Prescient building Operation utilizing Real Time data for Energy Dynamic Optimization

WP7 – DEMONSTRATIONS IN OPERATIONAL ENVIRONMENT

D7.3 – Demo site report #2 Turin

Version 1.0

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PRELUDE CONSORTIUM PARTNERS

	Participant organisation name	Country
1	AALBORG UNIVERSITET	DK
2	TAMPEREEN KORKEAKOULUSAATIO SR	FI
3	ASOCIACIÓN DE INVESTIGACIÓN METALÚRGICA DEL NOROESTE	ES
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9	CORE INNOVATION AND TECHNOLOGY OE	EL
10	ESTIA SA	CH
11	EUROCORE CONSULTING	BE
12	IREN SMART SOLUTIONS SPA	IT
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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

EXECUTIVE SUMMARY

In the framework of the PRELUDE project, WP7 deals with the demonstration in the operational environment of the solutions developed by the project. After the definition of demo site monitoring and commissioning specification (T7.1), the technologies will be validated through a long-term test in real operating conditions in different pilot sites (T7.2-T7.6). PRELUDE solutions are formed by: the communication platform FusiX dataspace (EMTECH), forecasting modules –Weather and Energy Forecasting Module (CORE), occupancy module (FB)– and control modules –dynamic Free-Running Model (POLITO), climate correlation model (BUL), comfort-energy efficiency optimiser (STAM), Data-Driven Predictive Control (FB) and predictive maintenance system (LASIA)– and the measurement and verification framework (LIBRA) for performance evaluation of the solution.

Task 7.3 is implementing PRELUDE-connected technologies and smart solutions in a residential demo case building in Turin, in the North-West of Italy. The selected building is a multi-apartment built in 1960–1970s and composed of 30 apartments, 8 of which are directly involved in the project. The envelope presents low levels of thermal insulation, and the technological and dimensional characteristics of the building are consistent with the majority of buildings built during the Turin industrial expansion. The heating system is centralised and connected to the Turin district heating system and based on radiators with vertical column distribution, while tenants personally produce the domestic hot water via natural gas-fuelled boilers.

The building does not feature any previous type of monitoring or smartness components or any pre-existing on-site RES production plants. In addition, the tenants of the 8 apartments equipped with sensors present different characteristics in terms of age, lifestyle and number of family members. The apartments have been equipped with different levels of smartness in order to test and identify the optimal set of sensors and actuator systems that allows all the building tenants to monitor their energy consumption, optimise indoor thermal comfort and implement the best actions to achieve conscious savings, both in economic and energy terms.

Different PRELUDE technologies will be tested in the Turin demo building, and testing integration works are described in this report. In particular, the dynamic free-running module developed by POLITO will be tested considering two levels of smartness (pre-optimised control thresholds and the 24h forecasting module) to support via the project middleware self-actuation actions (the building does not have automatic actuators). POLITO will also test some PREDYCE additional functionalities, supporting model calibration. Additionally, LIBRA will test the M&V solution, and ESTIA will apply the EPIQR+ approach to suggest retrofitting solutions. Thanks to the different sensor installations, it is possible to test and validate another PRELUDE technology: the Comfort-EE optimiser, developed by STAM, in the context of Tasks 4.4 and 5.4. As discussed in the respective deliverables (D4.4. and D5.4), the control module focuses attention on the cost optimisation of the thermal and electrical energy consumption of the building. This is done by leveraging, weather predictions, Occupancy module predictions (FB) and linear energy optimisation, producing a week-ahead scheduling of the different loads. The results will be displayed in the developed Human Machine Interface, within the designed PRELUDE portal.

The expected impacts and conclusions are summarised in the final section.

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ABBREVIATIONS

ACM	Adaptive Comfort Model
API	Application Programming Interface
CDD	Cooling Degree Days
CDH	Cooling Degree Hours
CV-RMSE	Coefficient of Variation of Root Mean Square Error
ECM	Energy Conservation Measure
EPW	EnergyPlus weather file format
FR	Free-Running mode
HAN	Home Area Network
HDD	Heating Degree Days
HDH	Heating Degree Hours
HTML	HyperText Markup Language
HTTP	HyperText Transfer Protocol
IAM	Identity Access Management
IDD	EnergyPlus Input Data Dictionary
IDF	EnergyPlus Input Data File format
IoT	Internet Of Things
JSON	JavaScript Object Notation
JWT	JSON Web Token
KPI	Key Performance Index
LLE	Living Lab Energetikum
LowE	Low Emissivity
M&V	Measurement & Verification
MBE	Mean Bias Error
MC	Mechanical cooling mode
MCU	MicroController Unit
NMBE	Normalized Mean Bias Error
PM	Particulate Matter
PMV	Predicted Mean Vote
POR	Percentage Outside The Range
PPD	Predicted Percentage of Dissatisfied
PREDYCE	Python Realtime Energy DYnamics and Climate Evaluation
REeST	REpresentational State Transfer
RMSE	Root Mean Square Error
SAREF	Smart Applications REFerence
SOAP	Simple Object Access Protocol
SSO	Single Sign On
UI	User Interface
VOC	Volatile Organic Compound
WBD	Wet Bulb Depression

1. INTRODUCTION

This report summarises the preparation work done to set the Italian PRELUDE demo case buildings, supporting the integration of PRELUDE technologies. The main objectives are to support the analysis of owner and tenant acceptance of tested and implemented PRELUDE relevant technologies, considering that all involved end-users are totally voluntary and are not part of the project consortium stakeholders. Additionally, the objective of the Italian demo case is to test PRELUDE connected technologies and smart solutions in real settings, representing the local market cases. The application of the common PRELUDE methodology, scaled and differentiated in line to the specific demo case needs and scenario, starts with the definition and implementation of smart building monitoring systems and adopting the project common middleware based on FusiX to connect monitored conditions with models in a bi-directional way. In the Turin case, the actuation (from model to demo) bases on self-actuation actions (human interface) for comfort and energy optimisations, including the end-user involvement dimension and the correlated performing results in the application objectives.

This report elaborates the preparation of the Italian demo, composed by 8-flats located in a representative multi-apartment building of the 60s in the city of Turin. In this section, the motivations and objectives for this demo, a description of the monitoring plan specification and of the correlated intervention plan, and the description of the PRELUDE implementation are introduced. In the following sections, the general description of the building and its current state – see Section 2 (IREN) –, the performed actions in order to prepare the demo case, i.e. the monitoring system and tests – see Section 3 (STAM&POLITO) –, and the description of the PRELUDE's technology implementations and expected testing actions – see Sections 4.1(STAM), 4.2 and 4.3(POLITO), 4.4 (FB) and 4.5 (LIBRA) – including some preliminary results are detailed. Finally, Section 5 (IREN) summarises the expected impacts and shortly conclude the report.

1.1. Objectives and motivation

IREN is responsible for the identification and management of the PRELUDE demo case of Turin, in Italy: a multi-apartment building built in 1960–1970s representative for the Turin and general northern Italian residential building stock. According to the Italian part of the results of the European project TABULA, in the study carried out by the Turin Polytechnic ("Building Typology Brochure – Italy 2011"), most of the Italian buildings constructed after the Second World War were built in the 1960–1970s and the vast majority consists of more than 16 apartments.

The building is constituted of 30 apartments without any previous monitoring or smartness components. This building has a centralised heating system, connected with the city district heating solutions, based on radiators with thermovalves to support end-user control. Additionally, it is characterised by a prevalent free-running summer season, in line with many Italian and southern European residential buildings. The tenants show different level of involvements, representing real local conditions.

The main expectation from using this building in PRELUDE as demo is the possibility to study, test and identify the optimal set of sensors and actuator systems that allows all the building tenants to monitor their energy consumption, optimize indoor thermal comfort and implement the best actions to achieve conscious savings, both in economic and energy terms.

Considering the starting point and the specific reference market sector, different levels of smartness have been considered during the PRELUDE implementation plan, even if they are based on sensoring solutions and on end-user self-actuation actions, without the installation of automatic actuators. This has supported the implementation of PRELUDE technologies – see Section 4 – that may be compatible with this building typology and context, including the Comfort - Energy Efficiency optimizer developed by STAM and different PREDYCE functionalities developed by POLITO. In particular, IREN carried out installation and maintenance of sensors (environmental sensors, smart plugs, electricity meters, smart thermovalves) and data acquisition devices for 8 apartments; collected data/analysis of results, technology implementation and testing are performed by POLITO and STAM thanks to the end-user involvement mediated by IREN.

Referring to the overall PRELUDE motivations and aims, the following goals are pursued in the Italian demo:

- To improve the quality of life and the well-being of the tenants (indoor climate)
- To generate energy and financial savings
- To assess the comfort levels by adding monitoring solutions and supporting their usage
- To assess potential additional investments on a cost-efficiency basis
- To identify potential renovation scenarios (ESTIA)

Furthermore, the feasibility and replicability of the proposed monitoring plan and of the tested human interface actuation strategies and correlated optimisation platforms will be analysed in the future project steps, thanks to the demo implementation works here described. This also includes the possibility to verify the adoption of low-cost commercial sensoring environmental solutions – assumed from the tenant-oriented market sector – in a scaling-up vision.

1.1.1. Monitoring plan and specification

Before the PRELUDE project began, the demonstration building administrator and tenants were approached to assess their suitability and willingness to serve as demonstration case for the PRELUDE implementation. Considering the absence of any previous monitoring or smartness components, the data acquisition and monitoring would have represented an opportunity to improve the level of smartness of the building and the PRELUDE project would have offered the possibility to provide and test significant smart sensors infrastructure.

Given the large number of apartments available within the selected demo building, it was decided to involve 8 apartments in the project, located on different floors and with different exposures, representing the building in its entirety.
The 8 apartments of the buildings have been involved in the project to test 3 different levels of smartness. Smart sensors and actuator systems have been installed with the aim of defining different home automation solutions for hygrothermal comfort.
All apartments have been equipped with intelligent thermostatic valves (TADO®), enabling the remotely adjustment of the indoor temperature of the room through a smartphone application. All apartments have been equipped with air quality monitoring devices (AIRCARE®). In 6 out of 8 apartments the following sensors have been installed: electrical meter at home electrical cabinet, and smart plugs (SHELLY®) connected to different types of appliances such as washing machines, dishwashers, TVs, etc. In addition, window opening and closing detectors (SHELLY®) have been installed in 3 out of 8 apartments. Finally, only one apartment presents also a presence sensor (SHELLY®).

Table 1 Italian demo case – overview of smart sensors and data collectors installed in the selected 8 apartments.

	FLAT 1	FLAT 2	FLAT 3	FLAT 4	FLAT 5	FLAT 6	FLAT 7	FLAT 8
Raspberry Pis	X	X	X	X	X	X	X	X
Electrical meter at home electrical cabinet	X	X	X			X	X	X
Smart thermovalves	X	X	X	X	X	X	X	X

Air quality monitoring devices	X	X	X	X	X	X	X	X
Smart plugs	X		X	X	X	X		X
Window opening sensors				X	X		X	
Presence sensors					X			
Capetti sensors					X			

Raspberry systems enable the collection of data coming from SHELLY® and AIRCARE® sensors, while the thermovalves TADO® currently provide data only through the smartphone app and further access approaches are in the process of being defined.
The monitored parameters for each device are hereafter described:

- *Electrical meter*: apartment electricity consumption;
- *Smart thermovalves*: room air temperature and air relative humidity;
- *Air quality device*: Volatile Organic Compounds, Particulate matter (PM10 – PM2,5), Air quality index, Sound pressure, temperature, humidity, CO_2, Ambient light, Atmospheric Pressure and Elettrosmog;
- *Smart plug*: electricity consumption of single equipment;
- *Window opening sensors*: open/close;
- *Presence sensors*: presence of the user in the room.

In addition to the above-mentioned sensors, POLITO installed in February 2023 a detailed monitoring system in one of the 8 flats detecting air temperature, air relative humidity, and CO_2 concentration in the four main rooms. Additional sensors of illuminance will be also positioned near selected windows, while the supply and return temperatures in the main radiators will also be detected for a limited period. This additional sensoring solution is based on the Capetti Winecap system, with a SIM based gateway supporting cloud data storage and remote data access via SOAP. Thanks to the remote connection, data would be stored also in the FusiX middleware. Data storage is redundant, including storage at datalogger, gateway and cloud bases. Data will be retrieved with a 10-minute interval and transmitted via cloud approximately every hour. These sensors may help during the model verification stage, supporting a deeper test of some of the technologies expected to be tested in the Turin demo, and allows to compare monitored results at room level with single-flat monitoring points. This study may help in defining the scalability and the level of needed simplification to run the proposed approaches.

Additionally, POLITO has installed a weather station on an accessible roof nearby, detecting main weather variables, including monitored direct normal and diffuse radiation levels and external CO_2 levels. These data are used to feed models and support digital twin applications being accessible via REST for storing in the project middleware. In this case, the approach is based on the fact that a single station may feed multiple-buildings in a homogeneous urban tissue. In addition, Meteoblue wheatear credits have been acquired by POLITO to support the 24h forecasting scenario and additional studies.

1.1.2. Intervention plan

As starting point of PRELUDE intervention, an inspection of the building has been performed in order to assess the building's characteristics of the envelope, general state and dimensions.

Technical documentations related to the building envelope and systems, drawings and plans of the building have been retrieved and a preliminary presentation of the PRELUDE project to the building tenants has been performed under the guidance of the building administrator.

A phase of adhesion collection was performed and 8 apartments have been selected accordingly, being representative to build the whole model of the building (thus located on different floors and with different exposures). The availability of an internet network was included as essential requirement to enable the connection and the expected data communication from the smart sensors.

Subsequently, a detail of all the types of sensors to be installed inside the selected apartments was shared with the tenants, providing them all the information on the use of applications for managing devices via smartphone.

Then, an in-field campaign was performed in the 8 apartments in order to:

- Collect plans indicating number and room disposal;
- Install meters, sensors and system actuators;
- Download and configure the mobile apps for the monitoring and control of each sensor and explain to the tenant of to use and interact with them;

A phase of collection and analysis of data has been performed on:

- Data retrieved from the smart sensors and meters installed in the 8 apartments;
- Energy consumption data both at single apartment level and at aggregate level (electricity consumption of some apartments, thermal energy consumption of the 8 apartments and district heating consumption of the whole building).

In parallel, numerous periodical on-site interventions in the apartments have been organized for the entire commissioning phase, in order to ensure the correct maintenance of the devices such as, for example, the recalibration of the thermostatic valves, the replacement of the batteries, the restoration of the devices which for various reasons were found to be non-functional or faulty.

Periodic follow-up with the tenants and the building administrator are performed in order to collect feedback about their experience and involvement in the demo of PRELUDE project and providing input for a possible implementation of an ad-hoc solution to improve the accuracy of the measurements.

1.1.3. PRELUDE implementation

Considering the PRELUDE technology list, the ones implemented are identified in the following Table 2. Furthermore, their implementation work is detailed in Section 4, while an introduction of these solution is reported here below in devoted sub-sections.

Table 2 PRELUDE technology list and identification of the Turin tested ones

Technology	Implementation
FusiX integration	Yes
Dynamic Free Running enhancement by PREDYCE	Yes (self-actuation)
Indoor-outdoor correlation module	No
Weather and insolation prediction module	No
Occupancy module	Yes
District heating integration module	No
VRE community	No
Renovation roadmap and EPIQR analysis	Yes (EPIQR+)

Dynamic energy forecasting	No
Comport and Energy efficiency optimiser and customised GUI	Yes
Predictive maintenance	No
Measurement and Verification (M&V)	Yes
Aggregation model	No

1.1.3.1. Comfort-EE module

Similar to what is stated in Deliverable 4.4, within Work Package 4 (Proactive optimization functions), the work performed in Task 4.4 focuses on the development of a proactive optimization model of the customers' energy usage in the residential sector, by integrating and customizing the already-existing STAMs' En-Power platform with a comfort module. This is done to consider the possibility of electrical load shifting for energy demand response together with the indoor comfort conditions, thanks to an elaborated building thermal model based on a grey-box approach.

The first step of the procedure, in order to have the optimization, is the training of the grey-box thermal model. By consuming different data sources, it is possible to estimate the models' parameters. Various levels of model complexity are available based on the availability of data sources. The input variables, for the parameters' estimation are related to internal and external temperatures, HVAC energy consumption and global horizontal irradiation, in forms of historical time series. These variables are retrieved from FusiX thanks to the endpoint connections, provided by the IoT platform, described in the following chapters. If the dynamic variables not available, the model can also rely on static information, such as internal volume of the building and global thermal transmittance of the walls.

Once the model is trained, by retrieving all the possible data from FusiX, and asking the remaining needed information to the user, it is possible to run the optimization, which has an optimization time horizon of 7 days. The needed data are collected in a tabular form in following sub-chapter 4.1.2.

The outputs of the optimization, serves as input to the framework of Data Predictive Control and UI development within Task 5.4. In the context of the Turin pilot, a customized UI is developed to have the remaining input data by the user and to give the suggestions and recommendations on the optimal energy consumption scheduling and actuation in the next hour.

1.1.3.2. PREDYCE scenarios of use

As described in the PRELUDE deliverable D3.2, the PREDYCE Python library is built with the goal of allowing the development and testing of different scenarios of use, which can ease the analyses of several building and climate related aspects, support tasks that were once mostly executed manually such as model verification and test new methodologies. PREDYCE allows to run parametric massive EnergyPlus simulations on a developed building model, given a weather file, a personalised input file and eventual monitored environmental parameters. Concerning the Turin demo case, several of these scenarios are exploited for different purposes, even if the principal tested ones are the ones referring to free-running. Particularly, these scenarios are:

Sensitivity analysis: it is the base PREDYCE scenario and allows to perform parametric analyses by automatically modifying the base building model and then computing requested KPIs. Considering PRELUDE goals related to climate potential and resilience analyses, this scenario was thought to use as simulation parameter also the EPW file, such allowing geographical and/or temporal analyses. This approach will be mainly described in the PRELUDE D8.5 and in the final demo result report.

Model verification: it is a semi-automatic scenario since it still requires a human interpretation to best define its settings: which parameters to include in the calibration procedure, their ranges and the steps. It allows to choose among a pre-defined set of building parameters minimizing RMSE and MBE on the target variable (e.g., energy consumption or internal temperatures), comparing simulation and monitored data from the field.

24h forecast: it allows to optimize a building free-running setting considering both indoor thermal comfort (based on ACM) and eventual consumption (e.g., due to mechanical ventilation or other actuators). Its main idea is to suggest the best building setting (e.g., shading positions, windows opening, mechanical ventilation values) to manual users or to automatic actuators based on weather forecasting for the next day. This scenario, developed specifically for PRELUDE is target in the Turin demonstrator as high smartness level. Similarly, a threshold optimisation approach, developed using the PREDYCE optimisation tool upgrading the sensitivity scenario, to control with fixed values (temperature and/or irradiation) shading and ventilation openings (ventilative cooling), is also prepared for the specific building and local typical climate in line with description in the PRELUDE deliverable D5.4.

EPW compiler: it allows to automatically generate an EPW file starting from different data sources (e.g., weather station, web services). It includes the download of the data, the cleaning procedure, the computation of the missing variables and the EPW generation.

1.1.3.3. M&V Framework

As outlined in Deliverable 4.3, Task 4.3 within Work Package 4 (Proactive optimization functions) focuses on the creation of a measurement and verification (M&V) framework. Since direct quantification of energy savings is not feasible, the M&V methodology enhances the assessment of energy savings by comparing measured consumption before and after the implementation of an Energy Conservation Measure (ECM), while accounting for relevant adjustments to model changes such as weather, operational modifications, or renovations. The overall developments and methodology adhere to internationally recognized directives and protocols, such as the International Performance Measurement and Verification Protocol (IPMVP) and M&V 2.0 guidelines, incorporating the latest advancements in research and are descripted in detail in the deliverable 4.3.

Following the principles of the M&V framework, a Module is created to quantify and validate the energy savings attained through the optimization process enabled by the implemented PRELUDE solutions within a building. The primary objective of the M&V module is to establish an adjusted baseline model for all demo cases, enabling the prediction of post-intervention energy consumption and ongoing monitoring of energy savings facilitated by the PRELUDE solution on a monthly basis. Hence, the validation process entails collecting data for the facility, encompassing both pre- and post-intervention phases. Consequently, the module replicates the conditions after the intervention phase as if the intervention had not taken place, enabling a comparison between the actual performance and the anticipated performance without the interventions.

Finally, the M&V module is integrated with FusiX, and the resulting output is readily accessible through the Graphic User Interface (GUI) of the PRELUDE Decision Support System (DSS) upon request.

2. TURIN DEMONSTRATOR

2.1. Description of the building and their current state

The Italian demo case is a residential building located in the city of Turin, in the North-West of Italy (see Figure 1): a multi-apartment built in 1960–1970s and composed of 30 apartments, 8 of which are directly involved in the project. It shows a regular rectangular shape composed of 9 floors, with three flats per floor, and a commercial basement. With one entrance, the building has two vertical distributional spaces facing south presenting one stair and a flat each. Eventually, in some floors, even if not in the monitored cases, the central flat can be substituted by two independent smaller flats, being facing both stairs. The main building facades are oriented facing south and north.

The building is representative of the Italian building stock of the period 1960–1970s: the envelope, in line with TABULA typical conditions, presents low levels of thermal insulation, and technological and dimensional characteristics of the building are consistent with the majority of buildings built during the Turin industrial expansion. The building has not been renovated, nevertheless, most of the tenants from the 8 participating flats have substituted, at different moments, the original windows with single glass and a wooden frame, with different solutions, e.g. double glazing with aluminium frame (no break) or double glazing LowE with PVC frames. The heating system is centralised and connected to the Turin district heating system and based on radiators with vertical column distribution, while the domestic hot water is personally produced by tenants via boilers (mainly based on natural gas), while very few flats have installed a split cooling and dehumidification system in one or more rooms.

The building does not feature any previous type of monitoring or smartness components or any pre-existing on-site RES production plants. In addition, the tenants of the 8 apartments equipped with sensors present different characteristics both in terms of age, lifestyle and number of family members. The general involvement of people is medium-to-low representing a representative sample of typical Italian residential market conditions.

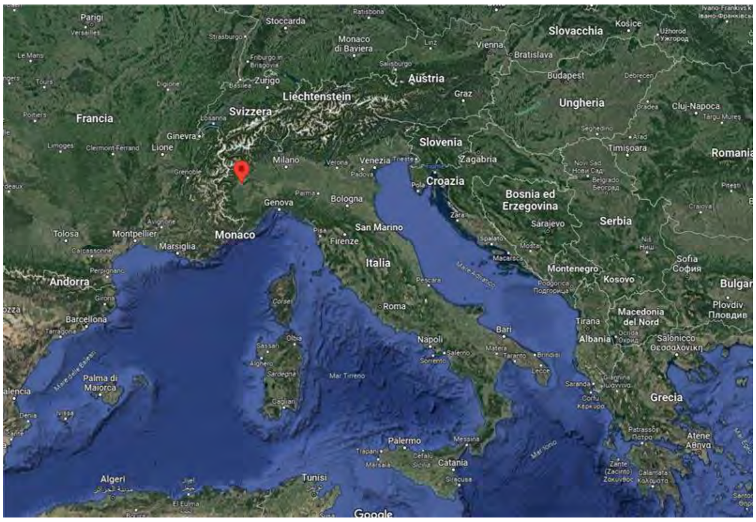


Figure 1 - Italian demo case location – multiapartment building in Turin, in Piedmont region in North-West Italy.

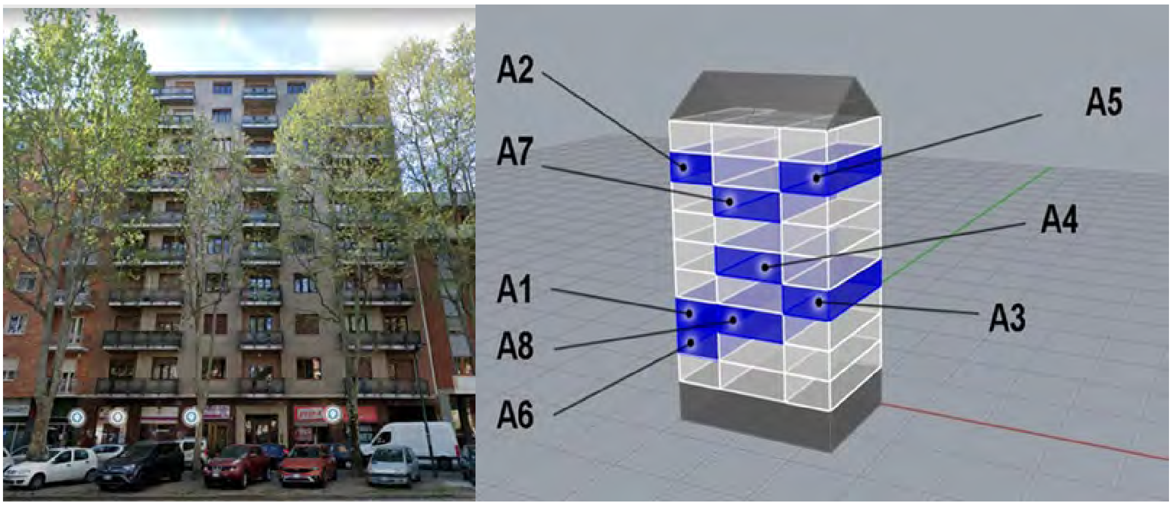


Figure 2 - Italian demo case – multiapartment building located in Turin. North view of the building (left) and overview of the 8 selected apartments equipped with sensors (right).

