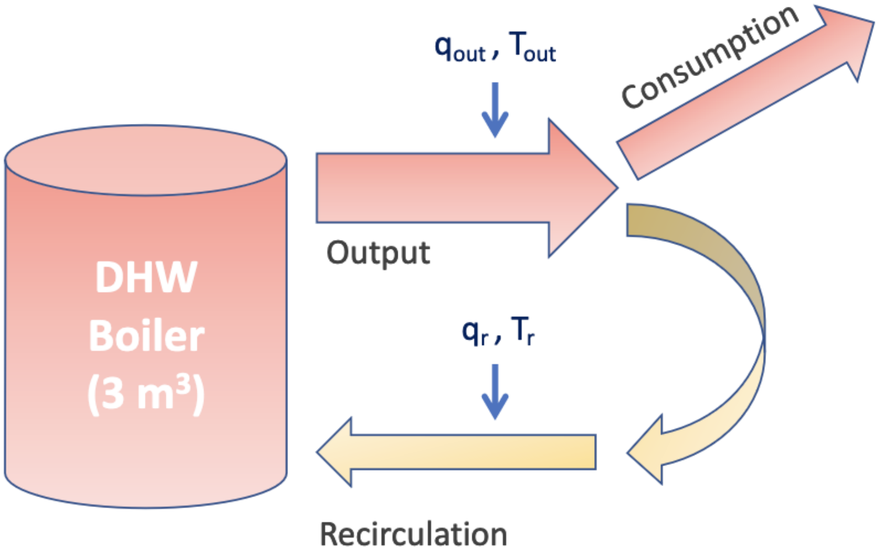

Figure 30: Scheme of the ultrasonic flowmeter installation on the DHW system. The blue rows represent the measure points of the flowmeter, qout and Tout are respectively the outflow and its temperature while qr and Tr are respectively the return flow and its temperature.

Figure 30 is a scheme of the installation of the ultrasonic flowmeter. With this installation it is possible to compute the energy consumption due to the actual DHW use (Q_C) and the consumption due to energy losses from the recirculation of DHW through the building (Q_R) as follows:

$$Q_C = C(q_{out} - q_r)(T_{out} - T_0) \quad (3.1)$$

$$Q_R = C(q_{out} - q_r)T_r \quad (3.2)$$

Where $C=1.16$ kWh/m^3 is the water's heat capacity and $T_0=12$ °C the temperature of the water inflow from Geneva's distribution network.

Using equations 3.2 and 3.1 to the flowmeter data, it is possible to compute the DHW energy consumption independently from the original monitoring sensors installed by Service Plus Energies. This computation estimates the energy consumption for DHW to 43 ± 2 kWh/m^{2}y, which corresponds to the previous computations shown in Table 8. The energy use due to DHW consumption, Q_C is 33 ± 2 kWh/m^{2}y, and the energy consumption due to the recirculation is 10 ± 0.5 kWh/m^{2}y.

DHW energy consumption calculated this way is still 27% higher than anticipated in Table 8. The exact cause of this performance gap remains unknown, but it is possibly due to a higher number of inhabitants than predicted by the SIA 380 standard. Indeed, the standard assumes the presence of one person per 40 m^2. This value is likely to be underestimated for Wendt 35. For example, on each refurbished floor there is one studio of 22 m^2. Furthermore, a visit to an apartment on the new floors showed that a couple with two children live in a 70 m^2 apartment. It is not possible to precisely determine the number of inhabitants of Wendt 35, but these indications show that the inhabitant's density is higher than the assumptions of the SIA 380 standard.

The energy losses for DHW recirculation correspond to about 23% of the total energy consumption for DHW. These losses can be reduced by insulating the DHW conduits that flow through the building. Furthermore, it is important to notice that the energy dissipated through this process contributes to the building's heating during the winter season. Since the building is heated for about half a year, it is possible to estimate that 5 kWh/m^{2}y of the DHW circuit contributes to the heating.

5.2.4 Energy fluxes

The monitoring of Wendt 35 allows representing graphically the energy fluxes from each energy vector to the final utilities. As above, the gas consumption and the precise energy needs for DHW are not fully known throughout the whole year. They are therefore computed using the known readings.

A Python script has been developed using the ploty library to produce the energy flux diagrams for a given time. For example, Figure 31 shows the energy fluxes during March 2022 and Figure 32 in July 2022. It is important to notice that these diagrams don't show the absolute consumption of the different systems but the relative one. For example, it is possible to observe that during the month of July the on-site electricity production (self-production) is much higher than the import, while in March the import was slightly higher.

It is interesting to notice that the energy flux into the HP is much smaller than its output. The rest of the energy comes from the cold source of the HP which is either ventilation or free cooling depending on the season and, therefore, the performance coefficient of the HP is higher than 1.

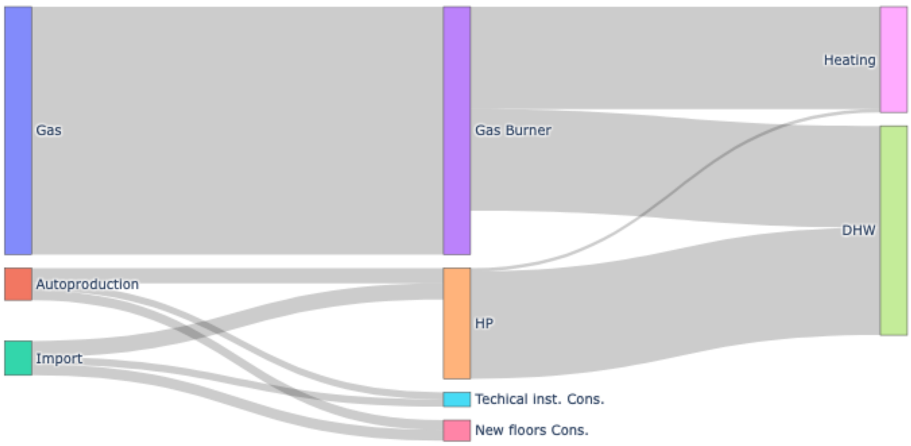

Figure 31: Energy fluxes in March 2022. The gas is used by the gas burner to produce heat for heating and DHW. Electricity is either produced on-site (self-production) or imported from the network to power the HP, all technical installations, and the apartments on the new floors. The HP produces heat for DHW mainly and space heating