2.1.1. System description

For space heating, the demo site building is connected from November 2021 to the district heating system of the city of Turin, the largest in Italy. It currently connects more than 50 million m^3 of buildings and the total length of the network is about 515 km.

An overview of the monthly district heating consumption referred to the demo building is provided in the following picture, for the period 2021–2023.

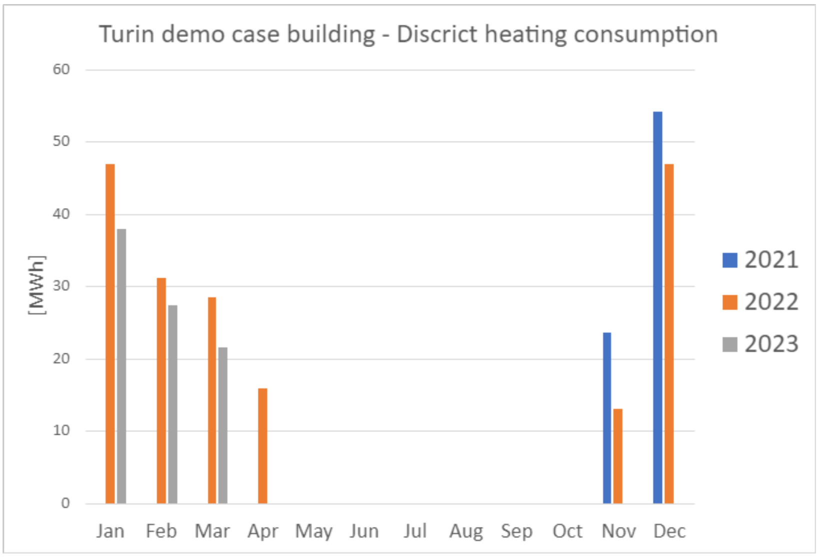


Figure 3 - Italian demo case building district heating consumption

For the domestic hot water, each apartment is equipped with an independent generation system fuelled by natural gas. No controlled mechanical ventilation system is present in the apartments nor in the building.

In order to trace the heat consumption trends of the building under study, it was possible to collect energy data using the monitoring system located downstream of the heat exchange substation serving the entire building. Accordingly, it was possible to collect the thermal consumption values recorded every 5 minutes. As an example, the graphic representation of heat consumption for representative days of the heating season recorded in 2022 is shown in the following.

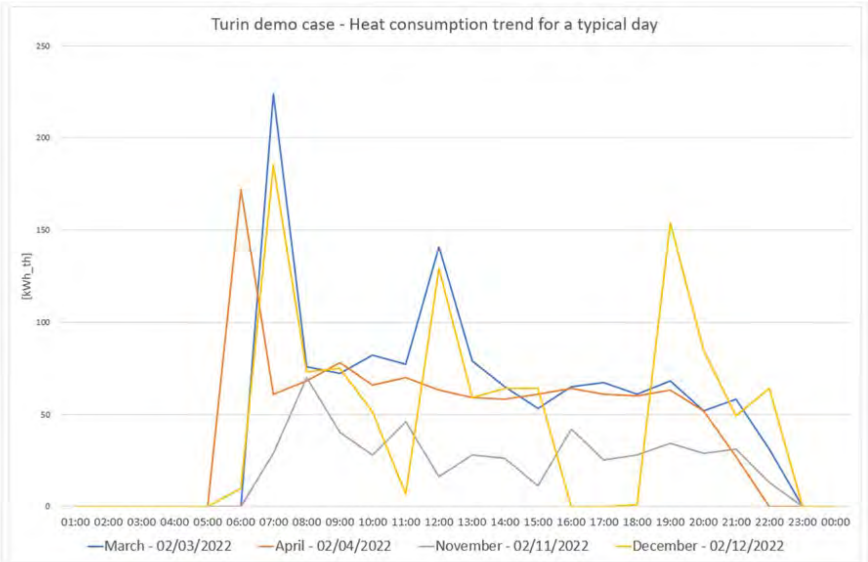


Figure 4 - - Italian demo case building – Heat consumption for representative days during heating season 2022

2.1.2. Motivation and user engagement to participate to the project

Since the demo site building was not provided of any previous monitoring or smartness components, the building administrator and tenants have been informed about the possibilities offered within the PRELUDE project and they have proved their strong interest to the reinforcement of the level of smartness of the apartments, through the installation of a smart sensors infrastructure, and very curious to test smart technologies with the objective to improve their energy consumptions and indoor comfort conditions throughout mobile apps for energy and comfort monitoring.

For the 8 selected apartments, the tenants were awarded with a smart infrastructure constituted by meters, sensors, actuators and have been guided by expert technicians in their installation, user guide and free-of-charge periodical maintenance.

2.2. Identification of key requirements matching demo requirements with PRELUDE technologies

In collaboration with the partners involved in the demonstration phase of the PRELUDE project, a list of parameters to be measured in the Turin demo site has been formulated as follows:

- Indoor air temperature
- Indoor relative humidity
- Indoor CO_2 level
- Indoor VOC level
- Indoor illuminance
- Window opening
- Electrical consumption
- Thermal heating consumption
- Outdoor environmental conditions

According to this set, research has been conducted in order to identify the most promising smart meters and sensors solutions available on the market or which have provided to be reliable in previous experience developed by the working group. The key requirements of such smart technologies were their low cost, low maintenance need and possibility to offer monitoring service and data collection through mobile app with an easy-to-understand graphical interface for end users.

In the framework of the PRELUDE project, the collected data are necessary for model development, support digital twin applications, analyse potential effects of different smartness levels on energy consumption and test the operability of smart components on FusiX.

2.3. Overview of the local regulations and standards

The Energy Performance Building Regulation in Italy interests three different levels: national, regional and local level.

The implementation of the Energy Performance of Buildings Directive in Italy started in 2005, with the national transposition Decree no. 192/2005, then with a Decree no. 311/2006 and finally with Decree n. 59/2009, which indicates Technical Specifications UNI/TS 11300 Part 1 to 4 (now 1 to 6) as the reference for the energy certification of buildings, in acknowledgment of the European Standard for the envelope and for the heating system. The four parts of the technical specifications UNI TS 11300 are the following:

(1) Determination of the thermal energy demand of the building in summer and winter;

(2) Determination of the primary energy requirements for winter heating and domestic hot water production;

(3) Determination of primary energy requirements for summer air conditioning;

(4) Use of renewable energies and alternative methods of generation for space heating and domestic hot water preparation.

For the thermal comfort requirements, the Italian national regulations are ISO 7730/2005 and EN 16798-1 standards.

3. PREPARATION OF THE TURIN DEMO CASE

In line with the monitoring plan specification described in Section 1.1.1, this section details the main installed sensor systems including the actuator solutions. Section 3.1 details the main monitoring architecture, including technical specifications of sensors and actuators. The IoT platform and data collections, the FusiX integration are described in Section 3.1.4. Additionally, Section 3.2 describes the additional downscaling sensor monitoring system, applied to one representative flat, including the description of sensors and sensor architecture, the cloud platform, the FusiX integration and sample exploration of initial retrieved data, including a short description of the adopted KPIs, retrieved by a monitored analysis performed via the PREDYCE tool (see the PRELUDE deliverable D3.2). Finally, Section 3.3 details the installed cloud-connected weather station, including the description of the sensors and their architecture, the FusiX integration, and a sample exploitation of current retrieved data.

The usage of all the mentioned monitoring solutions to support PRELUDE technologies is detailed in Section 4.

3.1. Technical specification of the proposed demo monitoring solution

3.1.1. Hardware Architecture

The heart of the system's hardware architecture provided by STAM is the microcontroller (MCU), consisting of an electronic device integrated on a single electronic circuit, also called an on-chip computer. The microcontroller is also responsible for pushing data in the cloud and thus it is a critical part of the data integration pipeline with the FusiX platform.
In Figure 5 it is shown the general architecture of the monitoring system on edge.

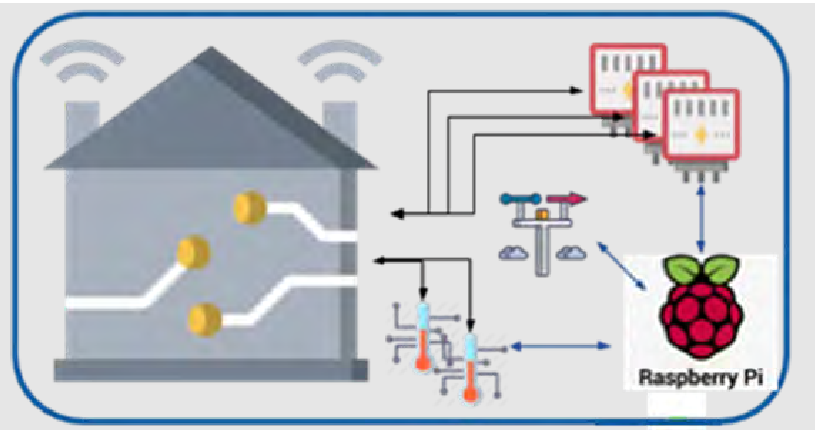


Figure 5 General architecture schema

3.1.2. Wi-Fi Internet sub-network

All the devices will send data through the Wi-Fi internet protocol. In each facility, a Wi-Fi internet sub-network is going to be created in order to achieve a clean and dedicated network for the IoT devices. This is the so-called HAN (Home Area Network) paradigm, commonly used in the building energy management.

3.1.3. Sensor specifications

As described in D5.1, there are several types of installed sensors in the different apartments of the Turin pilot. The overall specification of chosen sensors is described in the following.

First of all, as above-mentioned, the microcontroller, which enables the data streams through the Wi-Fi network, chosen to operate as a gateway is the "Raspberry Pi 4 B" model which is available from June 2019.

Figure 6 Raspberry Pi single-board computer installed in the demo site apartments

From the monitoring point of view, it is possible to distinguish two different categories of sensors:

- Energy monitoring devices
- Indoor monitoring devices

3.1.3.1. Energy monitoring devices

Smart Meters (SMs) are electronic devices capable of measuring energy consumption and complementary data compared to a traditional meter, as well as exchanging information using various types of communication protocols. The main provided measurements are:

1. Active power: It is the power that is instantaneously consumed in an electrical circuit, and it is measured in Watts (W). The monitoring of the power over time allows to obtain the energy consumption. In the case of generation from renewable plants and energy input into the grid, the power is indicated with a negative value.
2. Reactive power: It is the power exchanged between generators and electrical users. Reactive power is measured in reactive Volt-Amperes (VAR).

3. Voltage: Also called electromotive force, it is a quantitative expression of the difference in the electric potential between two points in an electric field and is measured in Volts (V).

In this work two main types of energy monitoring devices are analysed and installed:

- ShellyEM by Allterco Robotics is a 2-channel energy control and monitoring device which allows to monitor, simultaneously and in real time, the energy consumption of 2 electrical loads (single-phase) with current demand up to 120A. It is designed to be integrated into the electrical system and is usually positioned inside the electrical panels to monitor the power lines. The device, through a relay integrated inside it, also allows the control of switches and contactors, to include the remote ON/OFF (switching on and off) functionality of the entire power line. Allterco Robotics provides the APIs in open-source mode. It should be emphasized that the power consumption of the device, less than 1W, which allows the energy monitoring without affecting it.

- Smart plug which are equipped with a function suitable for the specific project purposes, as they have the ability to monitor consumption and, thanks to a Wi-Fi connection with the Raspberry microcontroller it is possible to save data on the cloud. It is also possible to remotely control it as regards of switching on and off, thus it is possible to control the operation of the air conditioner itself. It allows the monitoring of voltage, current, power and energy consumption and the logging of the monitored data. Two typologies from the Allterco Robotics are considered in Turin pilot: the Shelly Plug and the Shelly plug S.

STAM already tested all the energy monitoring devices shown above and currently it is possible to reach a power data sample every 10 seconds. The data are considered as average in 10 seconds and aggregated in order to reach a 5-minutes granularity.

Figure 7 Smart plugs installed in the demo site apartments

3.1.3.2. Indoor monitoring devices

The devices selected for the indoor monitoring are the devices by the AIRCARE Company. The company offers a communication service trough API directly from their platform, so that their dataflow is not going to pass through the above-described Raspberry Pi. The high-level AIRCARE sensor can provide several measurements which are the following:

- Volatile Organic Compounds
- Air Quality Index
- PM10 and PM2.5
- CO_2 and CO_2 equivalent
- Sound Pressure
- Temperature
- Humidity
- Ambient light
- Atmospheric pressure
- Wi-Fi signal level and networks
- Electro smog at High and Low frequency

For all the parameters the granularity is the average along 15 minutes for the AIRCARE PRO. In the PRELUDE Project the indoor monitoring relies on the model PRO, powered supply by AA batteries lasting up to 12 months.

Figure 8 Indoor monitoring device AIRCARE installed in the demo site apartments

3.1.4. IoT platform

The Turin pilot's data, in terms of air quality (Aircare) and energy meters (ShellyEM, Smart Plugs etc.) are stored on Thingsboard and the REST APIs exposed in the STAM's Data Retriever module which can be used to retrieve them. The REST APIs are accessible after authentication to the Identity and Access management application (Keycloak).
These three different modules and microservices are together providing the IoT which, in the last instance, is integrated with the PRELUDE data middle-ware FusiX in order to make the above-mentioned data accessible to the consortium.
In general, buildings, rooms and electrical and thermal loads, which are grouped under the name of Digital Twin, are the main focus of the performed work and they are modelled in the IoT platform as static, i.e., they do not change unless changes are made to the configuration of the environment (e.g., installation of new devices).

3.1.4.1. Data Retriever

The Data Retriever module is a module to retrieve time series of environmental and electricity consumption data from different data sources. More precisely, it exposes REST APIs to obtain a digital model related to the source configuration, e.g., the rooms of a building, the electronic equipment inside them and the corresponding sensors installed, and the telemetry related to these sensors.
The Data Retriever module is a Spring Boot-based microservice capable of obtaining telemetry from different data sources. Each of these sources can expose data and resources in a non-standard format. In order to interface with these sources and reformat the data into a standard format compliant with the SAREF ontology[1], the application is able to perform runtime loading of different adapter implementations and, following an HTTP request, choose the appropriate adapter based on a parameter in the request's JWT.
The main components of the module are:

- data-retriever-api: library containing the templates and interfaces for implementing new adapters;
- data-retriever-rs: Spring Boot application exposing the REST API to get the telemetry data and the digital model;
- data-retriever-thingsboard: sub-module containing implementations of the Thingsboard adapters.

A more detailed description of the sub-modules and their structure is given in the following sections.

Data-retriever-api

The sub-module data-retriever-api is a library that enables the choice between different implementations of adapters at runtime based on the pilotId claim extracted from the JWT of the HTTP request. To choose the correct adapter from those loaded in memory it exploits a Spring factory that uses the pilotId attribute to identify the services and components (i.e., Spring beans) that make up the adapter.
The library contains:

- the IAdapterCode and IAdapterProperties which represent, respectively, the identification code of an adapter and the minimal properties for configuring an adapter;
- a PhysicalObjectType enum representing the main types of "physical objects" that the application supports;
- the service interfaces that an adapter must implement to retrieve the digital model of the data source and the actual data;
- the resources and parameters of the HTTP request, described in more detail in the Data Model section;

[1] https://saref.etsi.org/

- a Spring converter that allows the textual representation of an adapterCode to be converted into its corresponding implementation (raising an exception if no adapter code was found);
- a Spring AdapterFactory singleton that contains the list of available adapters and contains the routing logic to the requested adapter based on pilotId.

Data-retriever-rs

The data-retriever-rs sub-module is the Spring-Boot application representing the REST layer of the data-retriever module. More precisely, it contains:

- the @RestController which exposes the endpoint for obtaining the data source configuration;
- the @RestController that exposes the endpoint to retrieve the telemetry data related to the available sensors.

All endpoints are protected via Keycloak: each HTTP request must be issued by an authenticated user on a Keycloak instance and must contain a valid JWT. The Keycloak instance that the application uses as OAuth2 Resource Server is configured via properties files.
From each valid HTTP request, the additional claim pilotId is extracted, i.e., the identification parameter of the adapter to be used to request data from the correct source and format it in accordance with SAREF (see Data Model section).
To do this, a Spring bean with PROTOTYPE scope is used, which is instantiated with the information of the current HTTP session, in particular the JWT sent with the request, at each incoming HTTP request.

Data-retriever-thingsboard

This sub-module is the standard implementation of the adapter to Thingsboard provided by default, which allows the IoT Thingsboard platform to be queried for data to be converted into SAREF-conformant resources.
In particular, it contains the implementations of:

- the IAdapterProperties interface with the configuration to connect to Thingsboard (properties are statically defined via a properties file);
- the IAdapterCode interface representing the identification code of this adapter;
- the implementation of the PhysicalObjectService with the BL to request the digital model of the configuration of the associated appliances and sensors from Thingsboard;
- the implementation of the TelemetryService with the BL to retrieve the telemetry time series of the installed sensors from Thingsboard.

The sub-modules data-retriever-api, data-retriever-rs and data-retriever-thingsboard do not have databases.
In the sub-module data-retriever-api, however, the classes representing the parameters of the endpoints exposed in data-retriever-rs and the returned resources are defined.
More precisely, in data-retriever-api one can find:

- the parameter classes TelemetryByDeviceTypesParams and TelemetryByDeviceUuidParams which allow the request to be made to a data source to be configured; it is important to note that the serialization/deserialization is subject to validation by means of javax validation annotations
- resources:
    - Measurement, which represents the telemetry data retrieved;
    - PhysicalObject, which represents the physical object containing generic master information and a list of devices/sensors associated with it;
    - Telemetry representing the association between sensor, device and telemetry retrieved.

It is important to note that the returned resources conform to the SAREF ontology and its extensions.

In the following Figure 9 the SAREF ontology graph is represented, where it is possible to notice the entities inside the boxes and the relationships that can be modelled which are represented by the arrows connecting the boxes.

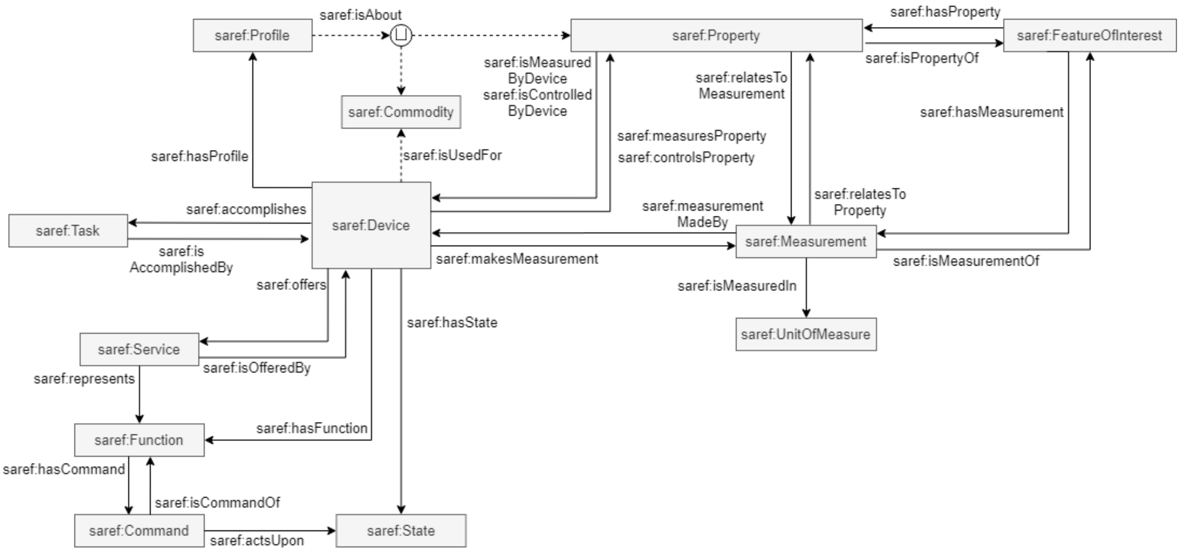


Figure 9 Graphical schematization of SAREF ontology

3.1.4.2. Thingsboard

Thingsboard[2] is an open-source platform for the Internet of Things (IoT) that allows the easy connection and management of devices, data collection, visualization, and analysis. It provides a comprehensive set of features for building end-to-end IoT solutions, including device management, data visualization, analytics, and rule-based automation. It is designed to be highly scalable, flexible, and customizable, making it an ideal platform for a wide range of IoT applications. Thingsboard platform is built on top of the Java Virtual Machine (JVM) and is based on a microservices architecture. It uses Apache Kafka as its message broker, allowing for reliable and scalable communication between devices and the platform, while it supports a wide range of protocols for device connectivity.

This type of platform also provides a web-based user interface for managing devices, visualizing data, and configuring rules for automation. The user interface is built using AngularJS, a popular front-end framework, and is designed to be responsive and intuitive. Moreover, Thingsboard supports a variety of data storage options, including Cassandra, PostgreSQL, and TimescaleDB. This allows users to choose the data storage solution that best fits their needs. In addition to its core features, Thingsboard also provides a variety of extensions and plugins that allow users to customize the platform to their specific use cases. These include custom dashboards, integrations with third-party services, and plugins for data analysis and visualization.

Overall, Thingsboard is a powerful and flexible platform for building end-to-end IoT solutions, providing a comprehensive set of features for device management, data visualization, analytics, and automation.

In the energy field it can be applied to energy monitoring and management, providing a comprehensive solution for tracking energy usage, identifying inefficiencies, and optimizing energy consumption.

[2] https://thingsboard.io/

3.1.4.3. Keycloak

Keycloak[3] is an open-source identity and access management (IAM) solution that provides single sign-on (SSO), social login, multifactor authentication, and authorization services for web and mobile applications. It was developed by Red Hat and released under the Apache License 2.0 and it is designed to simplify the task of securing applications and services by providing a centralized authentication and authorization framework.

Keycloak is built on top of Java, and it uses a variety of open-source libraries and frameworks, such as Wildfly, Undertow, and Hibernate. It can be deployed as a standalone server, as a Docker container, or as a Kubernetes cluster. Keycloak provides a web-based administration console, which allows administrators to configure users, groups, roles, and policies. It also provides a set of APIs and protocols, such as OpenID Connect, OAuth 2.0, and SAML, that can be used to integrate Keycloak with other applications and services. Keycloak supports various authentication mechanisms, such as username/password, social login (e.g., Google, Facebook, Twitter), and multifactor authentication (e.g., SMS, push notifications). It also supports different authorization models, such as role-based access control, attribute-based access control, and dynamic authorization policies.

3.1.5. FusiX integration

In order to integrate the Data Retriever module, together with the Turin pilot Thingsboard instance, with FusiX platform different APIs are exposed and documented. For this, a documentation is available for the partners in order to properly communicate and retrieve data.

OpenAPI is chosen as framework for the exposition and sharing of the developed IoT platform. This is done because it is an open-source specification for building and documenting RESTful APIs. OpenAPI is widely adopted in the software development industry and is considered a standard for designing and consuming APIs. The OpenAPI specification defines a language-agnostic interface for describing the functionality of an API, including its endpoints, parameters, request and response formats, authentication methods, and other details. This interface is written in YAML or JSON format and serves as a machine-readable contract between the API provider and consumer.

The exposed OpenAPI specification are shared through the open-source tool Swagger at a specific endpoint. The Swagger toolset is very useful for building, documenting, and consuming RESTful APIs because it can include several components, such as a graphical user interface for designing and testing APIs, a code generator for automatically generating client code in various programming languages, and a documentation generator that can produce interactive API documentation in HTML format.

Inside of the documentation, it is possible to distinguish three different services to retrieve the data which are referred to the three entities in the operated SAREF ontology:

- **Buildings and spaces (rooms):** to obtain the configuration of buildings and spaces, the REST API exposed via the GET/buildings endpoint can be used. Entering the token obtained after authenticating with user credentials in the authorization header, the metadata for buildings and spaces associated with him will be provided;

- **Loads and power lines:** to retrieve the list of monitored loads and power lines, the REST API exposed via the GET/physical-objects endpoint can be used. Entering the token obtained after authenticating with user credentials in the authorization header, the metadata for buildings and spaces associated with him will be provided, metadata relating to the physical objects, connected devices and sensors will be provided.

- **Telemetries:** two endpoints can be used to obtain sensor telemetry:

[3] https://www.keycloak.org/

1. GET/telemetries by entering in deviceTypes a list of device types from those currently supported (aircare, shellydw2, shellyem, shellymotionsensor, shellyplug-s, shellyplug);
2. GET/sensors/{sensorUuid}/telemetries using the sensor identifier obtained from the list of monitored loads.

The reference dates (from and to parameters) must be specified according to the ISO format yyyy-MM-dd'T'HH:mm:ss.SSSXXX. E.g., 2023-02-17T00:00:00.000Z.

3.2. Additional sensors for detailing room monitoring

In one of the apartments (A5), additional environmental sensors were installed by POLITO to make possible additional analyses and more detailed tests of the PREDYCE functionalities and of the developed free-running optimization algorithm (see Sections 4.2 and 4.3). Additionally, these sensors allow for investigating the difference between having a single home-based sensor per flat or one sensor per room and support the discussion about the feasibility of using low-cost sensoring systems available on the private market in respect to professional measurement cloud solutions, such as the one here installed.

3.2.1. System specification and hardware architecture

The selected monitoring system is based on the CAPETTI Winecap solution[4]. It is composed by battery-based dataloggers with different sensors showing a compact, scalable and integrable solution where loggers communicate with a SIM-based gateway via the Winecap LuPo (long range) communication protocol. The solution is cloud connected and allows to visualise, in semi-real time, the monitored data via the Winecap webservice. Additionally, monitored data are accessible also via SOAP to be automatically retrieved by middleware solutions, such as the common PRELUDE one.

The system is specifically selected being:

- Scalable and modular (new dataloggers may be added or substituted easily while each logger may be accessed/controlled directly via a computer connection, in addition to the cloud level)
- Requiring a limited number of plugs (only the one of the gateway) and avoiding cables thanks to the use of internal batteries with a long lifespan
- Acceptable by end users thanks to the neutral visual aspect of the loggers (white compact boxes) avoiding, with the exclusion of surface temperature sensors for radiators, external probes
- Based on a commercially available solutions, allowing for being replicated and adapted to scaling up intervention
- The remote access to data via both a proprietary cloud web-platform and via SOAP
- The independency from local internet connections thanks to the integrated SIM
- The reduction of data loss risks having redundant saving positions (including loggers, gateway and cloud resources)
- The use of secure protocol such as SOAP which is connectable to the FusiX PRELUDE common middleware

Data are saved each 10 minutes and transmitted via the gateway to the server infrastructure each hour, the data saving interval may be changed remotely via the Winecap webservice. Considering the nature of the specific installed extra-monitoring architecture, only one gateway is needed to support the installed probes.

[4] See www.capetti.it/en/company (last view 29/05/2023)

3.2.2. Sensor specifications

Installed dataloggers are able to monitor environmental variables in main A5 rooms, including air dry bulb temperature, relative humidity, and indoor air quality, via a CO_2 probe. Additionally, illuminance sensors are also positioned in order to indirectly detect shading system activation. A presence detecting probe is also installed in the main room. Finally, radiators supply and return contact temperatures are monitored. Here below are detailed the specifications of each installed sensor type.

Modular wireless Datalogger Gateway (MWDG-GSM-B)

The installed solution is based on a gateway with a SIM slot allowing to receive data from connected dataloggers, store and transmit data to the Capetti infrastructure. The gateway is independent by local internet connections and has 2 antennas. Additionally, it is the sole part of the installed system requiring an electrical plug, although the redundancy of data storage abilities allows to reduce the risks of data losses if the electrical plug is disconnected.

Figure 10- Sample commercial image of the installed Capetti gateway [https://www.capetti.it/]

Wireless smart datalogger CO2, Pressure, Relative Humidity and Temperature (WSD00THCOP):

These sensors allow to monitor all the four mentioned variables. Atmospheric pressure is an extra variable offered by the selected solution. These sensors have a red signal that may be activated to provide alerts to tenants when a certain variable is reaching a specific threshold. Although this functionality is currently not activated, it can be possible to manage the activation thresholds remotely via the Winecap interface.

Figure 11- A WSD00THCOP probes/dataloggers [https://www.capetti.it/]

Wireless smart datalogger Temperature, Relative humidity and Illuminance (WSD00TH2L):

These sensors allow to monitor air dry bulb temperature, relative humidity and illuminance (lux) values. For these sensors the position is critical to correctly monitor illuminance values. For this specific application case, some of them are positioned in a proper point of rooms allowing to detect a general illuminance restitution (even if never horizontally at working level), while in the other rooms they are positioned in agreement with tenants in order to indirectly detect if shadings are activated during daytime.

Figure 12 - - A WSD00TH2L probes/dataloggers [https://www.capetti.it/]

Wireless smart datalogger Light intensity - Physical presence (WSD00LP)

This sensor retrieves illuminance and presence. Only one has been installed and is positioned vertically on a shelf with a high view factor on the main room. The probe has a small presence detection couple that need to be not covered by obstacles.

Figure 13- A WSD00LP probes/dataloggers. [https://www.capetti.it/]

Wireless smart datalogger with two NTC10K transducer inputs (WSD12-TT10K + NTC10K)

This datalogger is equipped with two transducer probes allowing to measure contact temperatures within the range -50 °C … +105 °C. The measurement part is in brass, and the system is waterproof.

Figure 14- A WSD12-TT10K probes/dataloggers. [https://www.capetti.it/]

The following Table 3 reports main technical characteristics of the installed Capetti's sensors including measure ranges, precisions, and resolutions.

Table 3- Sensor characteristics (Capetti winecap)

	WSD00THCOP	**WSD00TH2L**	**WSD00LP**	**WSD12-TT10K + NTC10K**
Connection	Wireless, USB	Wireless, USB.	Wireless/USB	Wireless/USB
Indoor Temperature – transducer type	NTC10KΩ	NTC10KΩ		NTC10KΩ
Indoor Temperature – measure range	-10°C ÷ +60°C	-10°C ÷ +60°C		-50°C ÷ +105 °C
Indoor Temperature – measure precision	±0,2°C whole range	±0,2°C whole range		± 0.5°C @ 40°C
Indoor Temperature – measure resolution	0,01°C	0,01°C		0,01°C
Relative humidity – transducer type	CMOSens® technology	CMOSens® technology		
Relative humidity – measure range	0 ÷ 100%	0 ÷ 100%		
Relative humidity – measure precision	±2,0% (typical) from 0% to 90%	±2,0% (typical) from 0% to 90%		
Relative humidity – measure resolution	0,05%RH	0,05%RH		
CO_2 - measure range	0 ÷ 5.000ppm			
CO_2 - measure precision	0÷5.000ppm: < ±50ppm (+3% measured)			
CO_2 - measure resolution	1ppm			
Atm. Pressure – measure range	700÷1.100mbar			
Atm. Pressure – measure precision	Typical: ±2mbar (20÷80 % RH)			
Atm. Pressure – temperature dependency	±0,015mbar/K			
Light intensity - Transducer type		Photodiode array	Photodiode array	
Light intensity - Measure range		0 ÷ 16KLux	0 ÷ 16KLux	
Light intensity - Measure resolution		1Lux	1Lux	
Presence – transducer type			PIR	
Presence – measure range			Coverage 360°C 102° horizontal angle – 92° vertical angle	
Presence – distance			12 meter circular	
Presence – ΔT needed for detection			≥4°C target and environment	

3.2.3. Implementation plan

Indoor environmental variables, including air temperature, relative humidity and CO_2 concentration, are monitored in all principal spaces. Differently, illuminance sensors are able to detect valuable lux values in only two of the spaces (act104aa and act105aa), while in the others they are positioned in a way to allow a general check of shadings, but not allowing to correctly detect illuminance. Their positioning is defined in line with available spaces and after a specific discussion with end users in order to increase their acceptance. Regarding the contact radiator supply and return temperatures, three radiators are equipped with these sensors, while the fourth is not controlled in line with the specific agreement with the tenants.
Sensor positioning is reported in the following map-view – see Figure 15–, including the reference nomenclature adopted for each environmental space (room) in respect to the main room's usage. The nomenclature is adopted to locate and identify both sensors and simulation model results in order to connect them in the PREDYCE platform – see Section 4. For sensors, the nomenclature also includes the acronym used to identify the specific monitored variable. Table 4 describes the adopted approach. For example, *F08_A5_act105aa_T_db_i[C]* identifies an internal dry bulb temperature probe located in a living room, in demo A5 at the building floor 8.

Table 4- The PREDYCE nomenclature structure for sensors

Demo name	*_floor/block name*	*_room/activity name*	*_MAC sensor address*	*_type of measured variable*
Free name	1 letter digit + 2 number digits	Act, 3 number digits, 2 letter digits	MAC+8 number digits	Coherent with the PREDYCE tool

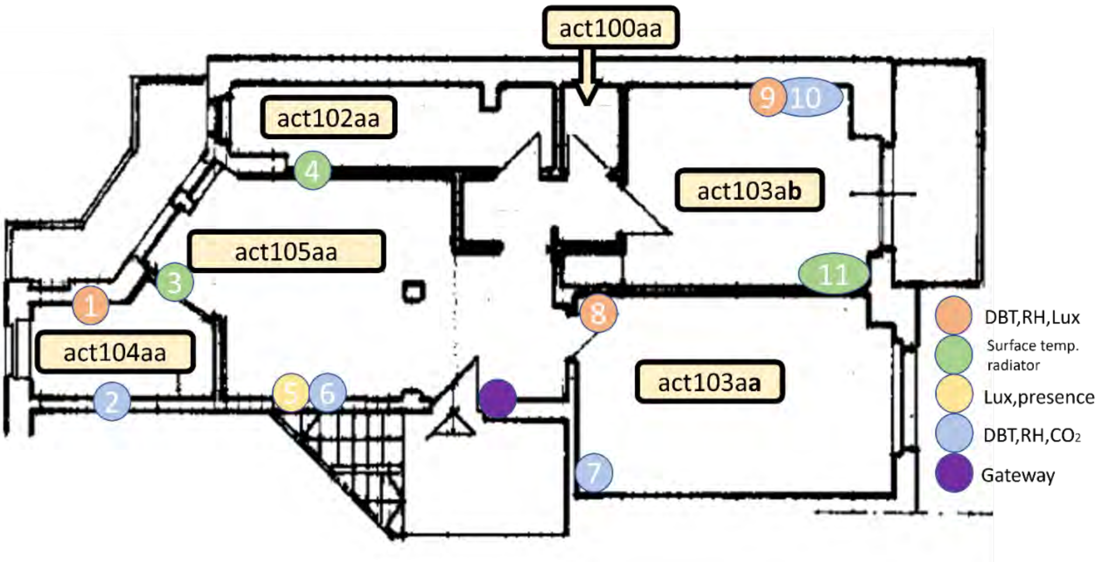


Figure 15- Apartment A5 – the installed additional sensors and their spatial implementation.

Concerning the Turin demo, measured data are available after the in-situ installation arrived on the 9th of February 2023.

3.2.4. FusiX integration

The Capetti system has been selected to be compatible with the FusiX platform via SOAP. Data are transmitted each hour packaging for each sensor the measured collected from the previous transmission step. Each datalogger has a proper MAC allowing its identification, the same is for the gateway that also has a licence key to support cloud facilities and the SOAP connection. A list of sensors and related naming to identify the datalogger locations and measured variables is implemented and shared with relevant partners. Similarly, the same terminology has been implemented in the PREDYCE model in order to potentially align PREDYCE monitoring-simulated data integration – see Section 4.

3.2.5. Calculated environmental KPIs via PREDYCE

Several Key Performance Indicators (KPIs) will be tested on the Turin demo case and the installed sensors will allow to verify the validity of simulation results on the calibrated model comparing them to the same KPIs computed also on monitored data. In order to compute the KPIs on both simulated and monitored data, the PREDYCE library described in the PRELUDE deliverable D3.2 will be exploited.

The main KPIs that will be analysed on the demo case can be divided into two main categories, the ones related to indoor comfort and those related to energy consumption. Concerning indoor comfort, both thermal comfort and indoor air quality are considered. The main indoor air quality indicator will be the concentration of CO_2, even though limited comparison with monitored data will be possible since only one room is monitored in each of the apartments. More detailed analyses for CO_2 distribution will be possible only on the A5 apartments, where all main rooms are monitored. Considering instead thermal comfort indicators, two main models will be used: the Adaptive Comfort Model (AMC) – see for example (N.Fergus, M.Humphreys, & S.Roaf, 2012)– and the Fanger model – see for example (PO.Fanger, 1970; F.Nicol, 2022). Concerning the Adaptive Comfort Model, which is used during the free-running periods, both old (EN 15251:2007) and new (EN 16798-1:2019) European standards can be used for the computation of the running mean temperature. Figure 16 shows two visualizations examples of ACM KPI generated through PREDYCE. The Fanger model instead is used during the heating periods, in line with the one described in ISO 7730 standard. Particularly, different comfort categories are suggested according to PMV (Predicted Mean Vote) ranges – i.e., category I (±0.2 PMV); II (±0.5 PMV); and III (±0.7 PMV): hours falling in cat. III are considered in thermal discomfort. Default values are assumed for Fanger model parameters, but they can also be personalized on request: the clothing level is assumed to be 0.5 clo, while the metabolic rate is set to 1.2 met, corresponding to standing relaxed condition or sitting activities. Moreover, both the air temperature and the operative one can be used as indoor comfort KPIs (e.g., through carpet plots, bar charts or timeseries analysis). It should be underlined that, for both the ACM computation and the operative temperature, the monitored air temperature is adopted and compared with the simulated operative.

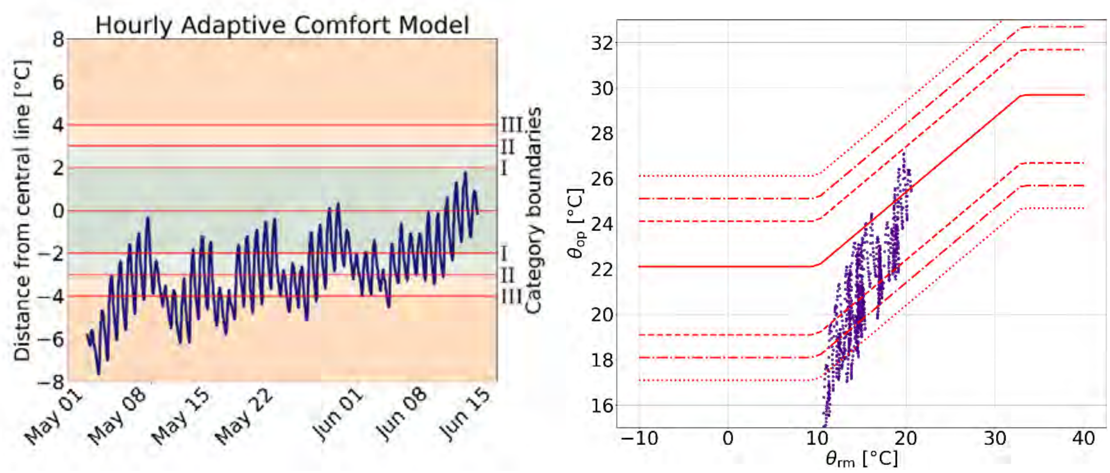


Figure 16- Examples of visualization of the Adaptive Comfort Model KPI through PREDYCE.

Concerning instead energy related KPIs, main indicators will be the net heating consumption and the energy signature (1D and 2D) as described in deliverable D3.2. Figure 17 shows an example of energy signature visualization through PREDYCE. It is possible to calculate, under request, different versions of the energy signature, e.g., considering the sole external temperature. For the Turin demo building, the monitoring of useful and final energy is lacking, suggesting that this KPI may be eventually defined at building levels using the district heating node values provided by IREN. Specific simulations may be run under request to define this KPI, although assuming a high expected performance gap.

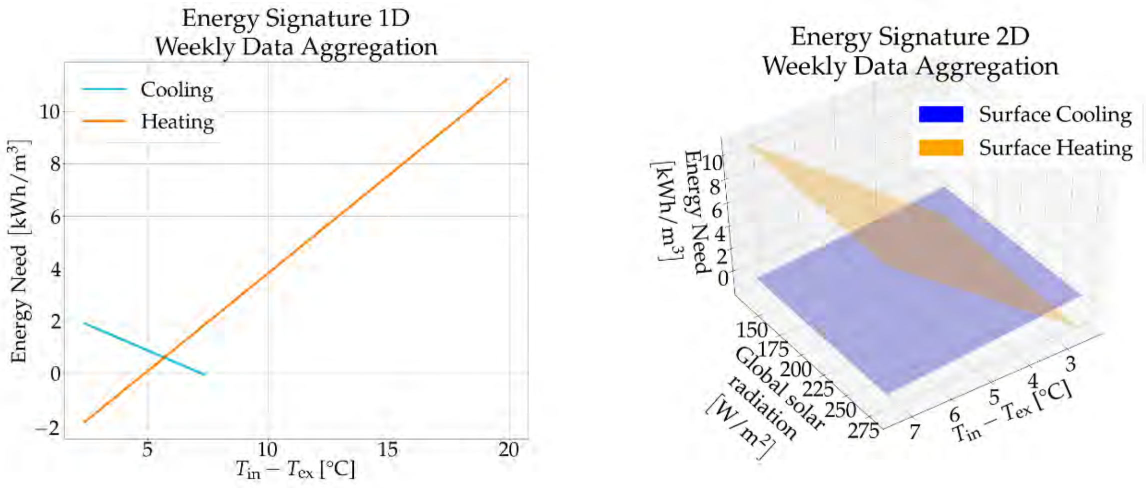


Figure 17- Example of 1D and 2D energy signature graphs generated inside PREDYCE.

3.2.6. Sample exploratory data analyses

In this Section some initial environmental data analyses are reported, performed by adapting the KPIs calculation module of the PREDYCE tool. The exploratory study includes:

- CO_2 concentration analysis,
- room temperature distributions,
- relative humidity values and correlated plotting of temperature and humidity on the well-known psychrometric Givoni chart
- thermal comfort analyses during the heated period, including the PMV/PPD model
- thermal comfort during the free-running period, using the adaptive thermal comfort model
- illuminance analyses (to indirectly analyse shading activation and not for visual comfort)
- the occupancy profile of one room
- radiator supply and return temperatures and retrieved delta values.

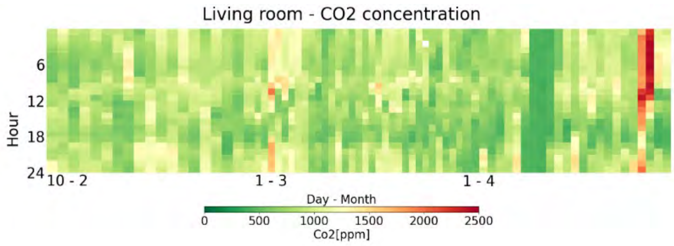
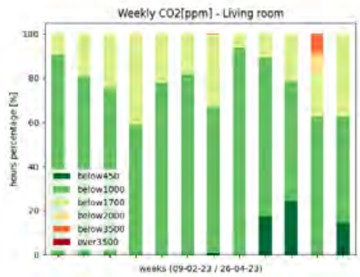
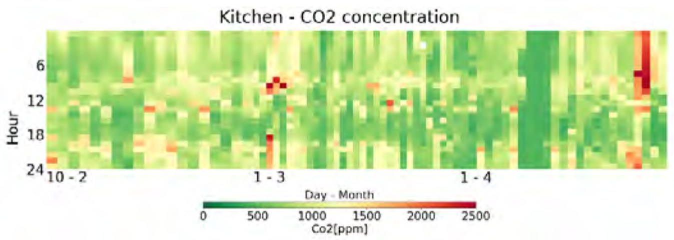
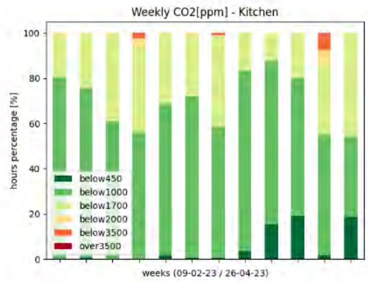
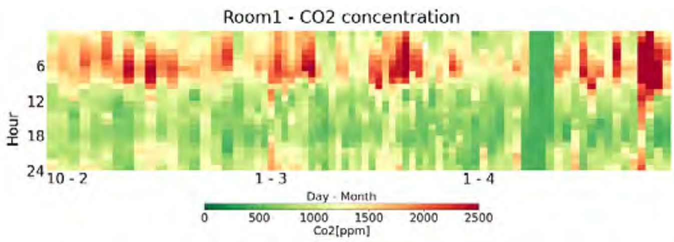
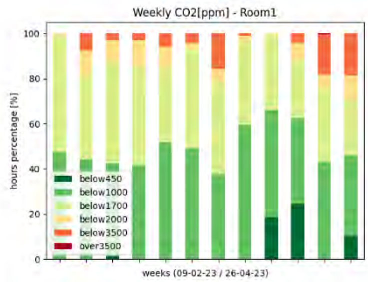
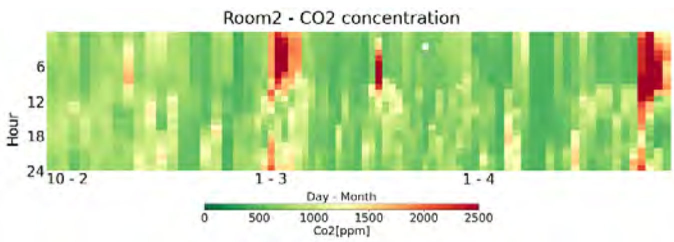
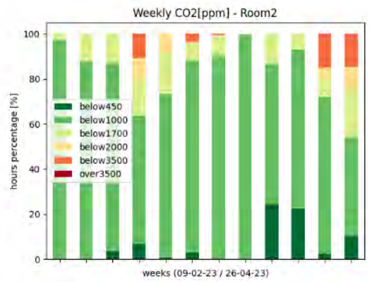
Here below each analysis is reported.

CO2 concentrations

In the following Table 5, a summary of the data collected on CO_2 concentrations in the apartment's four main rooms is shown. The sensor data has been resampled (mean) with an hourly frequency, and heatmaps have been created to allow for the evaluation of the temporal variation of air quality in domestic environments. With these details, it is possible to estimate the occupancy profile of the rooms, as well as a schedule for the opening and closing of the windows for aeration.

In addition to the heatmaps, there is a graph that shows the percentage distribution of the weekly CO_2 concentration. In order to classify the quality of the air in the environment, an adaptation of the French national indicator ICONE is adopted, being the adopted CO_2 thresholds not homogenously defined in between countries. In this case, we consider periods in which almost no internally added CO_2 is present, i.e. 450ppm is a value near the externally monitored CO_2 level, followed by a double acceptable threshold – 1000ppm and 1700ppm – considering that the first is assumed as a reference in several standards or national recommendation, while the second is also identified in the ICONE reference. Three additional values are also considered: 2000 ppm, in line with Swiss threshold suggestions, and 3500 (below and above) to identify critical conditions and very critical conditions. Nevertheless, different thresholds may be defined under request via PREDYCE if a comparison with other demos or standards is needed, i.e. calculating the difference between internal and external CO_2 levels, in line with suggested thresholds of EN 16798-1, Annex B. The following graphs reported in the mentioned Table allow to analyse the percentage of time spent with an appropriate level of CO_2 in respect to time spent with a higher level of CO_2 at weekly base (right), as well as how this relationship evolves over the course of the year (left). Initial results show, for example, how CO_2 concentration in the thermal zone F08_A5_Act103aa presents high peak during early morning, while the zone F08_A5_Act103ab results to be intermittently used. In the other cases a general good ventilation is underlined, especially if we consider that the majority of data refers to the winter heating period.