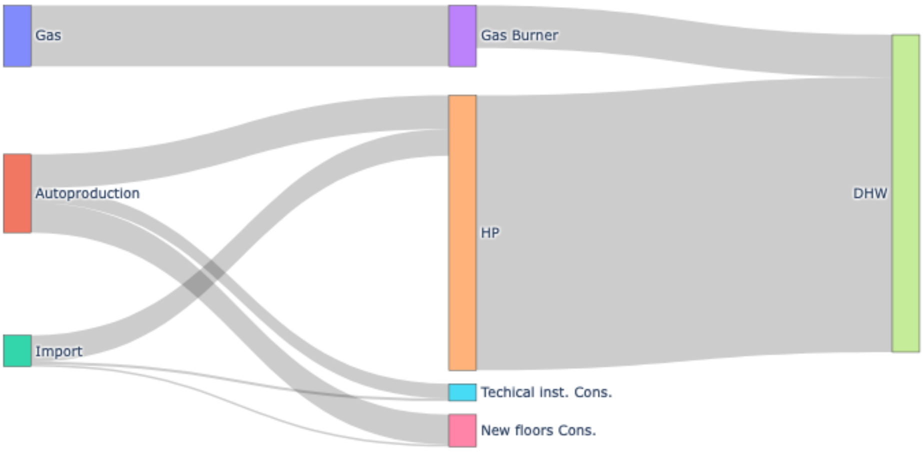

Figure 32: Energy fluxes in July 2022. The gas is used by the gas burner to produce heat only for DHW. Electricity is either produced on-site (self-production) or imported from the network to power the HP, all technical installations, and the apartments on the new floors. The HP is the main producer of DHW. No space heating is present as expected.

5.3 Global performance of the building: Performance of different technical installations

As discussed above, the technical installations have been renovated during the refurbishment with a state-of-the-art system. Here, the performance of some key components of this system are analyzed in order to complement the considerations developed in the previous sections.

5.3.1 Performance of the PV system

In parallel to the study of TAU on VRE, Estia performed some data analysis to assess the performance of the PV system and its accordance to the refurbishment project. This analysis's goal is to evaluate the performance of the PV installation, which includes a battery of 20 kWh capacity.

The data on PV installation is available from the end of February 2022. The following computations have been made with a dataset ranging for a year, from the 9th of March 2022 to the 8th of March 2023. As discussed above, the PV installation and the battery doesn't power the whole building but only the apartments of the new floors (RCP), the commons, and the technical installations. Figure 33 shows the behavior of the system during a typical sunny summer day, in this case, the 10th of August 2022. It is possible to observe that the PV cells fill all electricity needs during the day. The battery contributes to self-consumption during the evening. Furthermore, the PV cells don't reach the maximum power of 21 kWp. The most probable reason for this is the surface temperature of the cell. No active cooling of the panels is installed and their temperature is therefore not optimal for production. In order to observe the output of the PV cells by the hour of the day, a boxplot has been realized and it is shown in Figure 34. The maximal output reaches often 15kW and 16kW during mid-day, but never reaches the maximum output of 21kWhp. This behavior is expected as the real performances are always lower than the ideal ones.

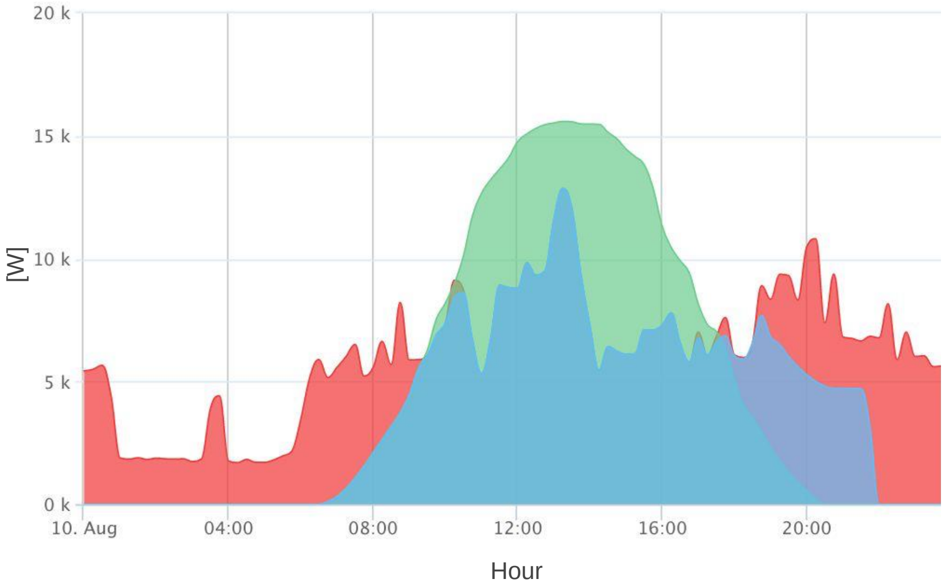

Figure 33: Typical performance of the PV installation during a sunny summer day (the 10th of August 2022). In red is the consumption of the RCP, the commons, and the technical installations, in green the PV production, in light blue the self-consumption (including battery charging) and in violet the battery discharge.

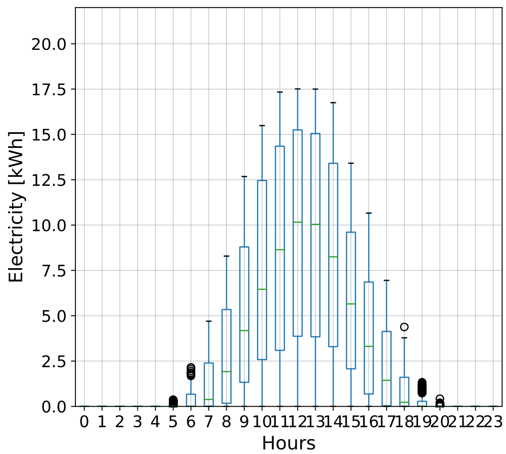

Figure 34: Boxplot of the hourly PV production from 9th of March 2022 to 8th of March 2023.