Table 5- CO2 explorative analyses

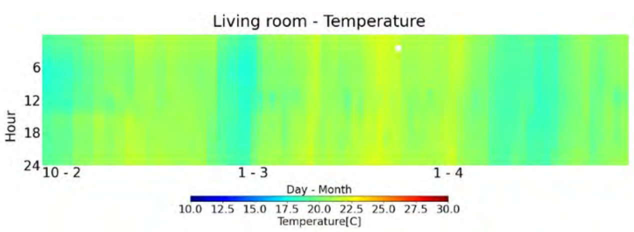
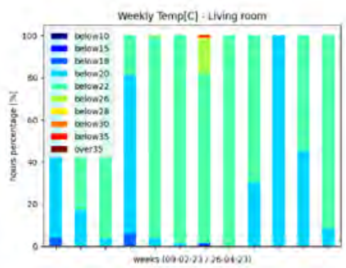
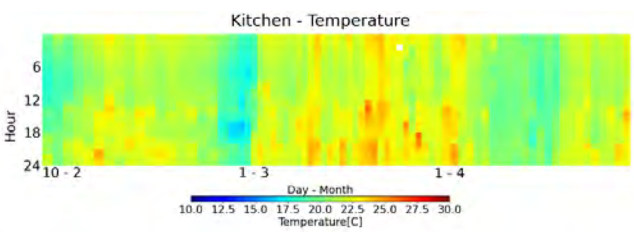
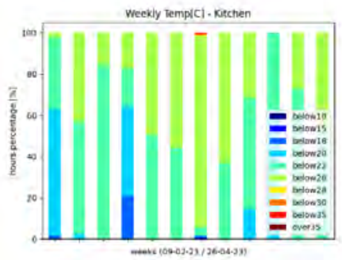
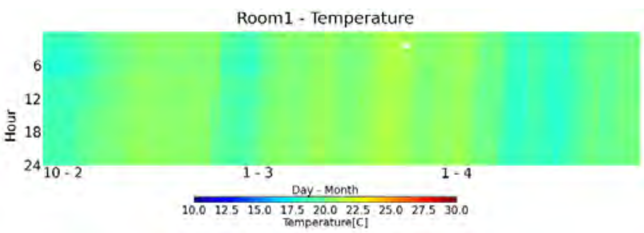
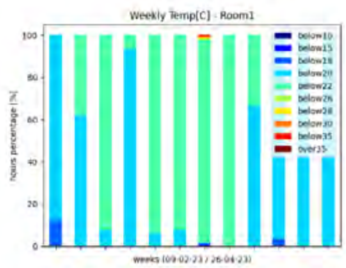
Rooms*	Carpet plot	Weekly percentage distribution
F08_A5_ Act105aa		
F08_A5_ Act104aa		
F08_A5_ Act103aa		
F08_A5_ Act103ab		

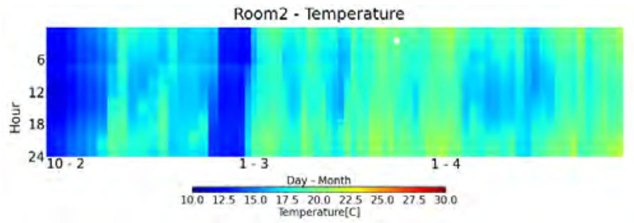
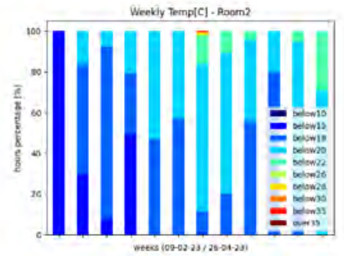
Temperature values

The heatmaps for the temperature sensors in the four main zones are shown in Table 6. As with CO_2, a bar plot highlights the percentage distribution of hourly temperature for each week. The intervals of values used for the classification range from the lowest interval (in dark blue), with a temperature below 10 °C, to the highest one (in dark red) with a temperature greater than 35 °C.

The highest temperatures are found in the zone F08_A5_Act104aa, especially in the evening hours, probably due to the use of household appliances and a concentrated occupancy profile, also considering the reduced surface area of the room. In addition, this space is south-facing and is not screened by any balcony and is therefore a potential overheating area during the summer. In the F08_A5_Act105aa zone and in the F08_A5_Act103aa one the temperatures remain more constant and in line with the values of "comfort". Differently, in the F08_A5_Act103ab zone the temperature drops drastically, due to the occasional use of this space, as also confirmed from the previous graphs relating to the concentration of CO_2, and the consequent turning off of the local radiator – see below.

Table 6- Air temperature explorative Analyses

Rooms*		
F08_A5_ Act105aa		
F08_A5_ Act104aa		
F08_A5_ Act103aa		

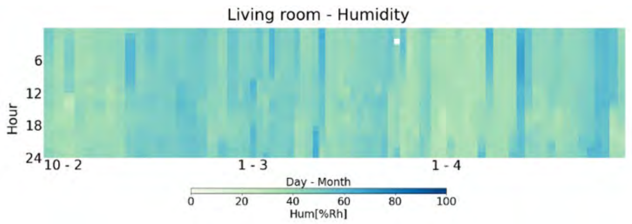
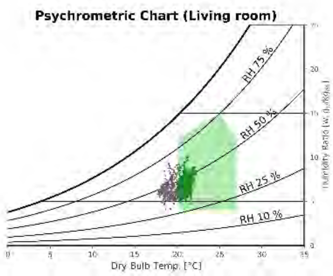
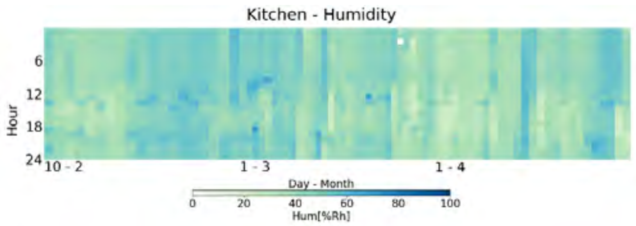
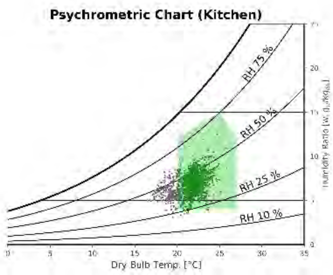
F08_A5_ Act103ab		

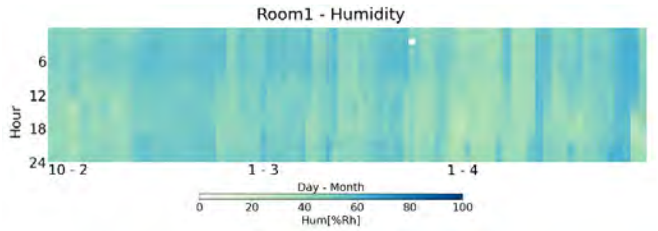
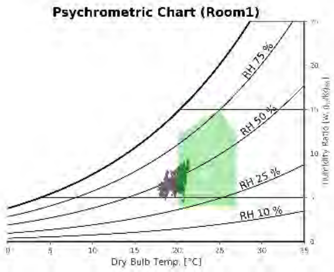
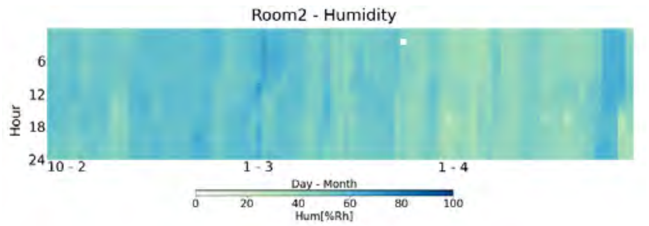
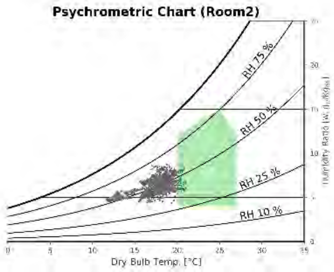
Humidity values and Givoni charts

In Table 7 are reported the heatmaps showing the relative humidity values recorded by the sensors inside the house. the colormap goes from a light green that represents 0% to a dark blue that indicates 100%. With respect to this variable, there is a slight difference between the two rooms (F08_A5_Act103aa and F08_A5_Act103ab) that are located on the north side and the two rooms that are located to the south (F08_A5_Act105aa and F08_A5_Act104aa). In these last two rooms, a little higher relative humidity is encountered, potentially due to occupancy profiles and slightly higher temperatures, which in every case assumes values between 40 and 60 percent for almost the entire duration of the current database, showing a correct comfort performance in line with EN 16798-1. In room F08_A5_Act104aa, some small peaks are monitored around lunch and dinner preparation times, in line with expectations.

Additionally, thanks to the Psychometric Chart (right), in which each point stands for a specific hour in the monitored period, described by the average hourly temperature and absolute humidity, it is possible to see how many hours in the studied time period are generally localised in the Givoni's suggested thermal comfort zone. As it is underlined, room conditions are generally in comfort, with the exclusion of the not-used room F08_A5_Act103ab, with some points showing a lower temperature.

Table 7- Humidity explorative analyses (right) and psychrometric Givoni charts (left)

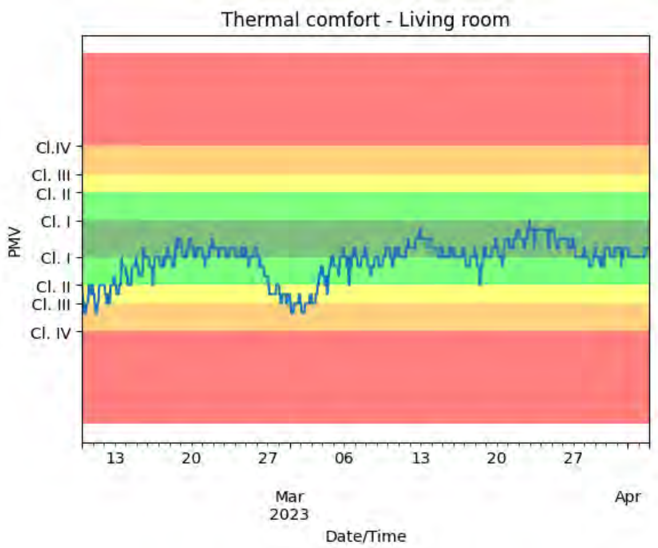
Rooms*		
F08_A5_ Act105aa		
F08_A5_ Act104aa		

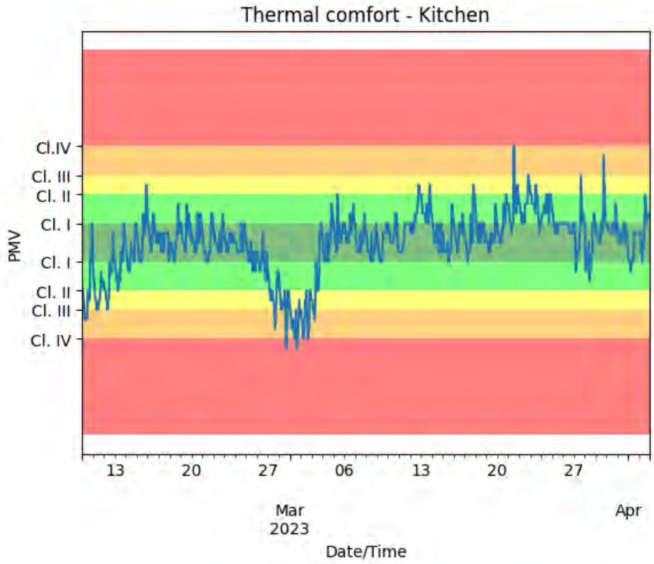
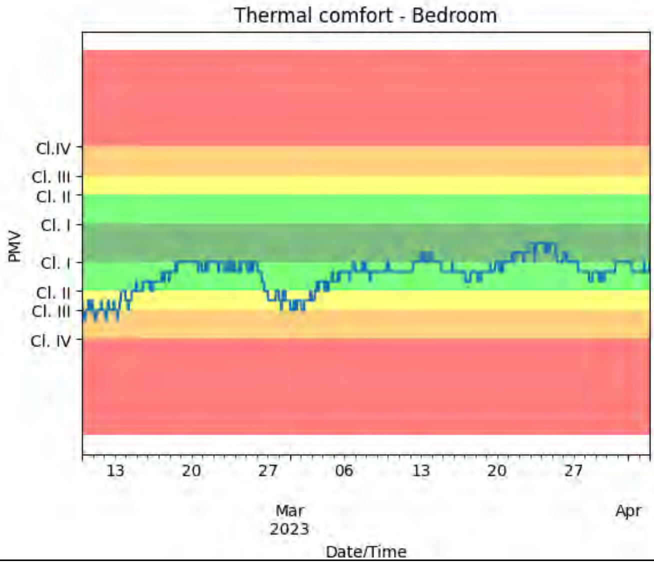
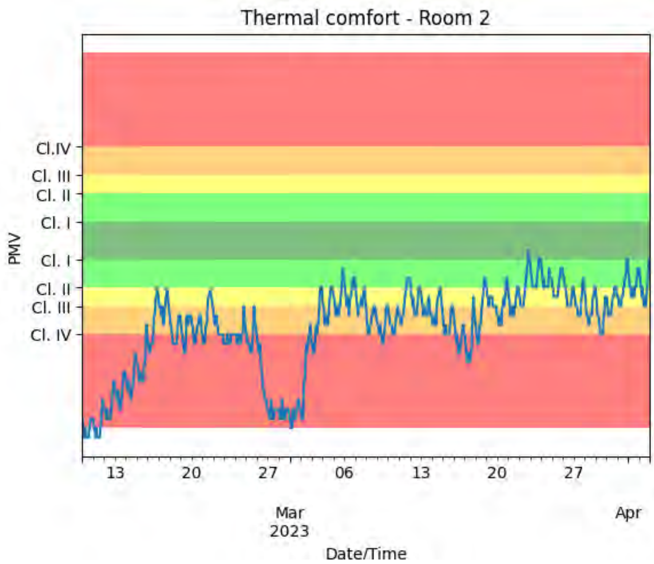
F08_A5_ Act103aa		
F08_A5_ Act103ab		

Thermal comfort (Fanger PMV/PPD mode)

The graphs related to the calculated thermal comfort during the heating period are shown in Table 8. In this study the Fanger's thermal comfort approach is adopted in line with ISO 7730 and EN 16798-1. In the case of the room F08_A5_Act103aa, the PMV was calculated using a value of clo (clothing insulation) = 2.5 (considering winter bed blanket) and met (metabolic rate) = 0.8 (assuming that sleeping is the prevalent activity). In the other three rooms, a clo = 1.0 and a met = 1.2 are used assuming typical winter clothing and met standard values for general residential activities. The comfort value in the first three rooms is typically within Cl.II, but in the room F08_A5_Act103ab, where heating is sporadic (as shown for example by the temperature graph), discomfort values are noticeably higher. Nevertheless, this room is almost not used as shown by the CO_2 path.

Table 8- Thermal comfort explorative analyses – heated season

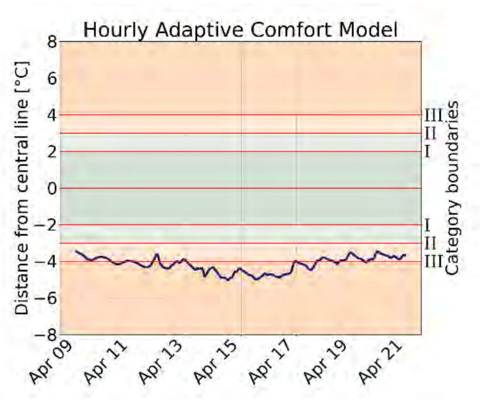
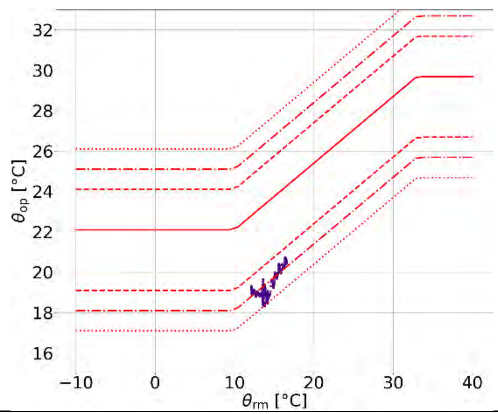
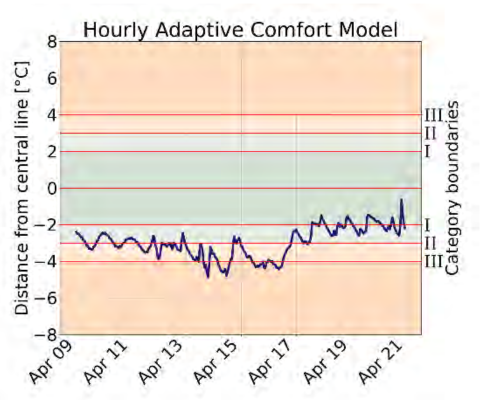
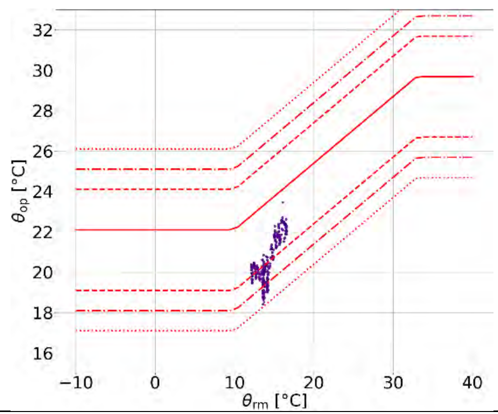
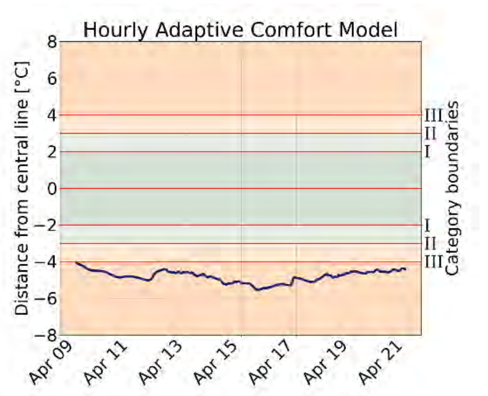
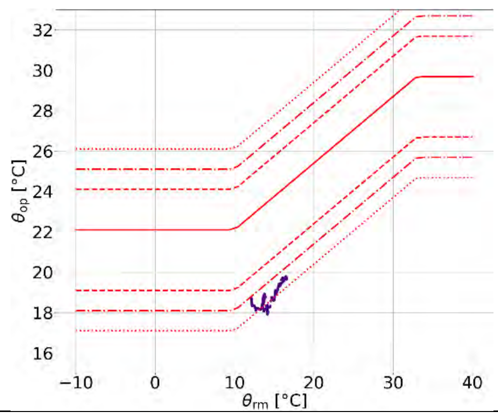
Rooms*	
F08_A5_ Act105aa	

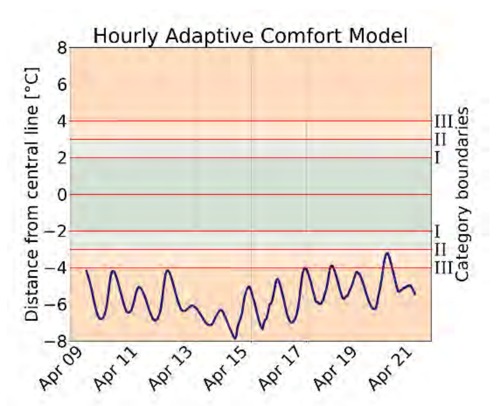
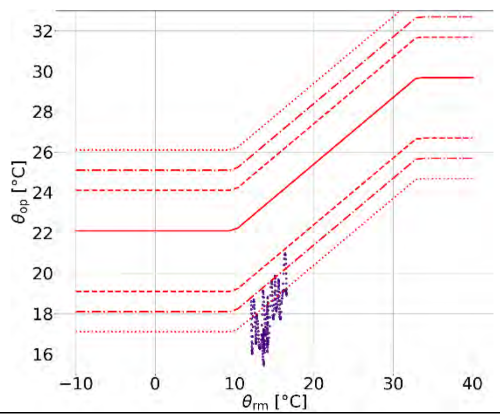
F08_A5_ Act104aa	
F08_A5_ Act103aa	
F08_A5_ Act103ab	

Thermal comfort (Adaptive Thermal Comfort mode)

When the heating system is switched off, thermal comfort is calculated considering the Adaptive Comfort Model, in line with EN 16798-1. The results in Table 9 show a relatively high discomfort value in each room with a consequent cold sensation. This result is probably due to the early shutdown of the heating system, in the year 2023 – due to energy-saving emergency rules – compared to previous years, in which the national standard consider that the heating season closes the 15th of April (with potential extensions) for the Turin climate class. The best results in terms of free-running comfort conditions are obtained in room F08_A5_Act104aa, since, as mentioned above, it has an average temperature higher than the other rooms.

Table 9- Thermal comfort explorative analyses – free-running season

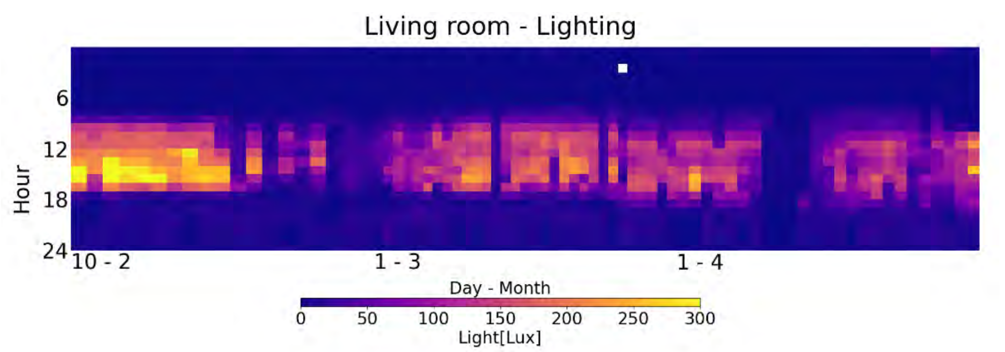
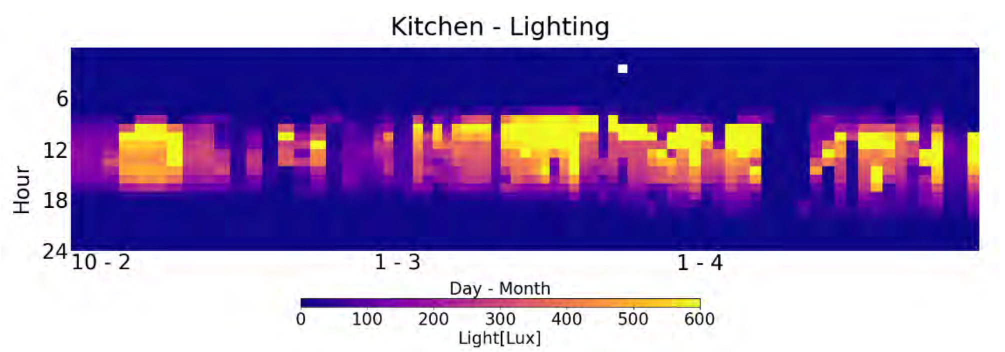
Rooms*		
F08_A5_ Act105aa		
F08_A5_ Act104aa		
F08_A5_ Act103aa		

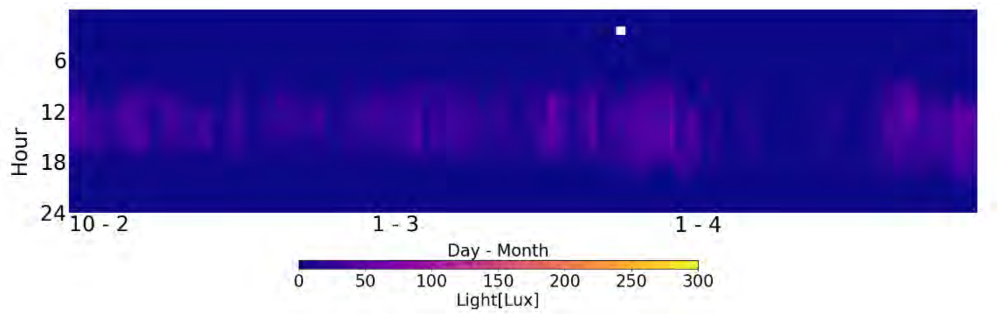
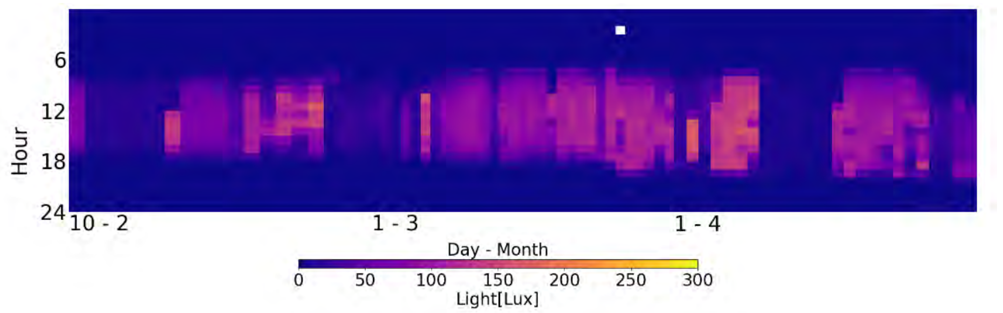
F08_A5_ Act103ab		

Illuminance sensors

The same procedure used for temperature, humidity, and CO_2 sensors is used to display the data monitored by light sensors throughout the rooms (Table 10). It is important to note in this case that the absolute value of illuminance registered cannot be considered feasible to analyse the visual comfort due to a sub-optimal positioning of the sensors within the environment. Sensor positioning is in fact originated by matching end-user availability and needs and PRELUDE technological requirements. However, the monitored illuminance is detected with the intent to potentially indirectly estimate a schedule for the shading of the windows by analysing daily illuminance significative variations, since shading system are not monitored or automated directly. In any case, sensors in rooms F08_A5_Act105aa and F08_A5_Act104aa are correctly positioned (even if for Act105aa the sensor is vertical, while in Act104 is horizontal) giving consistent values.

Table 10- Lighting sensor exploratory analyses

Rooms*	
F08_A5_ Act105aa	
F08_A5_ Act104aa	

F08_A5_ Act103aa	
F08_A5_ Act103ab	

Occupancy analysis

Direct occupancy monitoring is always a complex and generally unfeasible task in residential building units. In order to analyse the correlation between other environmental variables and occupancy, a single motion sensor has been installed in the building – see Figure 18 – showing a scattered daily profile in the considered central room.

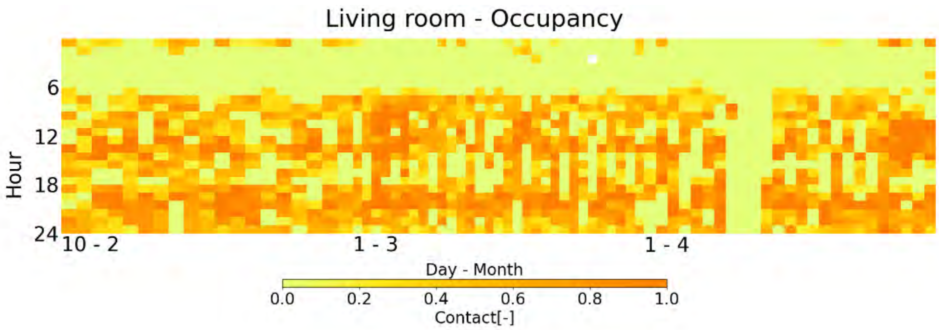


Figure 18- Exploratory analysis of occupancy profiles.

Radiator supply and return temperatures

In the end, representations of the graphics related to the three radiators that are in rooms F08_A5_Act105a, F08_A5_Act103ab, and F08_A5_Act102aa are given – see Table 11. Particularly in the first column, the temperature of the water entering (supply) and exiting (return) the radiators and their differences are displayed. Thanks to this final value, it is possible to estimate the heating system's turn-on profile inside the specific room, considering that the heating should be turned on when the temperature difference is greater than one degree Celsius. Each radiator has a thermovalve that may be controlled manually or remotely via the commercial TADO app, although the turning-on and -off is also function of the whole building heating availability from the district heating system, which is controlled in line with the maximum number of heating hours given by national and local standards. However, it is not possible to estimate the heat flow, missing the waterflow inside the radiators.

Table 11- Radiator supply and return temperatures

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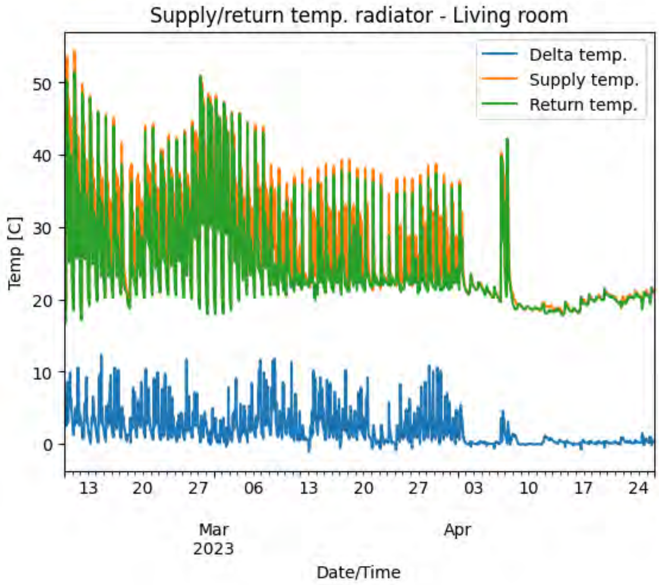
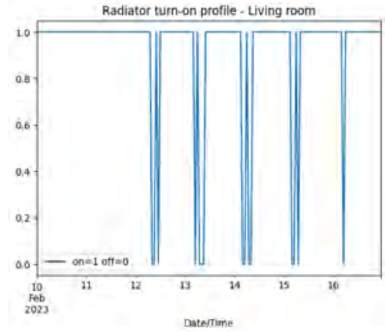
Act105aa</td><td>
</td><td>
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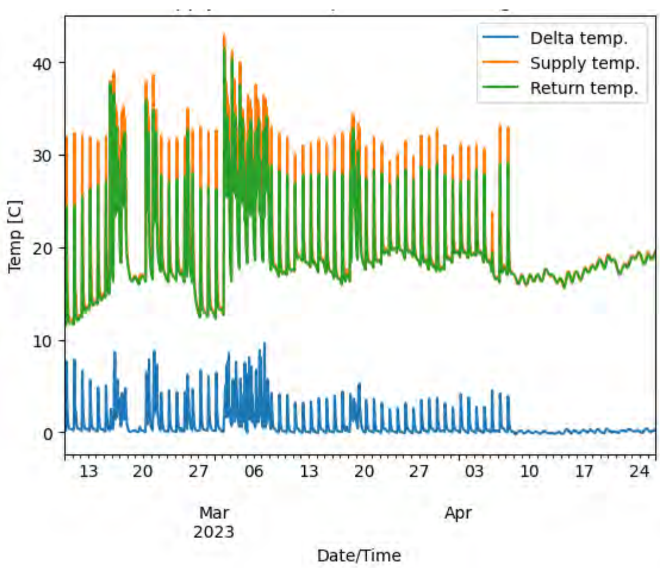
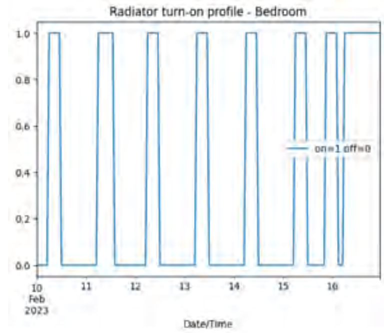
Act103a
b</td><td>
</td><td>
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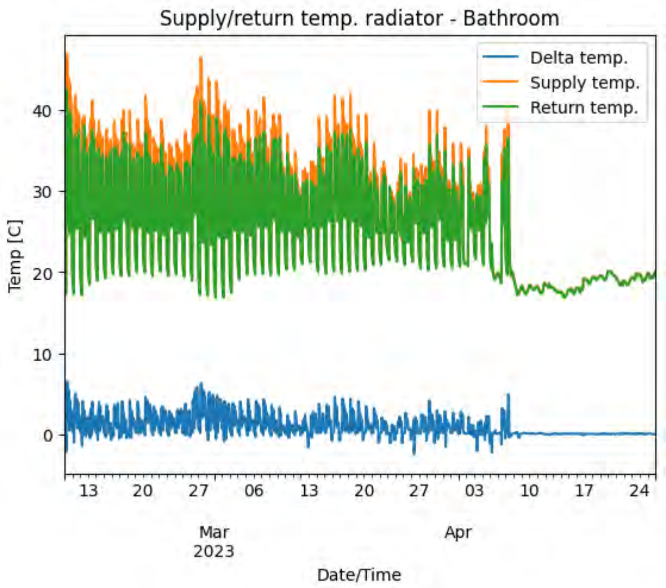
<td>
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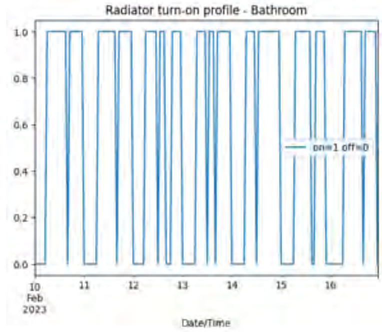
<td>
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3.3. Meteorological station

3.3.1. The installed instruments

In order to feed the dynamic energy simulations and analyse specific indoor-outdoor correlations on the monitored variables, a local meteorological station is needed. The station needs to allow cloud data accessibility to arrive till the real-time interaction. Additionally, several weather variables are necessary to the implementation of building correlated studies, especially to feed dynamic energy simulation via tools like EnergyPlus. For this project, to feed different PRELUDE technologies and detect real-time weather data, a complete meteorological station has been acquired for the Turin demo building. The station is assembled by Netsens and placed on a nearly accessible urban site identified, considering permission, accessibility and availability, in one of the nearer POLITO building units, using free space on the flat roof – see Figure 19. The distance between the demo building and the roof is small (2.4 km), while the roof is higher than all surrounding buildings allowing for correct monitoring of environmental variables. Considering the cost of a professional meteorological station and assuming a scalability potentiality of PRELUDE technologies, these instruments may be assumed to serve not a single building, but a large urban area supporting a large number of potentially connectable buildings. The station is directly powered, while a small accumulator and a supporting PV panel are also installed to reduce the risk of data discontinuity in case of interruption of the electrical plug. The station communicates via the cloud thanks to a SIM, and data are shared, about every 4 minutes, via both a Netsens cloud interface and via REST access compatible with the PRELUDE project common middleware (FusiX).

Figure 19- The installed meteorological station Exploratory analysis of occupancy profiles.

In addition to the control panel and plug, the meteorological station is composed by 3 monitoring instruments: i. a Thies Climate Sensor US, ii. a Kipp&Zonen all-in-one solar monitoring kit RAZON+, and iii. an outdoor CO_2 sensor by DeltaOHM (HD37BTV).

The station has been installed in April 2022 and data transmission started late afternoon of the 4th April 2022.

Regarding sensor specifications, the Thies sensor manual reported values are listed here below in Table 12.

Table 12- Specifications of the Thies Clima Sensor US

Precipitation	
Measuring range	0.001 ... 10 mm/min
Accuracy	typ. 95%
Temperature	
Measuring range	-50 ... +80 °C
Accuracy	±0,3 K (@ 25 °C)
Relative humidity	
Measuring range	0 ... 100 % rel. h.
Accuracy	± 1.8 % rel. h. (10 ... 90 % rel. Humidity)
Wind direction	
Measuring range	0 ... 360 °
Accuracy	±2 ° WS > 2 m/s

Wind speed	
Measuring range	0.01 ... 75 m/s
Accuracy	±0,3 m/s rms (< 5 m/s) ±3 % rms (5 m/s... 60 m/s)
Brightness	
Measuring range	0 ... 150 kLux
Accuracy	3 % of rel. measuring value
Air pressure	
Measuring range	260 ... 1260 hPa
Accuracy	±0.25 hPa @ - 20 ... +80 °C @ 800 ... 1100 hPa ±0.50 hPa @ - 20 ... +80 °C @ 600 ... 800 hPa ±1.00 hPa @ - 50 ... -20 °C @ 600 ... 1100 hPa

The sensor includes a GPS for defining the sun position and include a large number of Modbus channels allowing to retrieve measured variables and derived ones, including absolute air humidity and the wet bulb temperature. Among others, the probe measures air temperature, atmospheric pressure, relative humidity, wind speed and direction, brightness for different orientations, precipitation, precipitation type.

Concerning the RAZON+ sensor, it allows to monitor the direct and diffuse irradiations without the need to further apply splitting equations form the global horizontal value. This module includes a motor and a movable shading system to measure diffuse radiation in line with the local GPS position, day of the year and hour of the day. The specifications for the horizontal pyranometer detecting the diffuse radiation and the moving pyrheliometer detecting the normal radiation is given here below in Table 13 and are assumed by the technical manual.

Table 13- Specifications of the RAZON+ sensors

	PR1 smart pyranometer	**PH1 smart pyrheliometer**
Classification to ISO 9060:1990	Second Class	Second Class
Spectral range (50% points)	310 to 2700 nm	310 to 2700 nm
Zero offsets (a)Thermal radiation at 200W/m2 (b)temperature change at 5 K/h	 1 W/m2 1 W/m2	 1 W/m2
Non-linearity (100 to 1000 W/m2)	< 0.3%	
Directional response (up to 80° with 1000 W/m2)	< 20 W/m2	
Temperature response	< 1% (-20°C ... +50°C)	< 1% (-20°C ... +50°C)
Field of view	180°	5° ±0.2°
Slope angle		1° ±0.2°
Measurements range	0 ... 1500 W/m2	0 ... 1500 W/m2
Operation temperature range	-40°C ... +80°C	-40°C ... +80°C

The CO_2 sensor by DeltaOHM technical characteristics are reported from the technical sheet in Table 14.

Table 14- Specifications of the DeltaOHM CO2 sensor

CO2 measurement principle	NDIR - Double wave length infrared technology
CO2 measurement range	0 ... 2000 ppm
CO2 accuracy (20°C RH50% 1013hPa)	±50ppm +3% of measurement
Stabilization time (startup)	15 min
Long term stability	5% of the range / 5 years
Working temperature / RH	-5°C ... +50°C / 0 ... 90%

3.3.2. Data collection and integration

All values may be retrieved via the Netsens Live web service or required via REST API in XML format in order to feed PRELUDE technology requirements.

3.3.2.1. FusiX integration

The weather station communicates via REST and allows for a direct integration with the FusiX middleware. Additionally, the Netsens company, providing the control mainboard of the solutions, allows to access data in real time via its own webservice supporting basic data visualisations and the control of monitored variables and system status.

3.3.2.2. Weather data integration into PREDYCE and the EPW compiler

Weather data usage in PREDYCE – see also Section 4 – must be downloaded from the weather station and transformed into an EPW file to feed simulation. As described in deliverable 3.2, several variables are needed to run an EnergyPlus simulation and almost all of them are monitored by the installed weather station. An automatic procedure has been set up to execute the whole data flow from data downloading to a fully working EPW file generation. This flow is made of four main steps:

- The first step allows the creation of a CSV file containing downloaded raw data from the adopted data source. The Turin weather station API allows to download data through REST requests with a payload of maximum one week of data per request. This script can be automatized with the desired update frequency.
- The second step allows to clean the data generating a new CSV file. The adopted approach does not make use of complex cleaning algorithms, but it manages each type of data according to specific rules derived looking at timeseries, weather station manual and in accordance with EPW rules (e.g., respecting thresholds).
- The third step instead allows to generate a CSV file ready for further EPW filling. This is obtained by hourly aggregating the data and computing missing required variables through climatological expressions from other available information. For example, the Horizontal Infrared Radiation Intensity is derived from the measured dew point temperature, relative humidity and global horizontal radiation exploiting the formula provided by the Meteonorm manual (Meteotest, 2021).
- The last step, which exploits the Python pyepw library[5], allows to generate an EPW file from the CSV file and to integrate missing data from TMY or with custom filling strategies (e.g., cyclic, repetition of last available data) if needed.

[5] https://pypi.org/project/pyepw/

3.3.3. Sample exploratory data analyses

Using the file.csv described in the previous point, specific graphs are produced summarising the trend of some climatic variables from April 2022 to April 2023, including:

- Wet and Dry bulb temperatures
- Wet bulb depression (calculated)
- Wind speed and direction

and some comfort evaluation and technology applicability indices:

- Humidex
- Degree-day and degree-hour indices
- Givoni-Milne psychrometric chart
- Ventilative cooling dissipative potential (fixed ACH)

Some of these variables are directly measured, while others are recognised climate indices (e.g. Humidex) supporting the general summer discomfort evaluation.

Concerning the dry-bulb temperature, a heatmap (Figure 20) was made using the hourly average values directly extracted from the file.csv, with a colour scale ranging from a minimum of -10 °C (dark blue) to a maximum of +50 °C (dark red). To visualize the temperature trend in a more analytic way, it is also reported a graph that shows the line of the average hourly values of temperature for the first year of monitoring (April 2022 – April 2023) – see Figure 21. Additionally, in the same figure, the calculated value of the outdoor running mean temperature is also reported, which is at the base of the adaptive thermal comfort methodology, calculated in line with EN 16798-1.

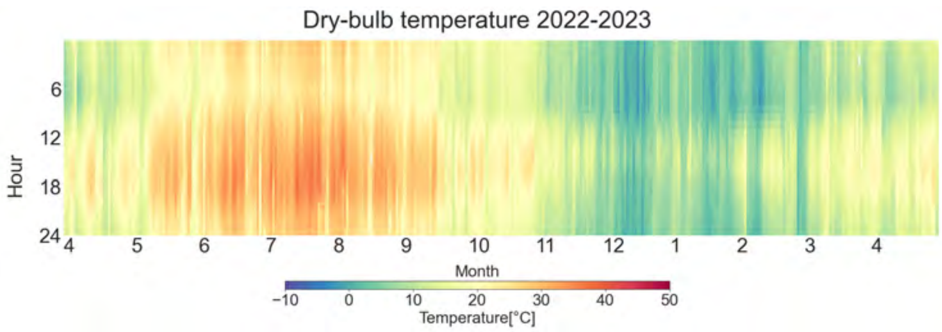


Figure 20- Carpet plot distribution of the hourly average environmental temperature values

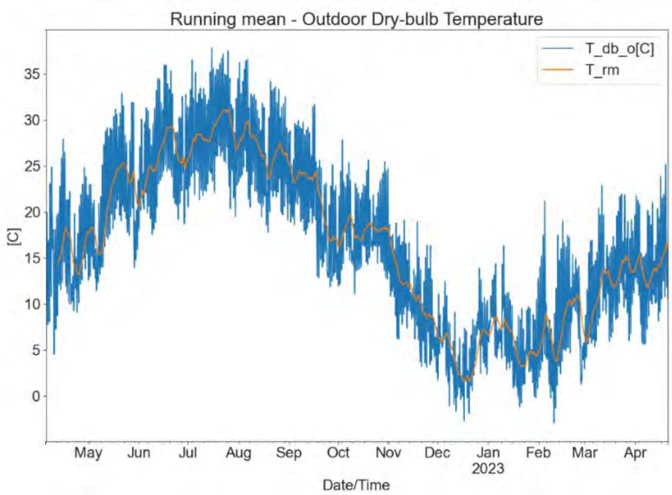


Figure 21- Hourly environmental temperature and calculated running mean values.

Concerning the humidity conditions, Figure 22 shows the heat map of the wet-bulb temperature using the same colour scale as the previous graph. The wet bulb temperature has been calculated from the monitored environmental temperature and the relative humidity using the following formula (R.Stull, 2011):

$$T_{\mathrm{wb}}[°\mathrm{C}] = \left(T_{\mathrm{db}}[°\mathrm{C}] \cdot \tan^{-1}\left(0.151977 \cdot \sqrt{\mathrm{RH}[\%] + 8.313659}\right) + \tan^{-1}(T_{\mathrm{db}} + \mathrm{RH}[\%]) - \tan^{-1}(\mathrm{RH}[\%] - 1.676331) + 0.00391838 \cdot \sqrt{\mathrm{RH}^3} \cdot \tan^{-1}(0.023101 \cdot \mathrm{RH}[\%]) - 4.686035\right) - 4.686035$$

with

$T_{\mathrm{db}}[°\mathrm{C}]$ = Dry-bulb temperature

$RH[\%]$ = Relative humidity

To evaluate the difference between the wet and dry bulb temperature a graph showing the wet bulb depression (WBD) is also provided in Figure 23. As it is underlined by this graph the WBD shows also values up to 15 degrees, with a lot of noise, in the summer months, while it is drastically reduced during the colder months of the year, maintaining slight variation between night-and-day cycles. This suggests that during summer periods direct evaporative cooling solutions may be considered in the local climatic conditions.

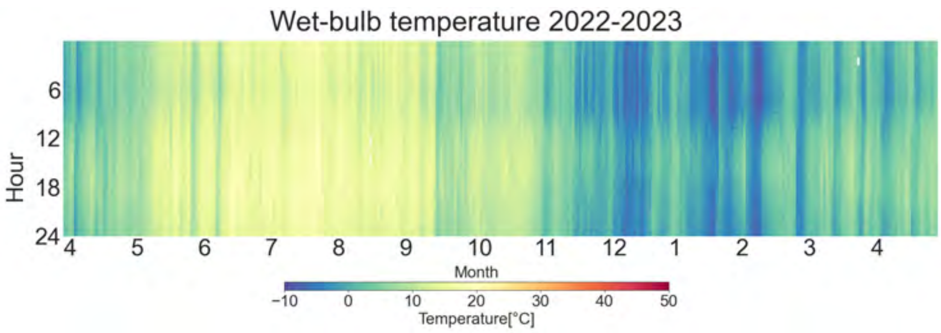


Figure 22- Carpet plot of the wet-bulb temperature.

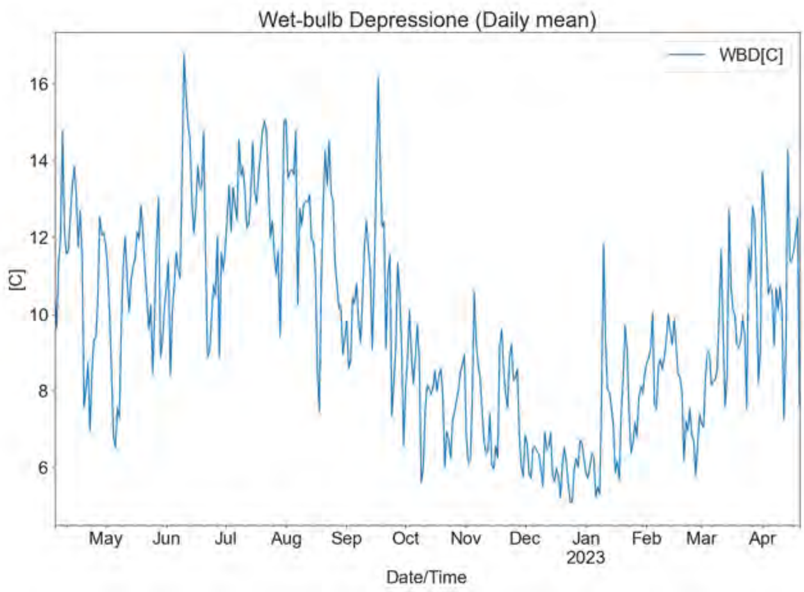


Figure 23- The wet-bulb daily mean distribution over months.

Additionally, a wind rose plot is reported in Figure 24 summarising the monitored wind data in the specific geographical area. The graph is constructed using the monitored wind directions together with the wind speed data in km/h, showing thanks also the percentage distribution of the speeds for each direction during the under-consideration year.

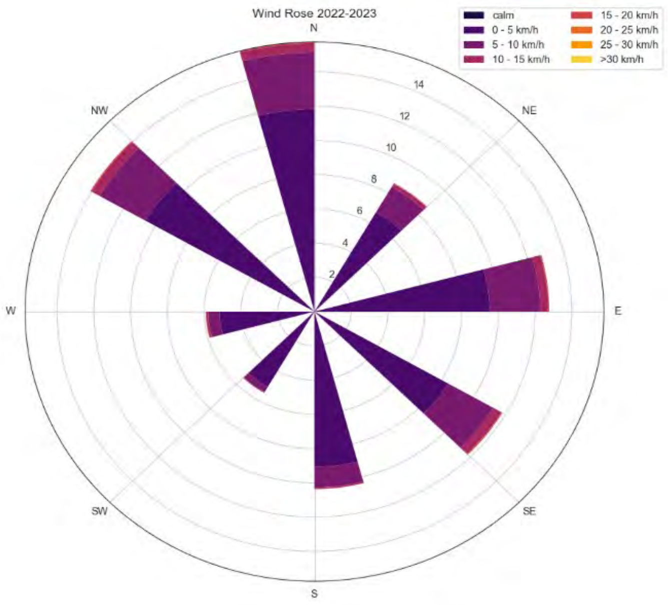


Figure 24- Wind-rose distributing wind directions and velocities in the monitored period

To calculate the perceived outdoor thermal comfort based on temperature and humidity, the Humidex index, first defined by (JM.Masterson & Richardson, 1979), is used. This index is representative especially of summer comfort stressing conditions, although several other indices may be calculated under request. Although this approach helps in analysing in synthesis the risk of overheating stress. It is calculated by applying the following expression[6]:

$$H[°C] = T_{db}[°C] + \left(0.5555 \cdot (0.06 \cdot RH[\%] \cdot 10^{0.03 \cdot T_{db}} - 10)\right)$$

The Humidex index is applicable between temperatures of 20 °C to 55 °C. At this interval below 20 °C is considered "well-being", while above 55 °C "high danger", no matter how much the relative humidity is.
Within this range, 4 sub-ranges are defined, each associated with a different comfort category, and are reported in Table 15.