Figure 35 shows the PV production and the exports during a full year. 5 days of June are reported in July due to a data transmission malfunction. It is still possible to observe that production in the summer season is about three times higher than during the winter. The exported energy is significant from March to October and negligible during the winter season. Figure 35 on the right shows the part of the energy produced by the PV installation that is exported on the network. During the summer season, this ratio exceeds 20% thus decreasing the self-consumption as will be discussed later. The total production over the considered period (9th of March 2022 to 8th of March 2023) is 24'250 kWh. This corresponds well to what was estimated by the provider of the PV installation, which estimated its yearly production to be 23'210 kWh [10]. It is important to recall that the efficiency of the installation decreases over time.

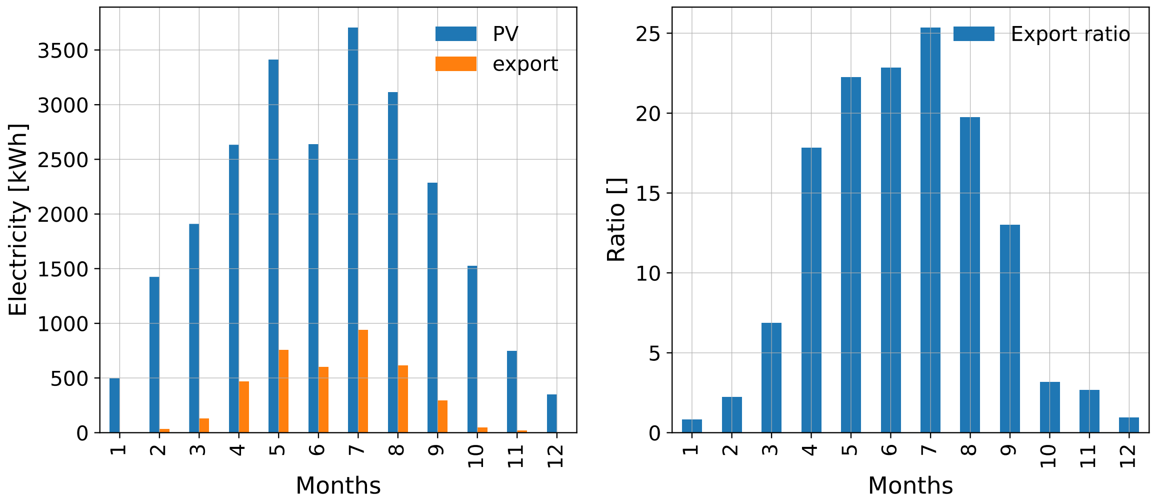

Figure 35: Monthly production and export on the left. Export ratio on the right. Both come from a dataset ranging from the 9th of March 2022 to 8th of March 2023

Finally, in Figure 36 it is possible to observe that the consumption of the RCP, the commons, and the technical installations is stable though the year except for the last two months where vacancies might be higher. As mentioned above, the data for five days of June are counted in July due to a malfunction in the transmission of data. The part of the consumption provided by on-site production is shown in Figure 36 the right. As expected, during the summer season the system is self-sufficient at 70%, while this drops at 20% in winter.

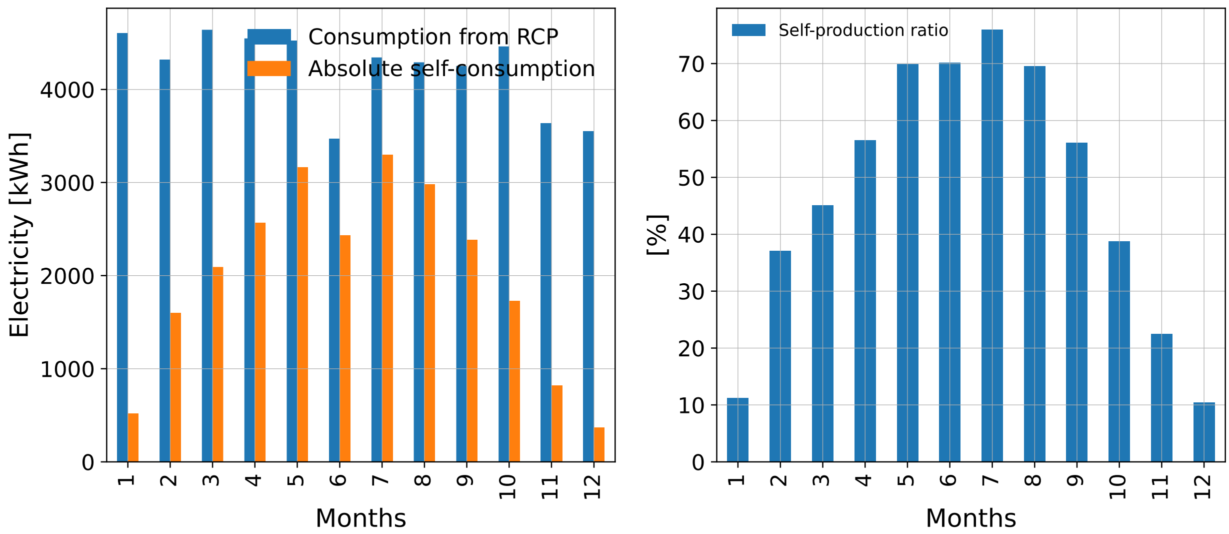

Figure 36: On the left: consumption of the community compared with the consumption from the PV production. On the right: ratio of the consumed energy coming from the PV production monthly.

5.3.1.1 Measured self-consumption

One of the main goals of the designers of the building's PV system was to maximize self-consumption. It is estimated that the self-consumption of the system reaches 84% [10] and would have been 49% without any battery capacity.

The self-consumption over a defined time period is defined as the ratio between the self-produced energy that is self-consumed and the whole self-production:

$$SC = \frac{PV + BD - E}{PV + BD} = 1 - \frac{E}{PV + BD} \tag{4.1}$$

Where SC is the self-consumption, PV is the photovoltaic production, BD is the battery discharge, and E is the energy export.

Self-consumption has been computed using equation (4.1) for each month of the considered year. The results are shown in Figure 37. As expected, the self-consumption is lower during the summer than the winter, since energy export in the winter season is negligible. Computed over the whole available period, the self-consumption reaches 85±1 %, which corresponds to the predictions of the provider.

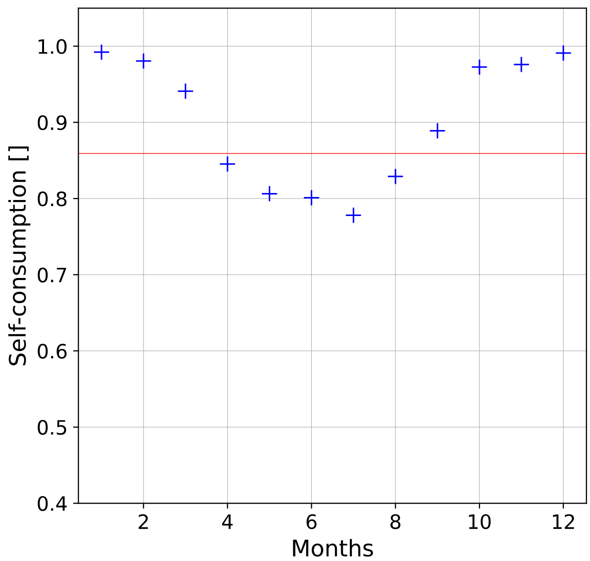

Figure 37: Self-consumption ratio for each month. The annual mean is shown by the red line and is at 85±1 %.

5.3.1.2 Measured autarchy

In order to estimate the autarchy of the building it is needed to estimate the consumption of the refurbished apartments. The monitoring data provides the consumption of the RCP, the commons, and the technical installations. The consumption of the technical installations can be easily subtracted since their electricity consumption is known from another sensor. To estimate the consumption of the refurbishment it is assumed that the apartment's consumption per square meter is constant. Furthermore, the consumption of the commons is estimated based on the SIA 2024 standard. The consumptions of the different parts can be seen on Figure 38.

This computation yields the results shown in Figure 39. Using the same approach, it is possible to estimate that the total consumption of the building is 62.5 % higher than the measure provided by the monitoring on the RCP.

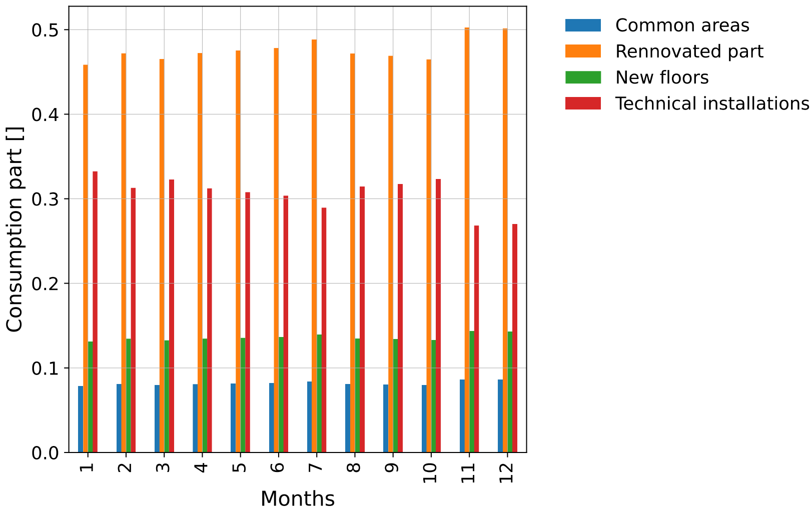

Figure 38: Estimation of the distribution of the consumption of the different sectors of the building by month based on SIA 2024 standard.

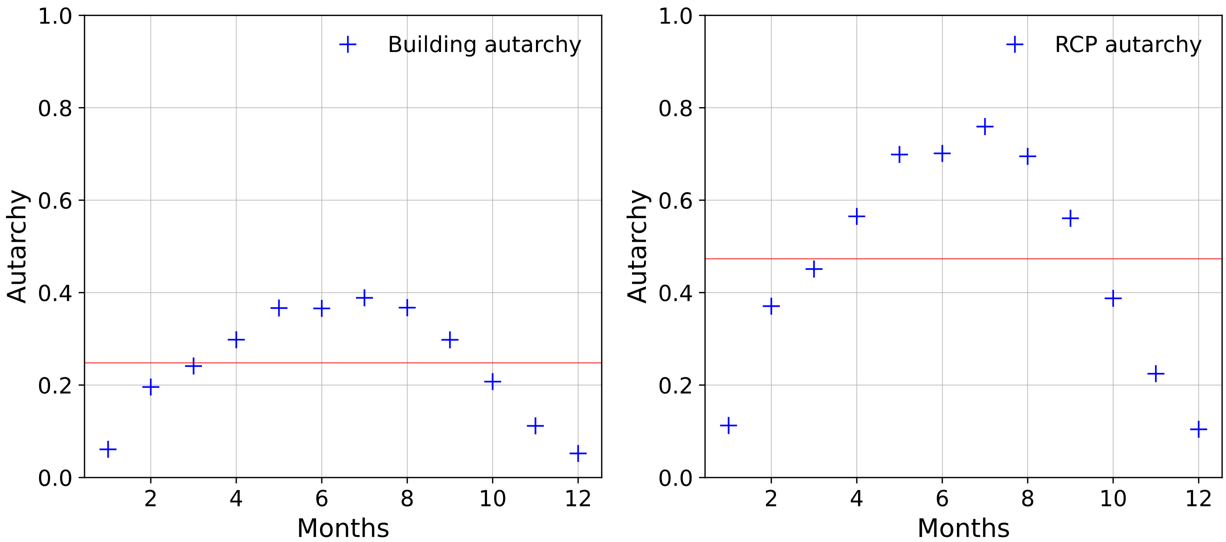

Figure 39: On the left: autarchy computed for the whole building. On the right: autarchy of the RCP only.