Table 15- Humidex assumed categories

Categories	**Humidex**
Well-being	$20\,°C \leq H \leq 27\,°C$
Caution	$27\,°C \leq H \leq 30\,°C$
Extreme caution	$30\,°C \leq H \leq 40\,°C$
Danger	$40\,°C \leq H \leq 55\,°C$

Such as visible from the Figure 25, during summer, especially in the afternoon and evening periods, the measured values are reaching stressing conditions, suggesting that countermeasures need to be applied and that potentially the outdoor conditions have a low dissipative ventilative cooling potential.

6 www.centrometeo.com/articoli-reportage-approfondimenti/climatologia/5008-indici-humidex-temperatura-equivalente

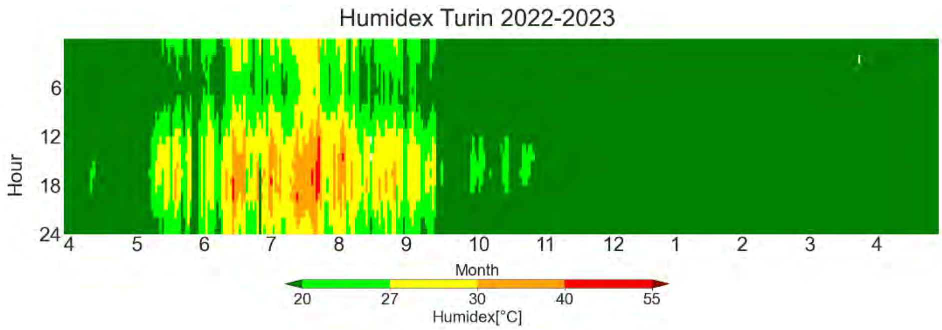


Figure 25- The obtained Humidex values.

In order to indirectly analyse the expected impact of climate-correlated variables on the potential heating and cooling energy needs, two indicators are adopted: the Heating and Cooling Degree Days (HDD and CDD respectively), calculated in line with the EUROSTAT methodology – see also the PRELUDE Deliverable D3.2 –, and the Heating and Cooling Degree Hours indices (HDH and CDH respectively) based on hourly difference from assumed thresholds. The heatmap in Figure 26 depicts the average hourly temperature's positive distance from the reference temperature of 24 °C, and this value is then used to calculate the Cooling Degree Day index. In particular, the HDD and CDD values are calculated by exploiting the PREDYCE tool considering the mean daily temperature to apply the EUROSTAT check (≤15°C for heating and ≥24°C for cooling) and subtracting, for the selected days, the mentioned reference temperature (18 °C for heating and 21 °C for cooling) from the environmental monitored value. All values strictly greater than zero are then yearly summed. In the below Table 16 are reported the results obtained in the first monitoring year, ranging from April 2022 to April 2023. Additionally, in the last column the alternative xDD results obtained by summing the yearly xDH values and dividing them by 24 (number of hours in the day) are also reported.

Table 16– Degree-day values

	Degree-day EUROSTAT values	Degree-day from ∑xDH/24
HDD	1601.64	2198.05
CDD	627.64	405.76

Additionally, the heatmap in Figure 26 depicts the average hourly temperature positive distance from the reference temperature of 24 °C, and this value is then used to calculate the Cooling Degree Hourly index. Similarly, Figure 27 shows the negative distance of the hourly average temperature from the reference temperature of 20 °C, in line with the suggested threshold for Italian xDD analyses, which graphically represents the Heating Degree Hour index.

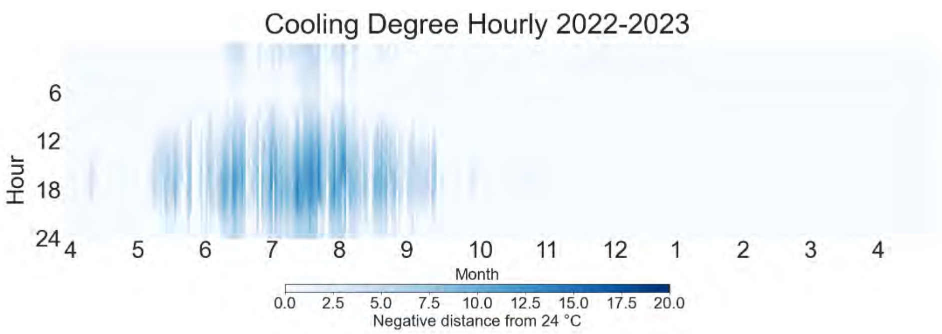


Figure 26- Carpet plot showing the CDH24 values

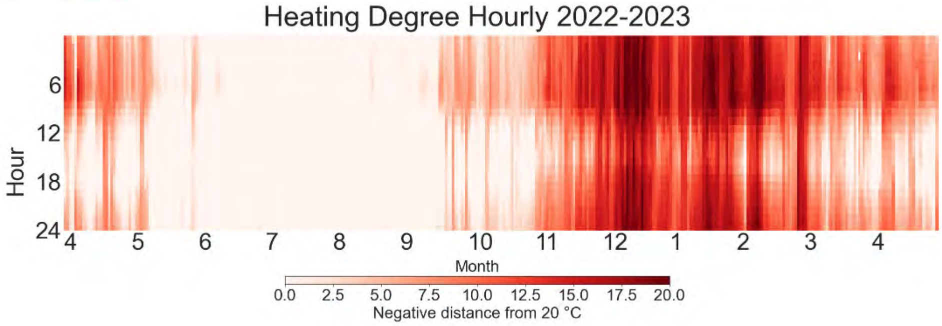


Figure 27- Carpet Plot showing the HDH20 values

Another PREDYCE-based analysis that is provided is the Givoni-Milne psychometric diagram shown in Figure 28. In this graph each point reports the hourly values of external dry-bulb temperature and absolute humidity of the air. The shown comfort zone is purely indicative, being referring to indoor conditions. All points that fall outside this area may generate, according to the specific season and indoor conditions, negative impacts by the activation of excessive ventilative flows (e.g. overcool in winter and increase heating gain in summer).
The graph underlines how, between April 2022 and April 2023, only about 25% of the hours assumes optimal temperature and humidity values, while Turin results to be a dominated heating climate, even if several points also show that cooling needs may be consistent.

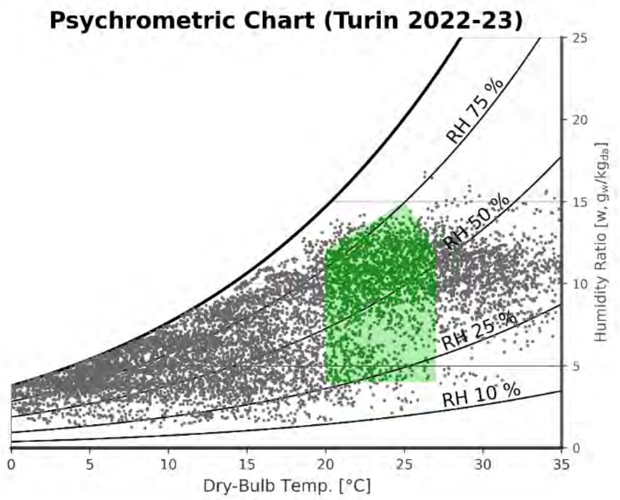


Figure 28- The Givoni-Milne psychrometric chart. Comfort area is purely indicative being referred to indoor conditions

Finally, to introduce some of the climate analyses that will be conducted in T8.5, a simple climatic study on the cooling potential for ventilative cooling is shown assuming fixed airflow rates. Space ventilation is an important factor to be considered, especially during the summer season, because it may ensure a consistent heat dissipation, which can significantly reduce, under specific environmental conditions, the energy needs for space cooling. For this report a ventilative cooling dissipative potential climatic study is reported, based on a KPI included in the PREDYCE tool – see the PRELUDE deliverable D3.2 – based on the following formula:

$$Q_{\text{vent}} = (T_{\text{ref}} - T_{\text{db}}) \cdot \text{ach} \cdot p_{\text{air}} \cdot c_{\text{air}} \cdot \frac{V}{1000}$$

Where:

T_{db} = External dry-bulb temperature [°C]

T_{ref} = Cooling temperature threshold [°C], default to 26

c_{air} = Air specific heat capacity $\left[\frac{W}{kg \cdot °C}\right]$, default to 0.278

p_{air} = Air density $\left[\frac{kg}{m^3}\right]$, default to 1.2

ach = Air change per hour, here assumed by default to 2.5

V = Volume of the building $[m^3]$, here assumed by default to 210 (near to the volumetric dimension of later apartments in the Turin demo building)

As it is underlined by the heatmap reported in Figure 29, the value of the potential heat gain dissipation, expressed in kWh, assumes consistent values for the duration of the hottest months, especially in the afternoon. Nevertheless, this potential need to be rescaled considering the designed flow (if mechanically driven) or the wind and stack driven flow and the real building space conditions.

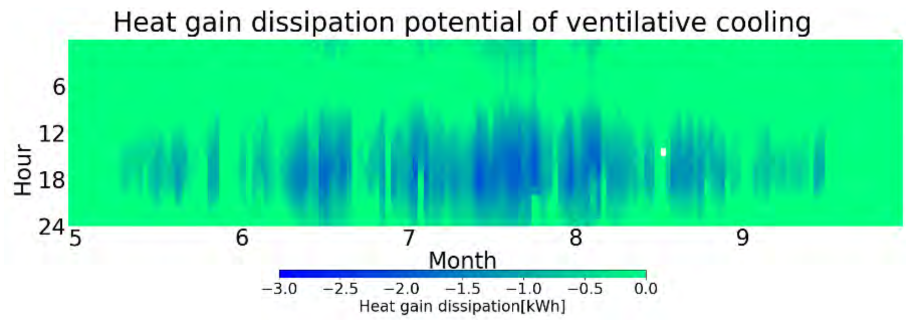


Figure 29- Carpet plot distribution of the calculated climatic ventilative cooling potential (negative heating impacts are not reported)

4. PLANNING AND IMPLEMENTATION OF PROJECT SOLUTIONS

4.1. Comfort - Energy Efficiency optimizer

4.1.1. Overview

In this section the Comfort - Energy Efficiency optimizer, developed by STAM in T4.4, is presented. The Deliverable 4.4, within Work Package 4 (Proactive optimization functions), offers a detailed description of the used methodology and developed tools. In this work a proactive optimization model of the customers' energy usage in the residential sector has been developed, by integrating and customizing STAMs' En-Power platform with a comfort module which considers electrical load shifting for energy demand response together with the indoor comfort conditions.

The algorithm relies on both an analysis of the appliances' flexibility of the household and on an empirical methodology for the thermal indoor comfort modelling. This information, together with an energy modelling approach of the building system, has been translated in mathematical terms to the Comfort-EE linear optimization model, in order to provide a seven-days ahead optimal scheduling for the energy loads.

Static information, such as building architecture, and dynamic measurements of the system status have been used to model the electrical/thermal systems. As possible to see in the following Table 17, part of the needed input data is retrieved thanks to the connection with the PRELUDE's dataspace FusiX.

The user feedback is also taken into consideration by the optimization algorithm. Through the UI, the resident can tune the preferred degree of indoor comfort by looking at the trade-off between estimated indoor temperature in the next hours and energy/cost savings among the outputs of the optimization. The proposed approach is part of the low-tech solutions for the improvement of residential energy efficiency.

4.1.2. Plan of intervention

As anticipated in the previous sub-chapter the focus of the proposed solution is the user's empowerment by exposing the right information and suggestions regarding his or her energy consumption efficiency. By means of a user-friendly UI.

The plan for the technology implementation is based on a two-steps process. First all the necessary datapoints are gathered in order to provide the input for the optimization. In this context data accessible from FusiX are analysed and the remaining static information, such as energy tariffs prices, nominal powers of installed units are given by the specific pilot owner.

The second step emphases the UI deployment and the user acceptance. In this framework, the developed platform is tested on the specific use case. Since the nature of the proposed low-tech solution, which relies on the citizen actions, the level of user-engagement is the objective to maximize in order to reach the most energy efficient possible building energy management.

As regards the first step, for each specific pilot implementation, a data requirement table is constructed and shared among the interest partners (Table 17). The table is the result of a system modelling approach, which allows a generalization of all the PRELUDE use-cases from an energetic point of view. In Deliverable D5.4 "PRELUDE data driven control", a more extensive analysis of the identified systems and sub-system is discussed.

From the schematic representations shown in D5.4, it is possible to relate each system with the needed datapoints for each of the physical/technical quantity. In this context and in the table construction, two different types of data are considered: timeseries or single values. Moreover, a classification of the data is performed in the case the measure is needed for the modules deployment or it is optional for a more advanced version of the module. In the last column of Table 17, the related FusiX datapoints identifier is shown if available, else the direct static value or the status of the research performed by the pilot's owner for the specific datapoint.

Table 17 Datapoints summary for Comfort-EE module

Data ID	Quantity	Is time series?	Need	FusiX identifiers / Information
0.1	Measured energy/power	time series	compulsory	Smart plug data (to be integrated in FusiX)
0.1	Nominal power		optional	Deduced from smart plug
0.1	Normal usage cycles		optional	Deduced from smart plug
0.1	Dispatchable usage cycles		optional	Deduced from smart plug
0.2	Internal temperature - real	time series	compulsory	ID: 226 (Indoor Temperature)
0.4	Energy input for space heating	time series	compulsory	District heating consumption divided by number of apartments (work in progress)
0.5	Windows opening / shading system	time series	optional	-
1.1	External temperature	time series	compulsory	Weather: Temperature
1.2	Irradiance	time series	optional	-
4.1	Energy tariffs		compulsory	Mapping of average energy costs (work in progress) Standard price for 3 tariffs schemes
4.2	Maximum power retrievable from the grid		compulsory	Deducible from energy meters consumption
4.3	Off peak power		optional	Electrical and thermal (work in progress)
5	**District heating**			
5.1	Energy measures	time series	compulsory	Thermal energy from district heating measurements (work in progress)

5.5	Energy cost		compulsory	District heating bills (work in progress)

As regards the construction of the thermal model of the building it is configured, considering each apartment as different unique thermal zones.

From an implementation point of view, the focus of the Turin use-case is the low-tech framework. In this context, the user-engagement is maximized by means of the GUI in which the optimal scheduling of the energy consumption is displayed, and notifications are sent to the user.

Moreover, thanks to the high availability of data concerning electrical consumptions of the household appliances in which the Smart Plug sensors are installed, the flexibility of the consumption and the demand response behaviour of the user is of primary importance. For this matter, from a software architecture point of view, a new microservice is implemented, thus new functionalities are tested and validated.

The new module, called Power Profile Service, is connected to the Data Retriever micro-service and to the Comfort-EE optimizer. From the data acquisition of the electrical loads, it is able to define typical and flexible usage cycles of each appliance. In this way, the Comfort-EE optimizer can receive the cycles as input, by avoiding a time-consuming phase of data input performed by the user. For the first version of the module, the typical usage cycles are the ones measured in the previous timeframe, i.e., previous week, while the flexible usage cycles are defined by extending forward and backward the usage cycles of a fixed number of hours, e.g., two hours.

From a general point of view, it is possible to state that the energy consumption of the considered Turin building has room for optimization. As many other households in Italy, the thermal energy consumption for space heating is centralized or is fuel-based, specifically using gas-fired boilers. In this framework the main thermal and electrical consumptions are decoupled, leaving a separated and sub-optimal solution for the Comfort-EE optimization.

Finally, data concerning the thermal energy consumption for space heating of the different apartments are disaggregated by analysing the overall building energy flows from the district heating network. In this framework, the estimated energy consumption is used as input for the training of the thermal model of the building, whose parameters are investigated, as discussed in the following sub-chapter.

4.1.3. Performance assessment

In order to evaluate the developed module in the considered use case a multistep process is approached. First the given data are analysed. This is performed by exploiting the PRELUDE common data platform FusiX. In this context the data are downloaded using FusiX APIs, pre-processed and finally stored for data visualization and analysis.

Once a reasonable amount of useful historical data is available, such as a minimum timeframe of 3 months, the second step can be performed. In this phase, as described in D4.4, the datapoints of the thermal energy inputs of the building, such as energy consumption of HVAC system and direct global irradiation, and indoor and outdoor local temperature measurements are consumed. The training of the thermal model of the building is run using one of the three possible version, namely R, R-C, or the α-R-C model. Thus, the estimated parameters are used for the test and validation of the predicting performance of the model in terms of Mean Absolute Error and Root Mean Square Error.

Having the built thermal model and the required data points, a test environment of the real application can be constructed. In this framework, during a fixed amount of time the overall architecture is operating, from back-end to front-end, testing and validating the overall data flows, from FusiX databases to the UI. The technical adjustments will be completed in this phase, in parallel with a first attempt in analysing the user acceptance of the proposed platform in terms of clarity of the information and finally the engagement of the residents.

After the implementation of the discussed technology the long-term test can take place. In this phase of the process the assessment of the intervention is carried out by the M&V module. The addressed methodology is described in D4.3 which concerns the cutting-edge methods for the calculation of different KPIs related to energy and cost savings, after a defined technological implementation takes place.

4.2. PREDYCE – modelling and verification

4.2.1. Overview of the proposed solution

Different PREDYCE usage scenarios are exploited on the modelled demo building to perform different tasks. Particularly, the model verification scenario is used to support the calibration of the model to follow the monitored indoor temperature behaviour as precisely as possible. The adopted methodology has its main reference in (D.Claridge & M.Paulus, 2019): it consists in minimising through automatic simulation runs the combined error measure $\mathrm{Error_{tot}}$ composed of RMSE (Root Mean Square Error) and MBE (Mean Bias Error) on a target variable – see eq. 1 – which is the (average) air temperature. The calibration signature, also defined in the same reference, is computed according to eq. 2. Different parametric actions applied to the building model allow to shift the curve, change inclination, and modify amplitude variations. Among the building parameters that can be modified through the automatic actions there are: internal mass; opaque envelope U-Value; windows U-Value and Solar Heat Gain Coefficient; air ventilation and infiltration. Eventually, other parameters such as shadings positions could be included in the list for specific case studies.

$$\mathrm{Error_{tot}} = \sqrt{\mathrm{RMSE}^2 + \mathrm{MBE}^2} \quad (1)$$

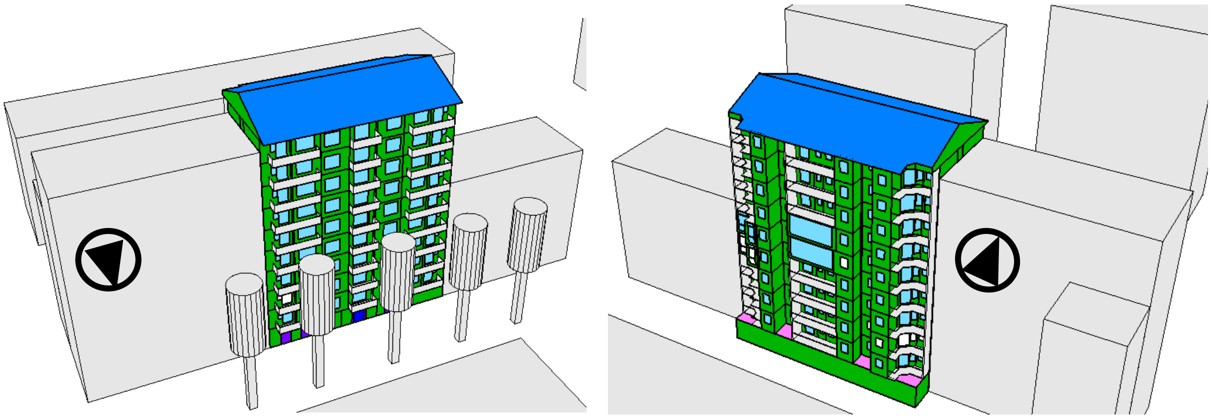
$$\text{Calibration signature} = \frac{T^{\mathrm{i}}_{\mathrm{db,meas}} - T^{\mathrm{i}}_{\mathrm{db,sim}}}{\max T^{\mathrm{i}}_{\mathrm{db,meas}}} \cdot 100\% \quad (2)$$

The calibrated model can be then exploited for different goals. Particularly, the PREDYCE sensitivity analysis scenario will be used to parametrically test the potential performance of different retrofit choices on both heating and summer free-running periods. The sensitivity analysis scenario allows to select among a large set of parametric actions (e.g. adding insulation with different thicknesses to boundary walls or to the roof, changing the windows system) and compute related KPIs, to verify the impact of different solutions and suggest possible best options. Sensitivity analyses to define a correlation heat map between different input changes and target output modifications considering energy and comfort – without considering cost analyses – will be developed, under request, in the demo result studies.

Moreover, the 24h forecast scenario will be used to try day by day suggesting the best behaviour for natural ventilation and shadings activation during intermediate and summer season to try avoiding or limiting over-heating. The application of this scenario is described in Section 4.2.3.

4.2.2. Model development and PREDYCE integration

In order to develop a Turin demo building model, an in-situ demo inspection is performed to verify and adapt cadastre data with the ones obtained by a geometrical relief check. Additionally, this inspection is used to verify window typologies and space distribution, together to acquire general information by the users in order to eventually modify standard schedules, i.e., the presence of not used and not heated rooms, etc. After the relief, the demo building has been modelled[7] through the DesignBuilder[8] software which allows to export a file input for an EnergyPlus[9] energy dynamic building simulation. Figure 30 shows an overview of the model from the outside. The main building façade faces North and is in front of a large tree-lined avenue; the other side of the building instead (facing South) is in front of an internal courtyard. The main surrounding buildings and trees have also been modelled in shape to consider their shadowing impact on the demo case. The building has two internal stairs, and each floor is composed by three apartments: figure 31 shows the layout of a generic floor. The central bigger apartment is sided by two specular smaller apartments with a slightly more irregular shape. Generally, bedrooms face North while kitchens and living areas face South. As a model choice, apartments which are not monitored have been modelled taking as reference structure apartments A1, A8 and A3. They have been treated as a unique thermal zone except for the rooms directly adjacent to the monitored apartments, which have been handled separately. Initial construction choices before model verification have been defined in line with the TABULA webtool[10] for the given period and assuming general material characteristics from Italian energy certification tools. Figure 32 reports a sample visualisation of the hypothetical layer distribution of vertical opaque external walls and horizontal slabs.



(a) *(b)*

Figure 30 Overview of the demo building model from Turin in (a) and from the internal courtyard in (b).