The previous computation allows estimating the autarchy of the whole building at 25±1 %. In Figure 39, on the left, it is possible to observe the autarchy by month of the whole building. This can be compared with the right part which shows the autarchy of the sectors of the building connected to the PV installation (the last two floors, the commons, and the technical installations). If only these sections are taken into account their autarchy would be 47%. In both cases, the autarchy drops during the winter as expected.

5.3.1.3 Battery performances

The battery complements the PV panels improving the performance of the whole installation. Based on the available data, it is possible to estimate that the battery reduces the import from the network by 3700±200 kWh per year. With the current cost of energy and taking into account the cost of the self-produced energy, the savings per year reaches 900±50 CHF. Since the overall cost of the battery was 12'000 CHF the investment would be profitable in less than 14 years. This result is not aligned with the study of TAU about VRE community (Section 5.1.3). Further research will be conducted to understand the misalignment of such results and they will be discussed in the overall case study deliverable (D7.7).

In Figure 40 it is possible to observe the percentage of days per month when the battery is fully charged. During the winter season, the battery rarely reaches its full charge. A more complete visualization of the contribution of the battery is shown in Figure 41, where the battery discharge is plotted against the hour of the day and the day. It is possible to observe that the battery never contributes after 22h. Furthermore, the battery discharge starts later during the summer since the sunset comes later.

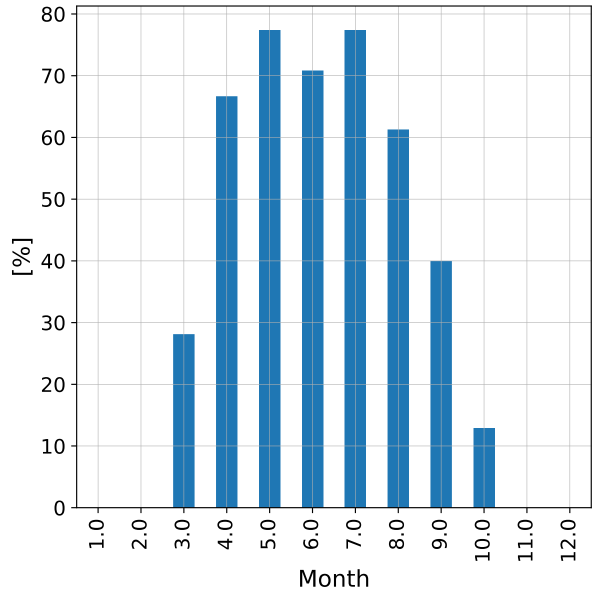

Figure 40: Days per month percentage when the battery is fully charged.

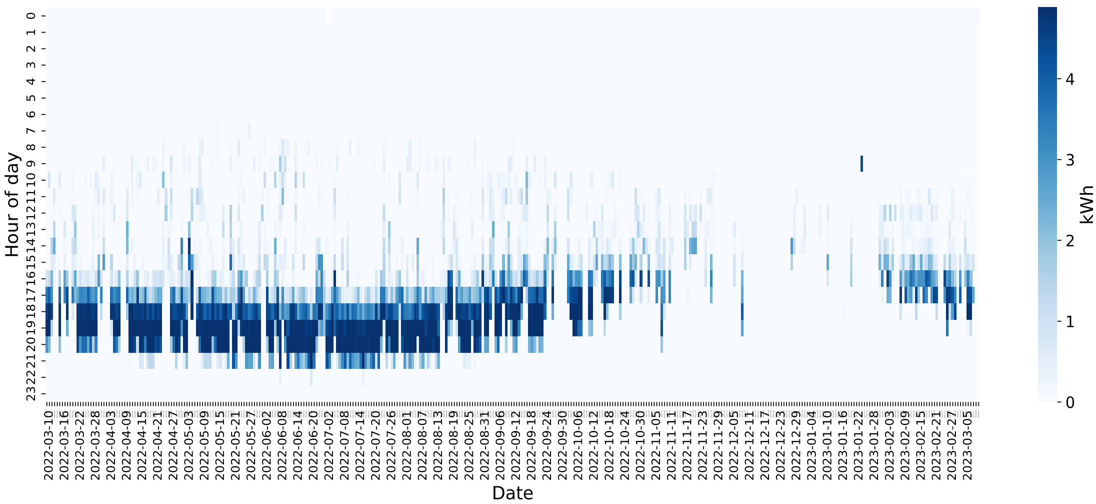

Figure 41: Heatmap of the battery discharge per hour from 9th of March 2022 to 8th of March 2023.

Finally, it has been estimated how self-consumption would decrease if the battery wasn't installed in the building. This computation has been done assuming that the efficiency of the battery charging-discharging cycle was 0.97 as in the battery specifications. In this scenario, for each day, the battery discharge is set to zero and the export is increased by 1.03 times the battery discharge. The results of the self-consumption by month are shown in Figure 42.

Over the whole period, the self-consumption without battery is estimated to be 70±2 %. The battery increases self-consumption by 15%.

The self-consumption without battery computed this way is much higher than the predictions of the provider who estimated this to 49% [10]. Since the model used by the provider to make this computation is not known, no explanations for this difference can be formulated.

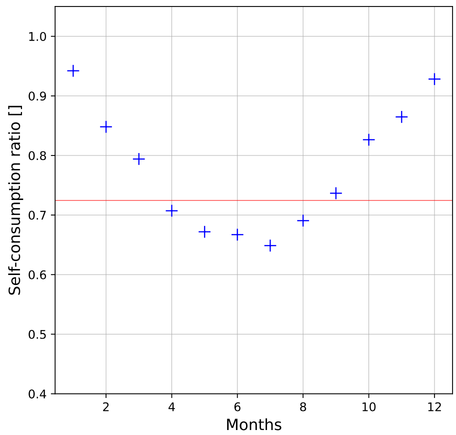

Figure 42: Estimation of the monthly self-consumption without battery. The red line corresponds to the self-consumption without battery computed over the whole year.