[7] Dr Yaakov Florentin (POLITO) worked in the definition of the initial model versions in DesignBuilder.
[8] https://designbuidler.co.uk
[9] https://energyplus.net
[10] ttps://webtool.building-typology.eu/#bm

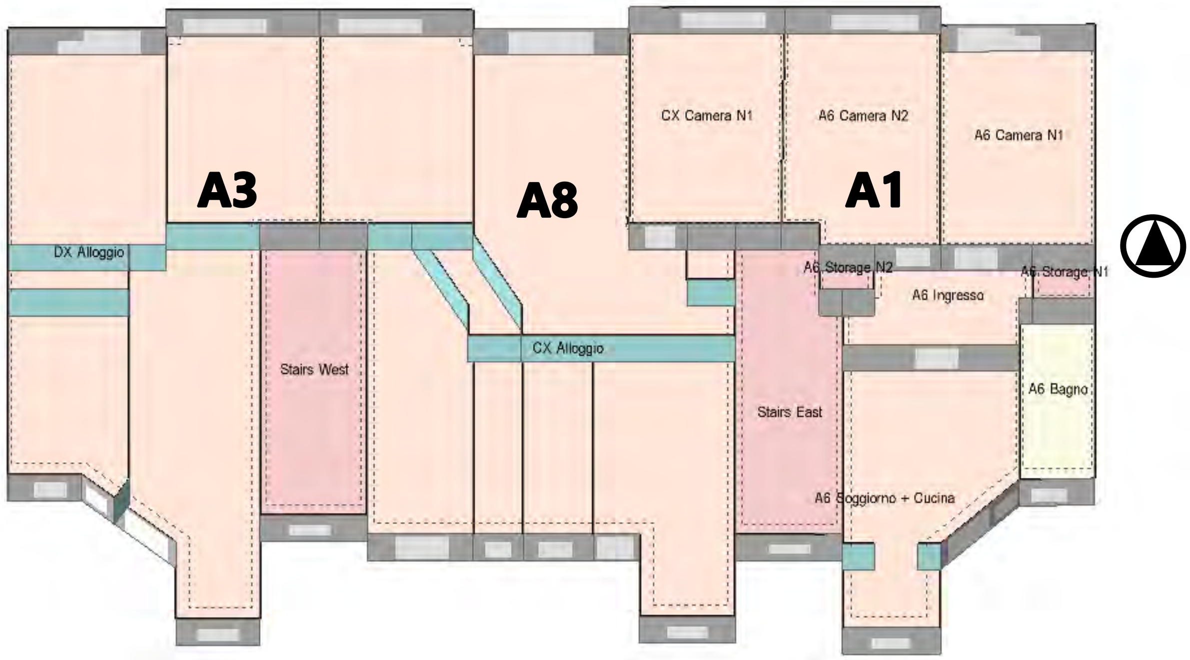
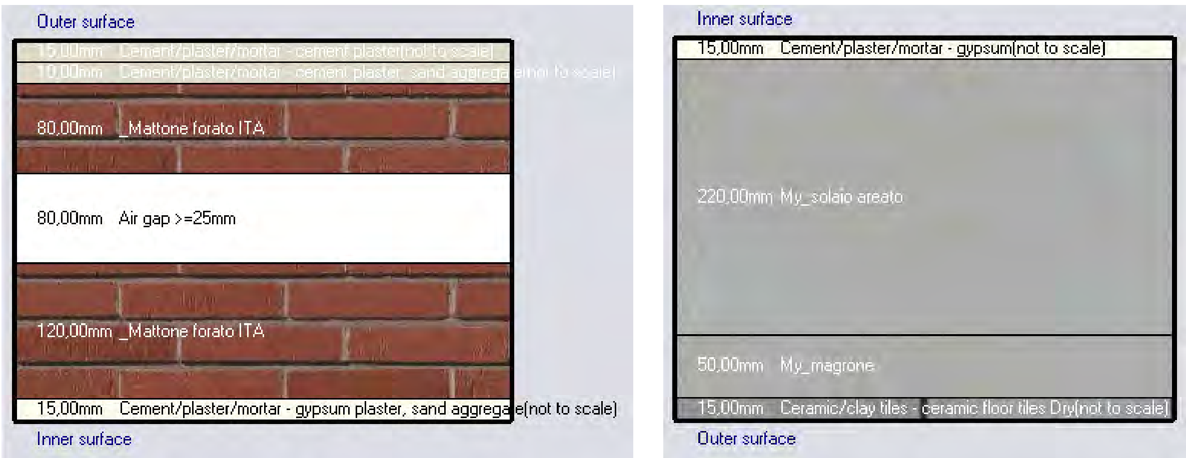


Figure 31- Overview of a generic floor structure based on 3 verified units located on nearer floors.



(a) *(b)*

Figure 32- Boundary walls (a) and floor separators (b) construction details.

Exported the original building model Input Data File for simulation (IDF format), the model is passed to the PREDYCE tool in order to perform input modifications and run the mentioned scenarios.

4.2.3. Model verification and initial results solution

Concerning the Turin demo case, monitored data from the Aircare sensors are available from 30/09/2022. This implied that only about one month of free-running data (October 2022) was available for the initial calibration procedure. Calibrating on the indoor temperature exploiting mainly the free-running periods was of great importance considering the application of various summer optimization scenarios such as the 24h forecasting – see Section 4.3. Moreover, not all the apartments were transmitting data at that time, hence data from the apartments A1, A2, A3, A4, A6 and A7 were used. The heating period ended at the beginning of April 2023, so few weeks of additional data could be used to test the reliability of the calibrated model so far on the apartments which were currently active: A1, A2, A3, A6, A8 and especially on A5, which was selected as main demo case for the 24h forecast scenario. Consequently, further analyses and eventual adjustments on the models may be needed in the following months.

The adopted calibration procedure for the Turin building consisted in minimizing the combined error measure described in section 4.2.1 on the indoor air temperature, by acting on several parameters related both to the monitored apartments and to the whole building. Figure 33 shows the starting point of the model verification process in October 2022 for all the monitored apartments. It can be noticed that apartments A3 and A4 are impacted in different ways by the presence of an enclosed balcony: A3 is characterized with very low temperature on the balcony, close to outdoor temperature, meaning that windows are probably kept most of the time open; A4 instead is characterized by very high temperature on the balcony which probably causes the flattening of the other rooms trend. Moreover, the Aircare sensor located in apartment A4 shows a peculiar behaviour, flat with very small peaks, not following the normal sinusoidal trend: this suggests that the sensor could be not correctly working, or it has been moved by the tenants in an inappropriate environment e.g., a wardrobe, maybe for aesthetic reasons. Concerning the other apartments, the starting point of the calibration procedure is promising and validates the model choices: only apartments A1 and A7 show a consistently shifted trend which should be then addressed by the calibration procedure. However, as shown in Figure 34, the starting point calibration signature is already quite good with most points inside the 5% error range.

The adopted calibration procedure consisted in acting first on all the parameters of the whole building considering as a target variable the average indoor temperature in all the monitored apartments, and then specifically in each of the monitored apartments considering as a target variable the air temperature of each apartment separately. Even if the Aircare sensor is in a specific room of the apartment, the average simulated temperature of all the main rooms is used for the comparison. This was done to obtain a final result representative of the whole apartment average behaviour. Table 18 shows the considered parameters for the whole building with allowed variation ranges and final best-found values, and Figure 35 the obtained calibration signature and temperature trend at this point. The average simulated trend is significantly better aligned with the monitoring and the calibration signature, even if it still presents sparse points, is centred around the 0 value.

Table 19 focuses on the separate apartments results. Windows values ranges are selected according to inspection and natural ventilation rate is simulated as an average daily effect (with an always on schedule) in the apartment. Best values were selected minimizing the error on the specific apartment to avoid undesirable compensation effect from other apartments still not optimized behaviour. Since ventilation rate is considered as an average effect, it is possible that in other periods of the year specific adjustments on the schedule or in the activation thresholds (e.g., based on outdoor temperature) may be needed for future applications. Figure 36 shows simulated and monitored temperature trend in the apartments at the end of the calibration procedure: some of the apartments (e.g., A1 and A2) presents a more uniform simulated temperature distribution in the rooms, while others (e.g., A3 and A4) presents greater shifts from the average. The apartments that at the beginning presented the greatest misalignment are solved at the end of the calibration process (e.g., A1 and A7). Figure 37 finally shows the calibration signature and average building temperature trend at the end of the calibration process. At this point, the reached error values are summarized in Table 20.

Figure 33- Simulated and monitored temperature trend at the beginning of the calibration procedure in October 2022.

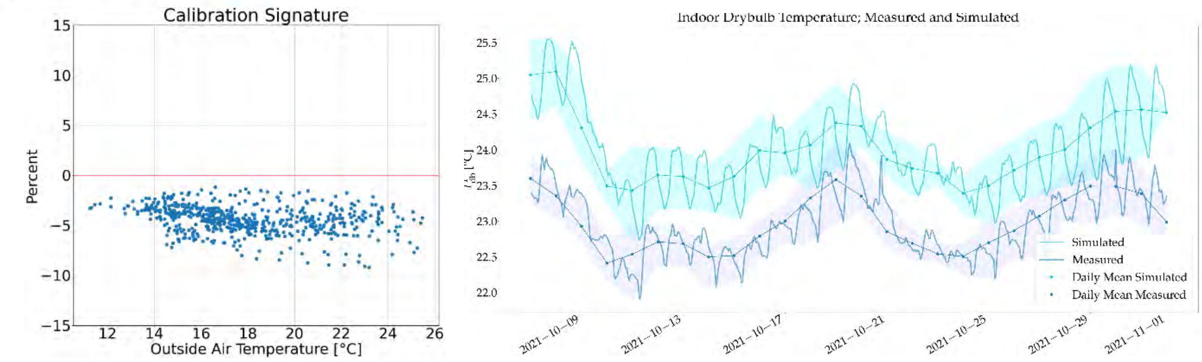


Figure 34- Calibration signature and air temperature at the beginning of the calibration procedure in October 2022.

Table 18– Calibration parameters for the demo building not including the monitored apartments.

Parameter	Starting point	Allowed variation range	Final value
Boundary walls – UFactor	1.107 W/m^{2}K	+/- 40% with step 0.05 W/m^{2}K	+25%
Roof floor – UFactor	1.106 W/m^{2}K	+/- 40% with step 0.05 W/m^{2}K	+40%
Roof – UFactor	2.930 W/m^{2}K	+/- 40% with step 0.05 W/m^{2}K	+20%
Unknown windows UFactor	2.708 W/m^{2}K	[1.5,5] with step 0.05 W/m^{2}K	5 W/m^{2}K
Unknown windows SHGC	0.703	[0.5,0.8] with step 0.025	0.5
Stairs air infiltration	0.3 ACH	[0.05,1.5] with step 0.15 ACH	0.95 ACH
Other apartments air infiltration	0.3 ACH	[0.05,1.5] with step 0.15 ACH	0.5 ACH
Stairs internal mass	-	[1,10] with step 1	1
Other apartments internal mass	-	[1,10] with step 1	6

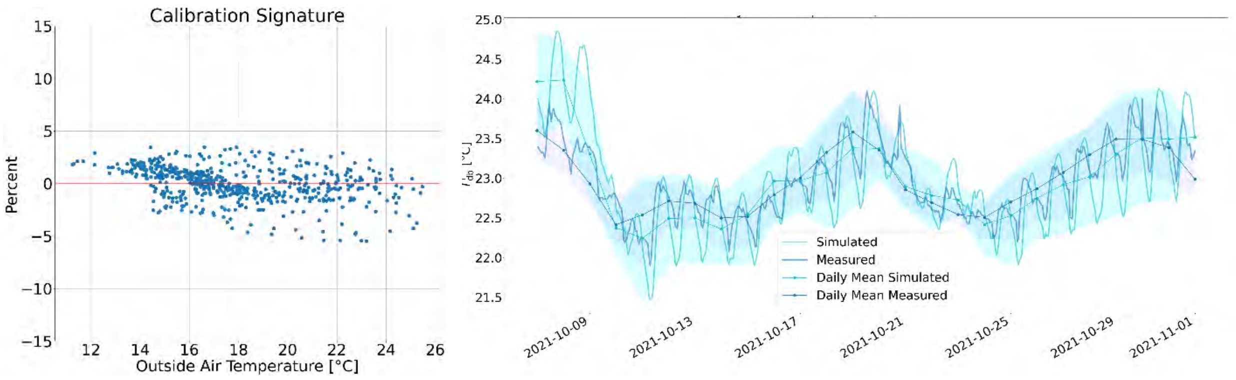
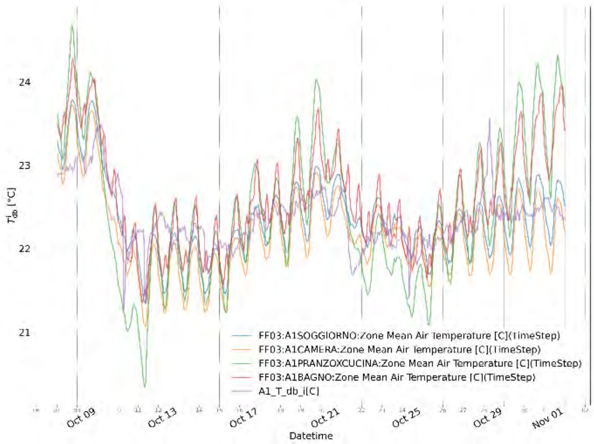


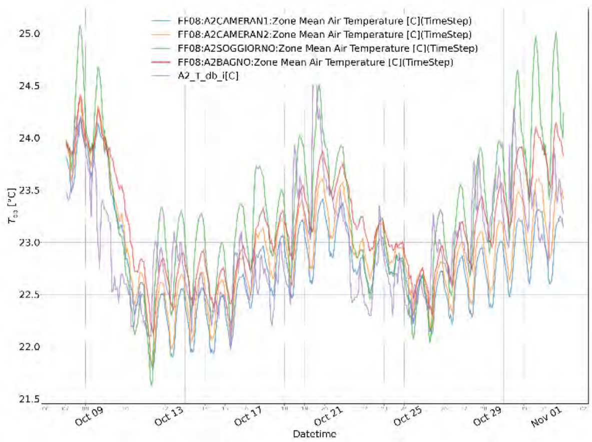
Figure 35- Calibration signature and air temperature trend at the end of the first calibration step.

Table 19– Calibration parameters for the demo building in the monitored apartments.

	Parameter	Starting point	Allowed variation range	Final value
A1	windows UFactor	2.71 W/m^{2}K	+/- 30% with step 0.05 W/m^{2}K	3.1 W/m^{2}K
	windows SHGC	0.70	+/- 20% with step 0.05	0.5
	air infiltration	0.3 ACH	[0.05,0.8] with step 0.15 ACH	0.5 ACH
	air ventilation	0 ACH	[0.05,1.4] with step 0.15 ACH	0.95 ACH
	internal mass	-	[1,10] with step 1	6

A2	windows UFactor	2.55 W/m²K	+/- 30% with step 0.05 W/m²K	1.66 W/m²K
	windows SHGC	0.70	+/- 20% with step 0.05	0.81
	air infiltration	0.3 ACH	[0.05,0.8] with step 0.15 ACH	0.2 ACH
	air ventilation	0 ACH	[0.05, 1.4] with step 0.15 ACH	0.95 ACH
	internal mass	-	[1,10] with step 1	6
A3	windows UFactor	2.71 W/m²K	+/- 30% with step 0.05 W/m²K	2.03 W/m²K
	windows SHGC	0.70	+/- 20% with step 0.05	0.88
	air infiltration	0.3 ACH	[0.05,0.8] with step 0.15 ACH	0.05 ACH
	air ventilation	0 ACH	[0.05, 1.4] with step 0.15 ACH	0.05 ACH
	internal mass	-	[1,10] with step 1	1
A4	windows UFactor	2.55 W/m²K	+/- 30% with step 0.05 W/m²K	3.19 W/m²K
	windows SHGC	0.70	+/- 20% with step 0.05	0.53
	air infiltration	0.3 ACH	[0.05,0.8] with step 0.15 ACH	0.35 ACH
	air ventilation	0 ACH	[0.05, 1.4] with step 0.15 ACH	0.95 ACH
	internal mass	-	[1,10] with step 1	6
A6	windows UFactor	6.12 W/m²K	+/- 30% with step 0.05 W/m²K	3.4 W/m²K
	windows SHGC	0.82	+/- 20% with step 0.05	0.9
	air infiltration	0.3 ACH	[0.05,0.8] with step 0.15 ACH	0.65 ACH
	air ventilation	0 ACH	[0.05, 1.4] with step 0.15 ACH	0.05 ACH
	internal mass	-	[1,10] with step 1	6
A7	windows UFactor	2.55 W/m²K	+/- 30% with step 0.05 W/m²K	2.81 W/m²K
	windows SHGC	0.70	+/- 20% with step 0.05	0.56
	air infiltration	0.3 ACH	[0.05,0.8] with step 0.15 ACH	0.2 ACH
	air ventilation	0 ACH	[0.05, 1.4] with step 0.15 ACH	0.95 ACH
	internal mass	-	[1,10] with step 1	5





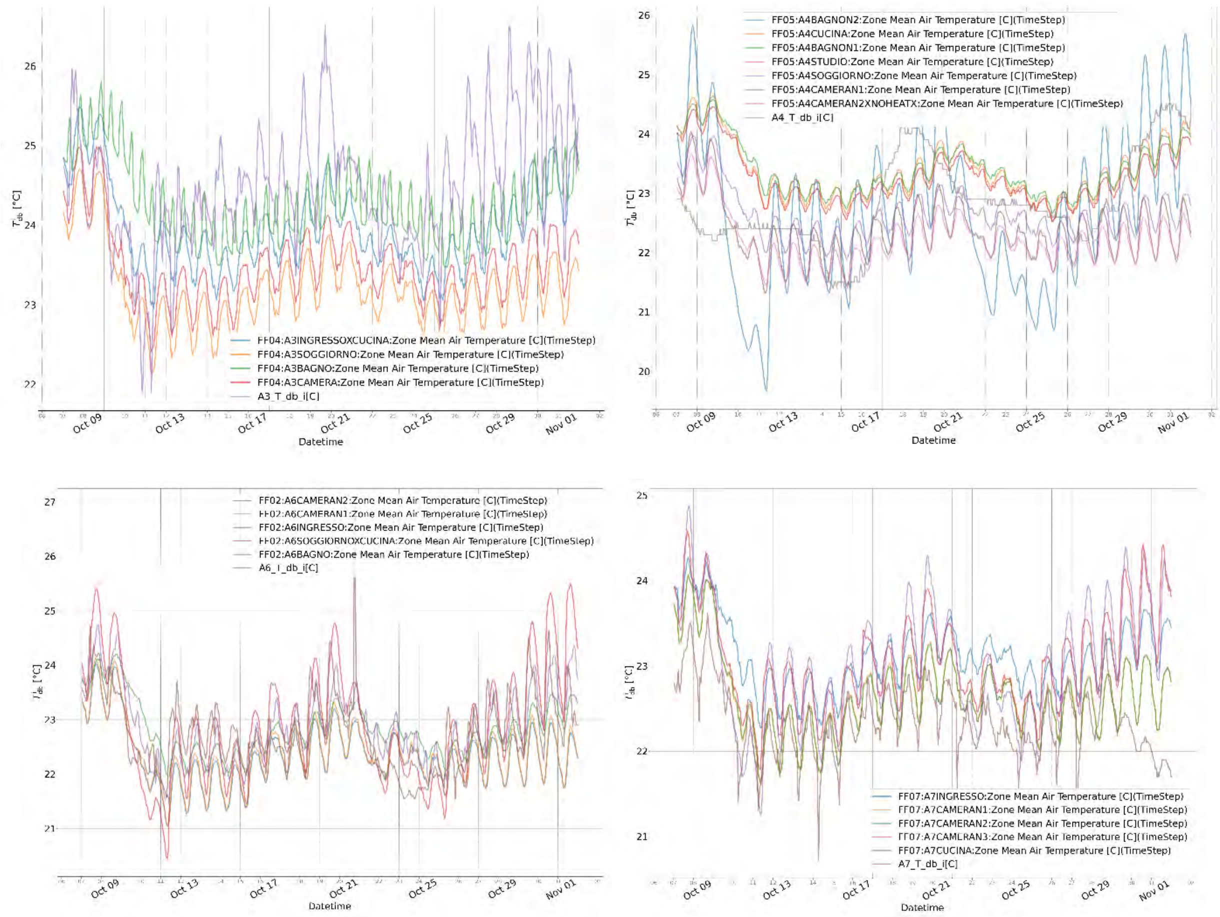


Figure 36- Simulated and monitored temperature trend at the end of the calibration procedure in October 2022.

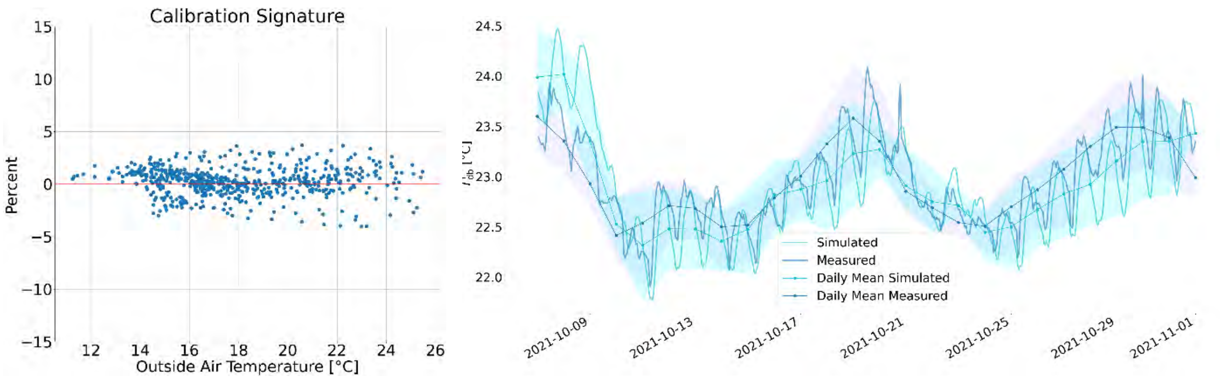


Figure 37- Calibration signature and air temperature trend at the end of the calibration procedure in October 2022.

Table 20– Final error values at the end of the calibration procedure in October 2022.

	Whole Building	A1	A2	A3	A4	A6	A7
MBE	-0.06	0.03	0.09	-0.79	0.01	-0.11	0.55
RMSE	0.32	0.43	0.40	1.08	0.77	0.54	0.64
$Error_{TOT}$	0.33	0.43	0.41	1.33	0.77	0.56	0.84

Figure 38 shows how the obtained calibration results perform in April 2023, also considering the apartments that were not transmitting yet in autumn (A5 and A8) which show a good alignment, while Figure 39 the calibration signature and average trend. It is clearly visible that all apartments present an increasing shift between monitored data and simulation, particularly from mid-April. This could be due to changed ventilation habits with respect to the autumn season, as showed in Figure 40, for apartments A1 and A2, where the indoor temperature threshold for natural ventilation activation has been decreased from 24 °C, more appropriate for winter, to 20 °C. The following summer months, which will be the first monitored summer, will be exploited to refine natural ventilation and shadings parameters and schedules.

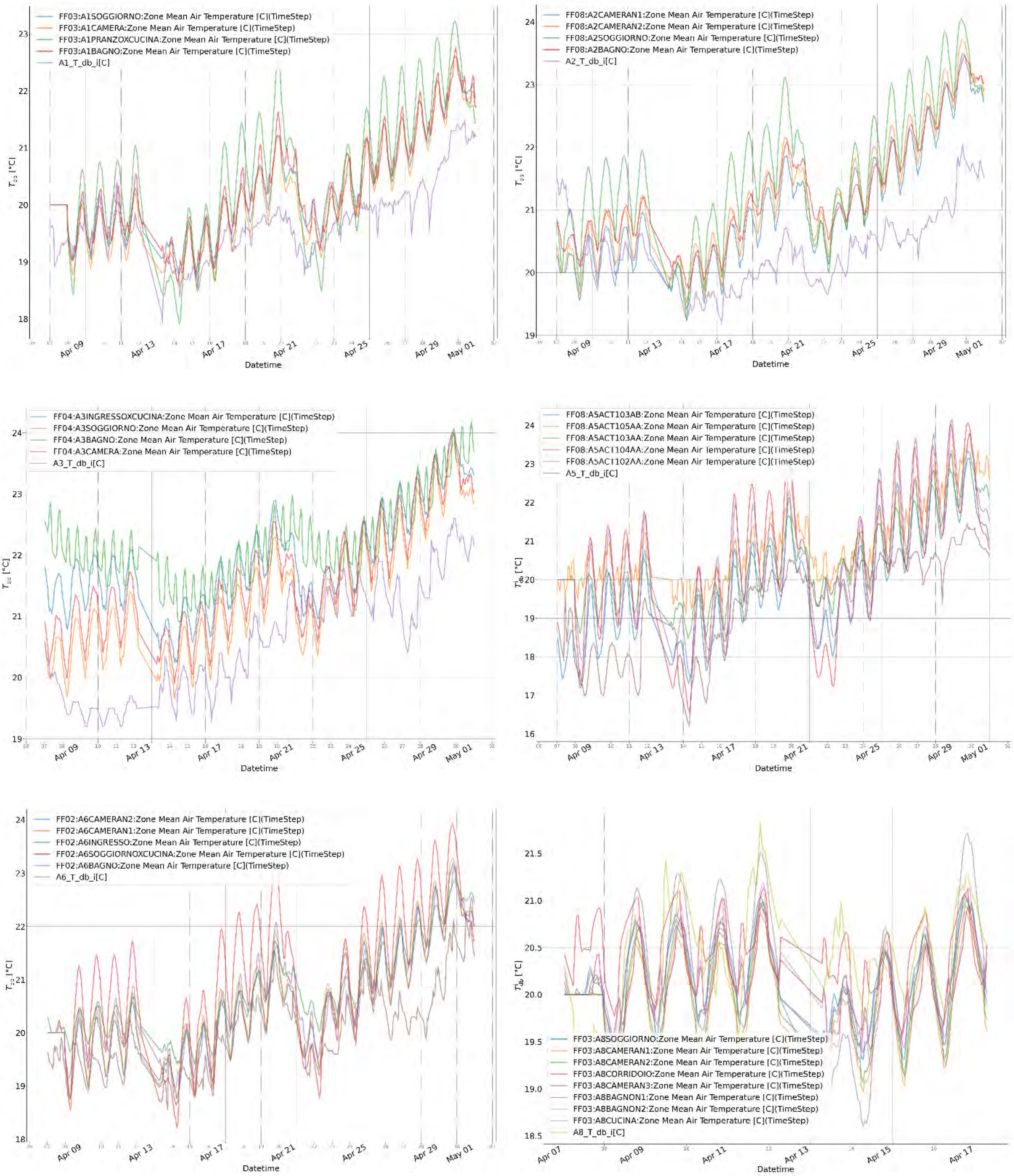


Figure 38– Simulated and monitored temperature trend in April 2023.