5.3.2 Gas burner

The gas burner is the main source of CO_2 emissions of the building as presented in Figure 29. Its main objective is to complement the heat-pump during the winter. It is also intermittently used in the summer to increase the DHW temperature for legionellosis cycles [16].

In Figure 43 it is possible to observe that the number of ignitions of the gas burner during the cold season is high, reaching 444 in January 2022 which corresponds to more than 14 times a day. Each ignition, independently from the type or burner, causes energy losses [17]. Throughout the year, the ignitions of the burner decrease, but even during summer, they don't fall below 100 per month, which is not a satisfying result. The high number of ignitions is also visible in the heatmap in Figure 44, where it is possible to observe that the gas burner is activated at 4am (winter hour) to provide the DHW needed in the morning. In general, the heatmap shows that the ignitions of the gas burner are mainly linked to the DHW need, not to heating. With some peaks of activity in the morning and late evening.

The behavior described above shows that the gas burner is oversized with respect to the needs. Indeed, its lower power output is 35 kW, which is high since its goal is to complement the HP. The gas burner was installed one year before the refurbishment; therefore it was dimensioned on the need for heating and DHW before the building's insulation. During the refurbishment, the owner decided not to replace the burner with a smaller one.

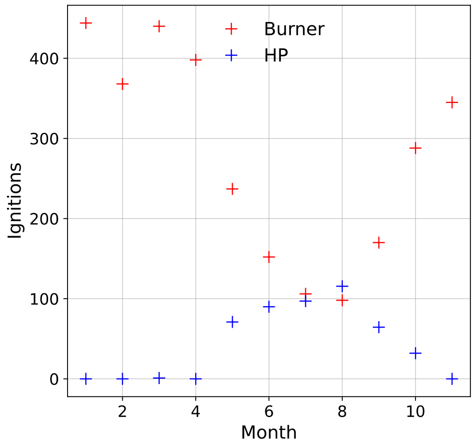

Figure 43: Monthly ignitions of the gas burner and the HP from the 1st of January 2022 to the 23th of November 2022.

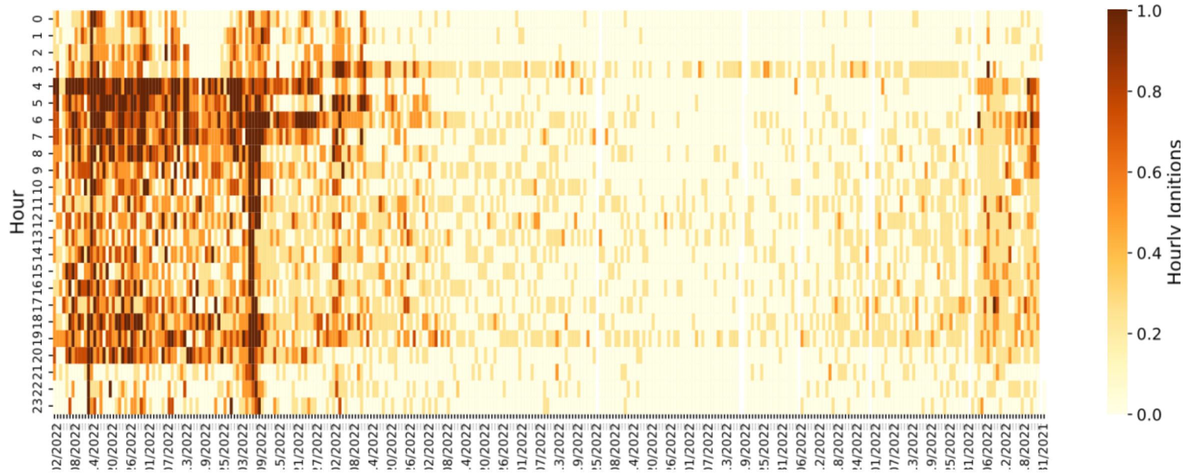

Figure 44: Heatmap of the hourly ignitions of the gas burner from the 1st of January 2022 to the 23th of November 2022.

5.3.3 Heat-pump

The heat-pump provides a more stable energy output than the gas burner as it's possible to observe in Figure 45. During the heating season, the HP works non-stop. Indeed, it has been verified that the first shutdown of the HP corresponds to the shutdown of the heating. Figure 43 shows also the ignitions of the HP which are much lower than the ones of the gas burner. Still, it reaches 100 ignitions during the summer. As for the gas burner, all ignitions induce energy losses. Furthermore, the lifespan of the HP can be negatively impacted by a high number of ignitions [18].

During summer the HP works almost continuously during the day, which is essential to maximize the use of electrical energy produced by the PV installation. Despite that, there are few scattered ignitions throughout summer days, which decrease the efficiency and lifespan of the HP.

The performance of the heat-pump are mainly determined by the coefficient of performance (COP), which is defined as the ratio between the energy output of the HP and the work (W) needed to produce such energy. W includes the consumption of the HP compressor, the resistance installed to complement the compressor as well as the circulation pumps on both circuits of the condenser and the evaporator. The COP decreases with the increase of the water's temperature departing from the evaporator. This is shown in Figure 46. The COP is excellent with respect to other HP monitored by ESTIA, reaching 4.5 with a departure temperature of 35°C. The linear regression clearly shows the performance reduction in function of the departure temperature. It drops by 0.84 for an increase of 10°C of the departure temperature.

Improved regulation of the gas burner and the HP should be focused on the reduction of the ignitions of both systems. During winter, the HP departure temperature shouldn't exceed 40-45 °C in order to maintain a high COP. This temperature corresponds to the needs of the heating system. On the other hand, the gas burner should work with fewer ignitions, complementing the HP to heat the DHW up to 60 °C.

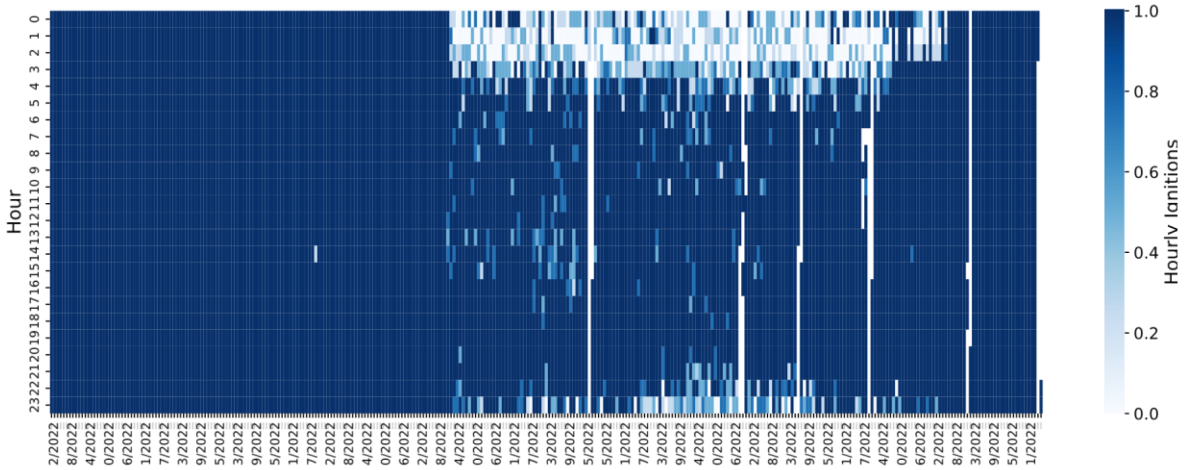

Figure 45: Heatmap of the hourly ignitions of the HP from the 1st of January 2022 to the 23th of November 2022.

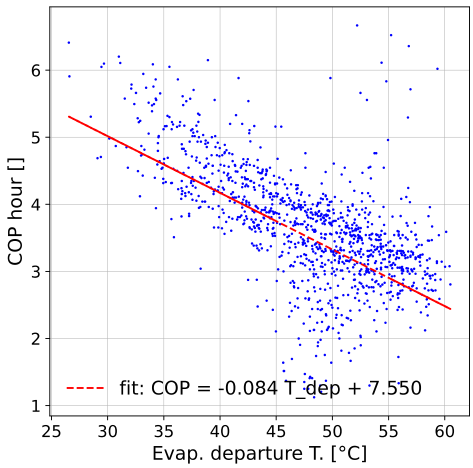

Figure 46: Linear regression on hourly HP's coefficient of performance plotted against the departure temperature of the evaporator.

During the summer the HP works mainly during the day, but ignitions can happen during the night. That should be avoided to reduce the ignitions from about three per day to one. The ignition of the burner should also be reduced. It should be used only for the legionellosis cycles once per week and to punctually complement the HP for DHW heating a maximum of once per day. Furthermore, the lower temperature of the main DHW boilers never drops under 45°C, and its mainly above 50°C. This means that the DHW stocking potential is not fully exploited at its full potential, allowing more flexibility in the settings of the technical installations.

In general, it is advised that after any changes to the technical installation's settings the performances of the HP and the gas burner are analyzed and compared with previous data. Indeed, the optimization process remains empirical.

6 Summary of results and expected impact

The KPI's listed in the proposal of the project are assembled here:

- Reduction of the Maintenance and Repair costs to 510€/a per occupant
- Final consumption of the building: 111.60 kWh/m²·a
- Annual overheating hours < 3%
- Metabolic CO_2 <1000 ppm
- RES as example (PV dimension and battery associated)

The maintenance cost for the building is evaluated by the building owner, CPEG. Table 9 resumes the maintenance costs for the different technical installations before and after refurbishment.

Technical domain	Before refurbishment [CHF/y]	After refurbishment [CHF/y]
Heating	4'157.20	
Heating, HP, monitoring, PV		9'040.75
Ventilation	1'071.65	600.65
Egain (regulation)	2'652.-	
Egain (temperature only)		1'833.-
Total	7'880.50	11'474.40
Total per household	171.30	204.90

Table 9: Maintenance costs before and after the refurbishment project

The important part of the maintenance cost after refurbishment is the data transmission for the project. The part of data transmission is 4'700 CHF per year. A large part of these are not essential for the function of the building and therefore this amount will be reduced once the project is finished. The final amount could be closer to 150 CHF per household.

In Section 5.2, it was described that the refurbishment project resulted in no performance gap in space heating and a light performance gap in DHW production. Finally, the overall consumption of the building for heating and domestic hot water was evaluated at 64 kWh/m² for the last year. This is an excellent result for a refurbished building recently commissioned.

Regarding the CO_2 measured in the two compliant appartements, the level often reaches 1000 ppm. Figure 47 shows the CO_2 level for both apartments that signed the GDPR agreement. The sensor in appartement 71 shows drift in the last 2 months of measurement. This is yet another example of failure of data surveillance as no system was introduced.

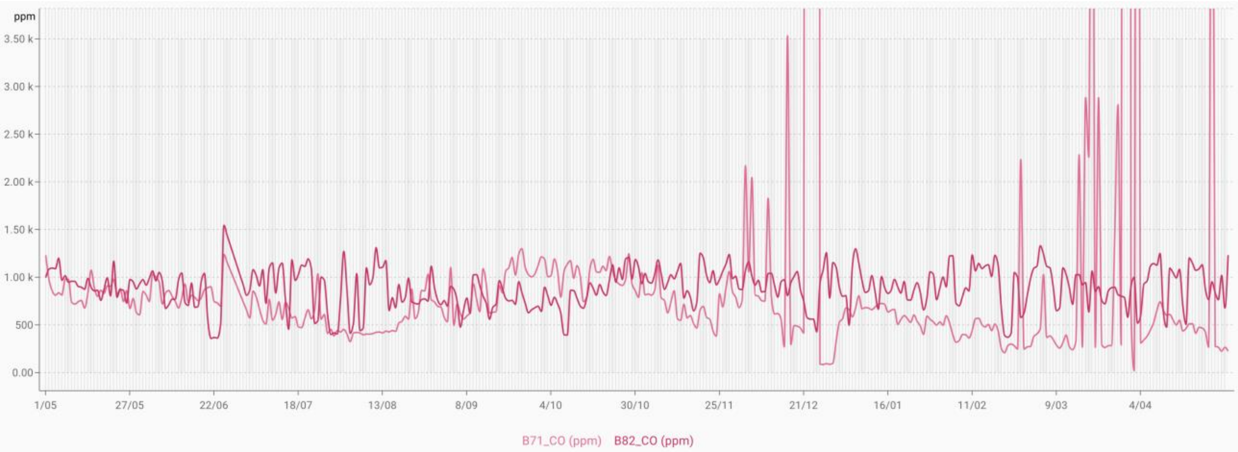

Figure 47: Metabolic CO2 measurements in apartment 71 and 82 over a whole year between 1st of May 2022 and 2023.

As observed on *Figure* 48, no overheating is measured in the two monitored apartments. This is mainly due to the freecooling system present on the last two floors. It allows to cool the appartements while using the recovered heat for the heatpump and production of DHW. This allows both comfort and energy efficiency.

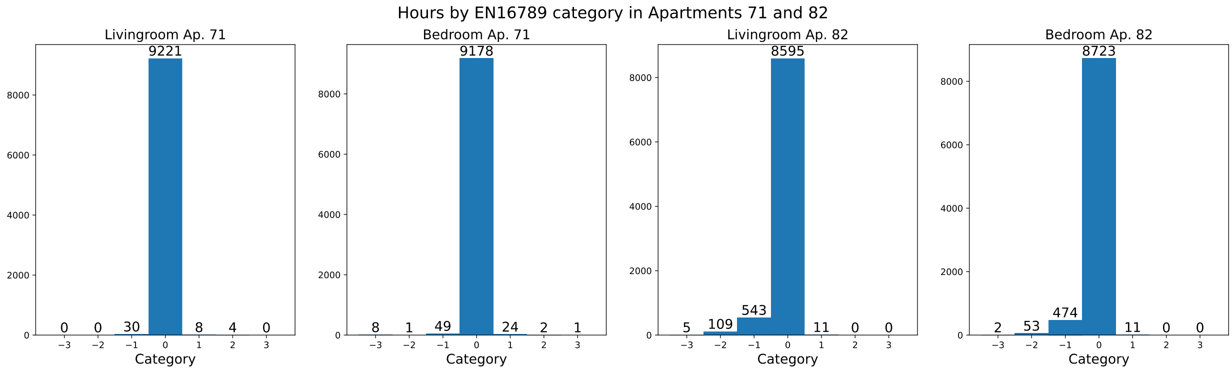

Figure 48: Histograms of indoor temperature classes according to EN16789 [14] for the two main rooms of both apartments complying with GDPR.

Overall, the building's energy goals are met. The use of the RES as data source for the different partners is working as TAU are using the data for their research. In addition, regarding indoor environment quality, the CO_2 KPI is not entirely met but the summer thermal comfort of the users (at least for the last two floors) can be proven.

The following implementation and research in this case study will include optimization of the technical installations ignitions, implementation of the data predictive control from STAM and discussion of results with TAU.

7 Conclusion

This analysis of Wendt 35 performance shows that the building performs as expected by the EPC, with zero performance gap on heating since its commissioning. This is a great achievement and was one of the main goals of PRELUDE for this building. Furthermore, it has been shown that the building meets the Swiss high energy standards requirements and those for the 2000W society.

On the other hand, the needs for DHW are high, therefore a complementary analysis has been carried out to elucidate the issue. The circulation of the DHW is responsible for a part of the loss but the consumption itself is higher than expected by the standards. The density of population in the building can be an explanation.

Wendt 35 is equipped with a RES installation that powers 10 apartments, technical installations, and the common areas. The analysis of its performance shows a high self-consumption, which is aligned with the provider estimations. Since the installation is small compared to the whole consumption, the building's autarchy remains low.

The key sub-systems of the technical installations have been analyzed in more detail. It has been shown that free-cooling is effective in reducing the temperature during the hot season with no increase in the energy consumption of the heat-pump system. Some optimizations of the HP and the gas burner exploitation have been found. These concern mainly their ignition frequency and sizing.

Finally, Wendt 35 is being used to test and verify some technologies developed by PRELUDE partners. The results are here presented and the following results and evolutions will be shared in D7.7.

8 APPENDIX A

a) ONLINE SOURCES

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[2] *Hannah Ritchie, Max Roser, and Pablo Rosado. "CO and Greenhouse Gas Emissions". In: Our World in Data (May 2020).* url: https://ourworldindata.org/emissions-by-sector

[3] *Energy Efficiency Trends in Buildings in Europe | Policy brief | ODYSSEEMURE.* 2021. url: https://www.odyssee-mure.eu/publications/policybrief/buildings-energy-efficiency-trends.html.

[4] PRELUDE : https://prelude-project.eu/

[5] *Regroupement dans le cadre de la consommation propre | SIG.* url : https ://ww2.sig-ge.ch/artisans_independants/offres-energies/solaire/ regroupement-consommation-propre.

[6] *Société à 2000 watts.* url: https://www.local-energy.swiss/fr/programme/ 2000-watt-gesellschaft.html#/.

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b) BIBLIOGRAPHY

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[16] "NOTICE TECHNIQUE 10 | 2021". In: (2020).

[17] Benoît Brandelet et al. "Impact of ignition technique on total emissions of a firewood stove". In: (2017). doi: 10.1016/j.biombioe.2017.10.047. url:http://dx.doi.org/10.1016/j.biombioe.2017.10.047.

[18] "ScienceDirect". In: (2014). doi: 10.1016/j.egypro.2014.12.217. url: www.sciencedirect.com.