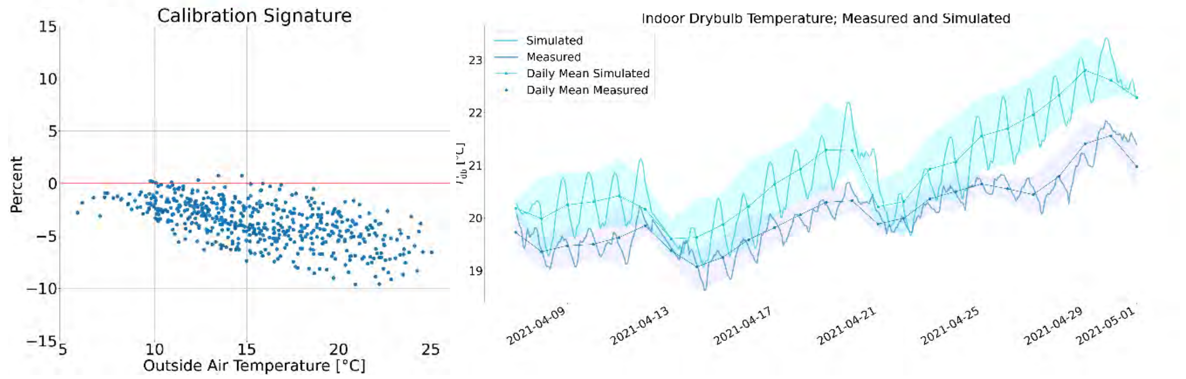


Figure 39– Calibration signature and air temperature trend in April 2023.

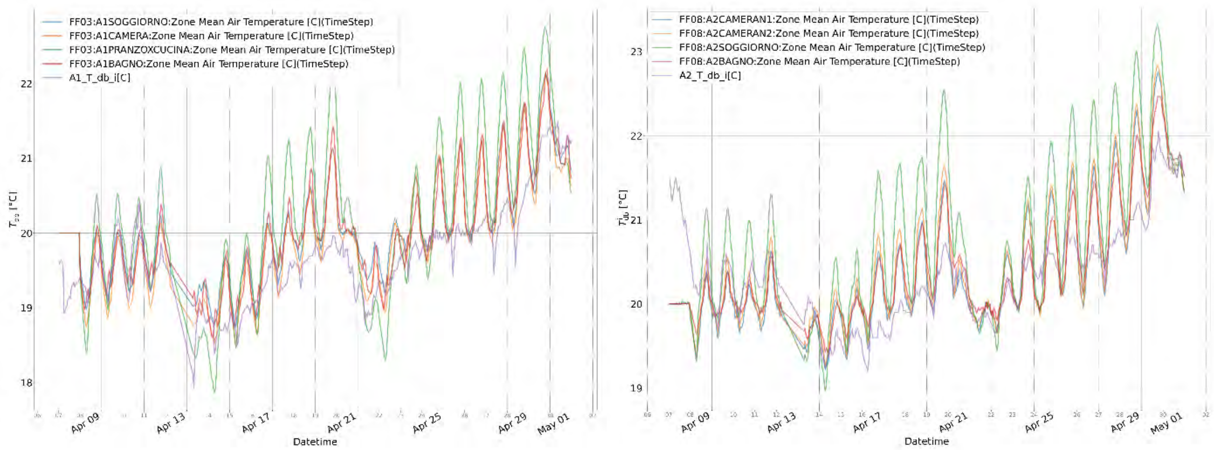


Figure 40– Simulated and monitored temperature trend in April 2023 – lower indoor temp. threshold for ventilation.

Concerning apartment A5, which has been selected as main test case for technology application, data are available from February 2023. Hence a shorter calibration procedure has been carried on so far considering three weeks in April 2023, once the heating period was over, to also have some validation days between April and May. The same is done for apartment A8. Both apartments show some missing monitored days in April. Figure 41 shows obtained results in the two apartments while Figure 42 the final calibration signature and average building temperature trend (with the roughly updated natural ventilation indoor temperature activation threshold). Table 18 shows the considered calibration parameters and the obtained best values, while Table 19 shows the obtained error measures in April 2023 in all the transmitting apartments. As previously described, A5 is not only monitored with the Aircare sensor, but also with Capetti sensors with room detail. Hence, it is possible to consider the alignment of all the main rooms instead of the average. The Capetti data will be then used to refine the apartment alignment for the 24h forecast application – see section 4.3.

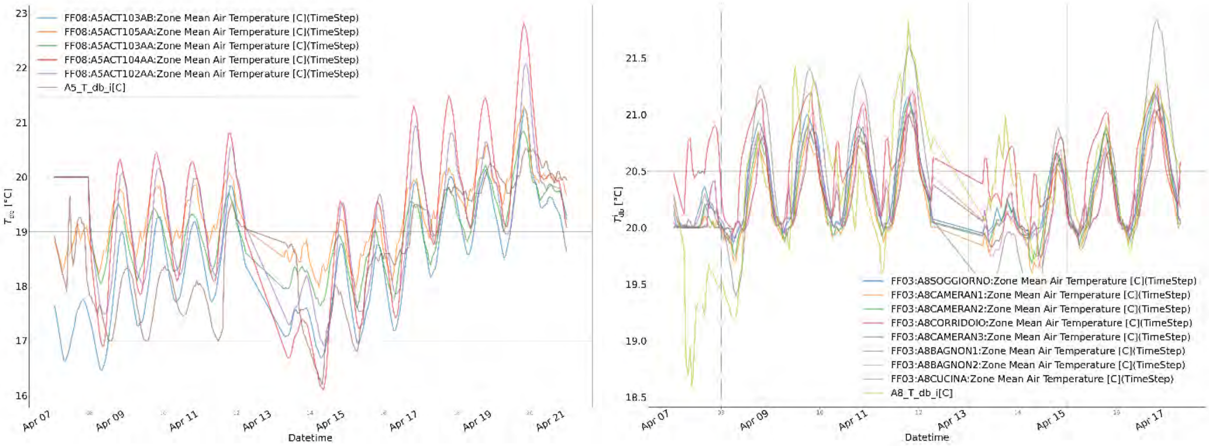


Figure 41– Simulated and monitored temperature trend at the end of the calibration process in April 2023.

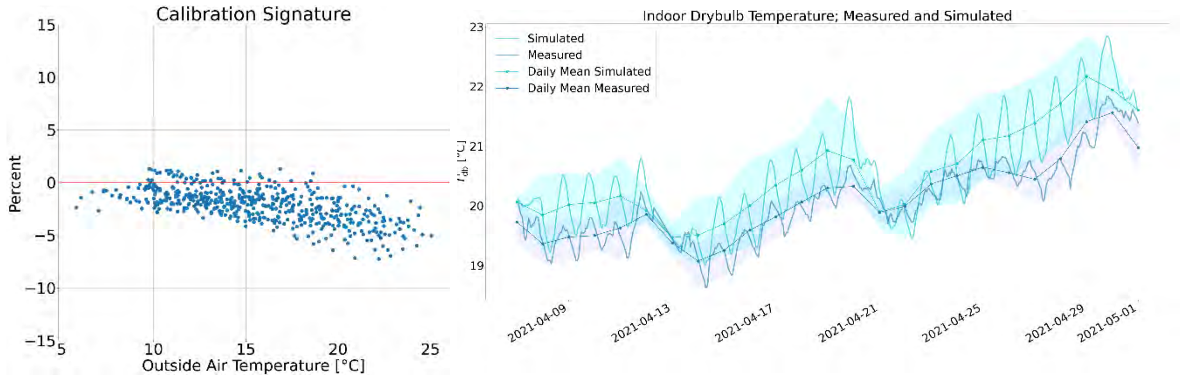


Figure 42– Calibration signature and air temperature trend at the end of the calibration process in April 2023.

Table 21– Calibration parameters for the demo building in A5 apartment.

	Parameter	Starting point	Allowed variation range	Final value
A5	windows UFactor	2.55 W/m^{2}K	+/- 30% with step 0.05 W/m^{2}K	2.93 W/m^{2}K
	windows SHGC	0.70	+/- 20% with step 0.05	0.53
	air infiltration	0.3 ACH	[0.05,0.8] with step 0.15 ACH	0.8 ACH
	air ventilation	0 ACH	[0.05, 1.4] with step 0.15 ACH	0.95 ACH
	internal mass	-	[1,10] with step 1	5
A8	windows UFactor	2.55 W/m^{2}K	+/- 30% with step 0.05 W/m^{2}K	1.66 W/m^{2}K
	windows SHGC	0.70	+/- 20% with step 0.05	0.86
	air infiltration	0.3 ACH	[0.05,0.8] with step 0.15 ACH	0.05 ACH
	air ventilation	0 ACH	[0.05, 1.4] with step 0.15 ACH	0.35 ACH
	internal mass	-	[1,10] with step 1	2

Table 22– Final error values at the end of the calibration procedure in April 2023.

	Whole Building	A1	A2	A3	A5	A6	A8
MBE	0.46	0.37	0.16	1.01	0.12	0.46	-0.04
RMSE	0.57	0.58	0.52	1.14	0.88	0.57	0.44
$Error_{TOT}$	0.73	0.68	0.55	1.52	0.89	0.73	0.45

4.3. PREDYCE – summer free-running optimisation scenarios

4.3.1. Overview of the proposed solution

As mentioned in the introduction, the Turin demo building tested different smartness level in the technological integration path. Also considering shading and ventilation for cooling operational control, different level of smartness are defined, running from uncontrolled and uninformed ventilation (random) – low smartness level – to forecasting optimisation scheduling definition via massive simulations runs (PREDYCE 24h forecasting) – high level of smartness. In particular, in addition to the random ventilation, in which no control is performed, two different level of smartness are proposed for supporting free-running choice optimisation:

- fixed optimised control thresholds – see the approach proposed in the PRELUDE deliverable D5.4 – for a medium-to-low smartness,
- and the 24h forecasting scenario of the PREDYCE tool – see the PRELUDE deliverable D3.2 – for the high smartness level.

The latter is applied in a sole demo unit (A5), while the former bases on the calculation of optimised control thresholds for the whole building but dividing north and south orientations.

In both cases any actuator is present to control shading and window openings – which are the two analysed free-running technologies – requiring to integrate results in the PREDYCE common visual application to support users in defining self-actuation behaviours.

In particular, the 24h forecasting scenario requires to run each day a large number of simulations, taking advantage by the PREDYCE sensitivity analysis potential via the automatic generation of IDF input variations, to identify the shading and window conditions that better guarantee a lower thermal discomfort by also considering the aggregation of hours when people cannot change conditions (e.g. during the night a sole value is defined for a larger set of hours being not possible to ask the tenants to wake up to self-actuating the windows). Considering the Turin demo case, comfort is based on the adaptive thermal comfort model, even if the tool may also consider the PMV/PPD approach for mechanically cooled spaces. The run of a massive amount of simulation to define the best schedules for the next day requires high computational power in terms of parallel cores and is performed on the POLITO PRELUDE-used server. In order to automatise the process, a shared work with relevant partners is under-developed to connect the 24h forecast run for Torino with the project middleware to further share results to end-users. Additionally, the module requires weather data of the past weeks to warming up the simulation and define the running mean temperature for the thermal comfort model, and the forecasted weather. The first series of data are retrieved by the above-described cloud connected meteorological stations, while the latter via Meteoblue[11]. Additionally, monitored indoor conditions need also to be retrieved to feed the previous-day simulation. The description of the implementation is given in Section 4.3.2, regarding both the A5 specific model implementation – Section 4.3.2.1 –, and in Section 4.3.2.2 for the 24h forecasting dataflow and integration.

[11] www.meteoblue.com

In line with the approach proposed in the PRELUDE Deliverable D5.4, the PREDYCE tool is allowing to perform optimisation analyses of specific parameters suggesting a best control threshold for low-energy and bioclimatic technologies. In particular, the approach is applied to suggest shading (temperature and global horizontal irradiation) and ventilative cooling (temperature) activation periods to the users. The approach is here applied to the whole building model described in Section 4.2, assuming the verified version of it. In order to facilitate the simulation flow and due to the long time needed to run each simulation, the new genetic optimisation function of PREDYCE is here adopted identifying best control thresholds. These values may be hence used by both automatic controls, which are not installed in the Turin demo, and by the common graphical interface to inform users about suggested shading activation and window openings to support summer comfort. This integration is currently under evaluation and may be refined under the next months. Optimised values and a methodological implementation description are reported in Section 4.3.3.

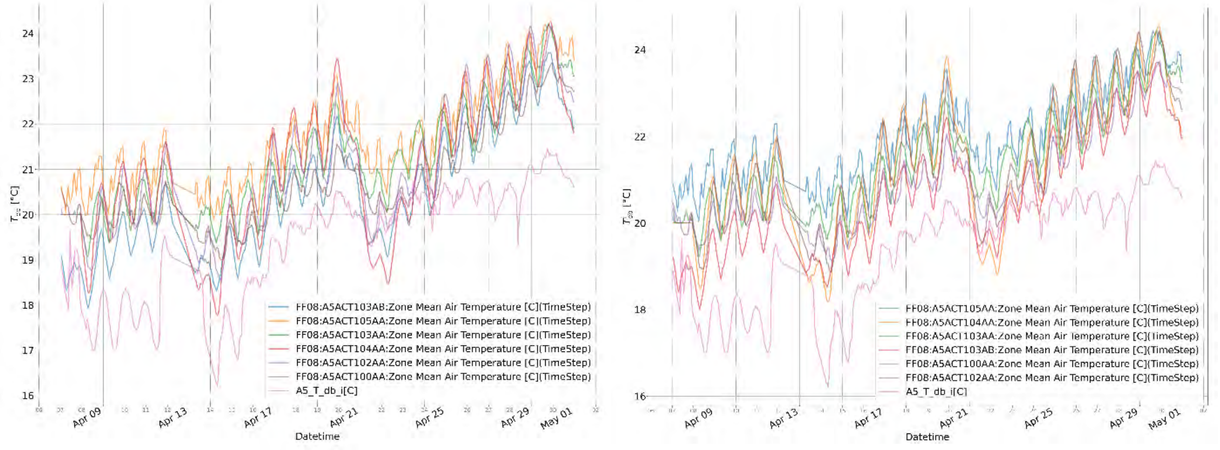
4.3.2. 24h forecasting scenario

In order to implement the 24h forecasting scenario a smaller focussed model for the A5 flat is developed – see Section 4.3.2.1. Thanks to the Capetti additional sensors, this flat is monitored at room details allowing to perform room optimisation or analyses potentially. Defined the model, specific implementation actions are described in Section 4.3.2.2.

4.3.2.1. Model development and PREDYCE integration

From the complete demo building model, a smaller model for the A5 apartment has been extracted to drastically reduce the simulation time and to ease the application of the previously described technology, which requires daily massive parametric simulations run. In fact, the weekly simulation time for the complete model is 502 seconds while for the smaller model it is reduced to 8 seconds. Figure 43 shows the adopted modelling solution: apartments of both above and below floors are kept without room detail, and on the same floor adjacent rooms of the central apartment and the stairs are also kept. Boundary envelope of the small model is set to adiabatic and as a boundary condition only a high building which could shadow the apartment is kept. The inside view instead is the same of the complete model, with room detail. Figure 44shows how these choices have a very small impact on simulation results (before the calibration procedure is carried on), hence results of the calibration procedure do not lose validity.

Figure 43– Overview of the model of A5 apartment.



(a) *(b)*

Figure 44– Aircare monitoring in April 2023 in A5: complete model (a) and smaller model (b) starting points.

4.3.2.2. 24h forecasting implementation in the specific flat

The A5 apartment has no actuators for shading or ventilation solutions, and both windows opening and curtains/shutters have to be positioned manually. Hence, in this case, the 24h forecasting output is focused on suggestions for the tenants that are divided in blocks of hours according to their availability, e.g., it can be unfeasible for users to change the status of windows during night-time or activate shading when they are not at home during working time. For this purpose, the embedded schedules in the model for windows and ventilation are modified and assigned to custom CSV files in order to be modified in a granular way. The room's temperature and relative humidity monitored data from Capetti are retrieved from FusiX platform and used to force the behaviour of the rooms to guarantee the most accurate starting point for the simulations. For each 24h launch, the apartment is thus forced to behave like the real building until the current day from which the simulation program tries to estimate its behaviour with the different combinations of shading and ventilation parameters, using forecast weather data as support. Since the apartment features many windows, it has been decided to create three main groups in order to reduce the amount of simulation parameters; the following groups are considered: i.) north-facing windows, ii.) bathroom and living room and iii.) kitchen. For every block of hours, the status of the shading and ventilation for each group is chosen in order to maximize the thermal comfort for the rest of the day; following launches for the next blocks of hours are then utilised to create a schedule that cover the entire day. In case some strategies do not provide a major benefit in term of thermal comfort during specific moments, it has been decided to keep shading activation and ventilation as low as possible to maximize natural daylighting and prevent excessive air flow in the apartment. The result of each 24h launch is converted to a text file to be given to tenants as suggestions.

4.3.3. Shading and ventilation activation threshold optimisation

The proposed low-to-medium approach to suggest shading and ventilative cooling activation based on optimised thresholds is defined in line with the PRELUDE deliverable D5.4. The approach adopts the PREDYCE tool to identify, for the given model of the whole building – see Section 4.2 of this report –, optimal control values for the shading and the window operations to support free-running comfort in the building spaces. The adopted model version is the pre-verified one, and results may be re-tuned on the final calibrated model during the next project months. The methodology performs a sensitivity analysis to identify, for typical weather Turin conditions, the thresholds for activating i.) the sole shading, ii.) the sole ventilation and iii.) the combination of both techniques to minimise a.) thermal discomfort in the free-running mode and alternatively b.) minimise the cooling needs of potential split units in the mechanical mode. Considering the latter, only a very limited number of flat shows the present of a personal cooling solutions, leaving to the end-users the potential activation of those typical market split systems.

In order to calculate these optimal thresholds, the PREDYCE tool is used, taking advantages of the integration in the tool – an action currently under implementation – of different genetic algorithm optimisers. Genetic algorithms, in particular, are methods for evaluating different starting configurations and recombining them to create novel solutions, which are then assessed by choosing the best to discover "optimal" solutions. These recombination and selection phases correspond each to an iteration of the algorithm. These algorithms are effective despite their "random" character, especially when it comes to multi-objective problem optimisation. They do this by returning all of the Pareto front's (the optimisation front) optimum solutions, which are selected from the created populations at each generation. In particular, Pyomo is the Python package integrated in PREDYCE that enables the execution of various optimisation procedures. The genetic algorithms NSGA2 (for optimising two objectives), NSGA3 (for optimising three or more objectives), and its variants RNSA2 and RNSGA3 are taken into consideration. These algorithms allow for the identification of "reference points" for additional optimization choices inside the Pareto Front. The optimisation is performed on the whole building, retrieving different values for the north and the south facades – for the shading control – in order to consider both solar expositions. The following Table 23 identify the defined control cases and the tested control parameters, leaving to the further implementation into control rules or suggestions to end-users, based on simple threshold control logics – see for example

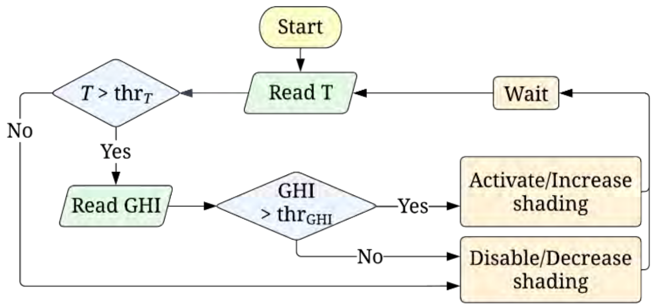


Figure 45 –, the selection of the case that better represents each unit application. Regarding the tested control parameters, the following variation ranges are considered:

- Shading threshold GHI (range values: 50–800 W/m^2)
- Shading threshold inside air temperature (range values: 10–35 °C, continuous values)
- Shading threshold outdoor air temperature (range values: 10–35 °C, continuous values)
- Ventilation threshold difference in temperature between indoor and outdoor conditions (range values: 0–10 °C)
- Ventilation threshold minimum indoor temperature (range values: 12–30 °C)
- Ventilation threshold maximum indoor temperature (range values: 15–40 °C)
- Ventilation threshold minimum outdoor temperature (range values: 10–28 °C)
- Ventilation threshold maximum outdoor temperature (range values: 15–40 °C)

The optimised target variables to be minimised are:

- thermal discomfort
    - o adopting the adaptive thermal comfort model, i.e. the cumulative distance from the central line, for the free-running mode;
    - o and the percentage outside the range (POR) indicator based on PMV/PPD for the mechanical cooled mode,
- the cooling energy needs (Q_c) – for the mechanical cooled mode only considering latent cooling (temperature variations and dehumidification).

Cooling energy needs include both sensible cooling (temperature control) and dehumidification – simple HVAC mode in EnergyPlus – considering that the very few installed personal cooling systems are split units. A sample EER of 6.5 is assumed for the sensible cooling and of 4.2 for the dehumidification, in line with a sample commercial domestic spit unit (Mitsubishi), looking at technical sheets. The POR, adopted for mechanically cooled cases, is mainly used to prevent overcooling effects, e.g., at night.

The analyses base on the sole summer season, when the heating system is off, and are conducted in the main summer period, assumed from the 1st of June till the 31st of August. Results are reported in Table 24. The optimal threshold values can be used to support a low-to-medium alerting of the end-users to suggest shading and window-opening activations preventing summer overheating risks when environmental conditions are favourable to exploit the free-running cooling potentials (heat gain prevention and heat gain dissipation via natural ventilation).

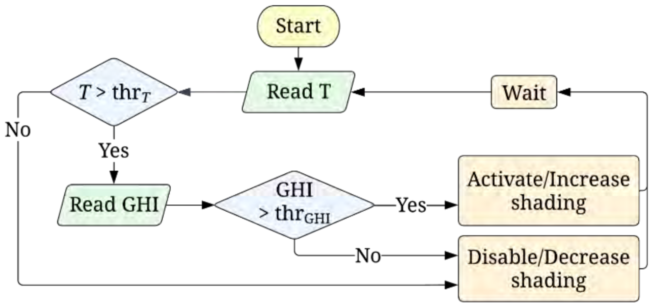


Figure 45 - sample control flowchart for shading

Table 23 - the shading-ventilation threshold approach: identification of the considered cases and control value variation ranges

Control case	**Mode** (FR = Free-Running; MC = mechanical cooling)	**Variables**	**Notes**
Reference case	FR	None	North & South facades
Reference case	MC	None	North & South facades
i. Shading only	FR	Te (outside)[°C], GHI[W/m^2],	North & South facades
	MC	Te (outside)[°C], GHI[W/m^2],	North & South facades
ii. ventilation only	FR	Delta Tin-Te[°C], Min indoor Temp [°C], Min outdoor Temp [°C], Max indoor Temp [°C], Max outdoor Temp [°C]	North & South facades
	MC	Delta Tin-Te[°C], Min indoor Temp [°C], Min outdoor Temp [°C],	

		Max indoor Temp [°C], Max outdoor Temp [°C]	
iii. Combined	FR	Te (outside)[°C], GHI[W/m^2], Delta Tin-Te[°C], Min indoor Temp [°C], Min outdoor Temp [°C], Max indoor Temp [°C], Max outdoor Temp [°C]	North & South facades
iv. Combined	MC	Te (outside)[°C], GHI[W/m^2], Delta Tin-Te[°C], Min indoor Temp [°C], Min outdoor Temp [°C], Max indoor Temp [°C], Max outdoor Temp [°C]	North & South facades

Table 24 - Retrieved optimal thresholds and correlated targets

Control case	**Variables**	**Optima**	**Target**
Reference case - FR	None	none	Dist Acm 4.91
Reference case – MC	None	None	Qc 23.06 POR 0.96
i. Shading only - FR	Te (outside)[°C], GHI[W/m^2],	14.56 54.50	Dist Acm 3.65
i. Shading only - MC	Te (outside)[°C], GHI[W/m^2],	12.68 54.57	Qc 22.92 POR 0.35
ii. ventilation only - FR	Delta Tin-Te[°C], Min indoor Temp [°C], Min outdoor Temp [°C], Max indoor Temp [°C], Max outdoor Temp [°C]	1.15 25.95 16.98 36.59 35.53	Dist Acm:0.94
ii. ventilation only - MC	Delta Tin-Te[°C], Min indoor Temp [°C], Min outdoor Temp [°C], Max indoor Temp [°C], Max outdoor Temp [°C]	0.12 19.58 12.49 39.23 32.33	Qc 14.64 POR 0.56
iii. combined - FR	Te (outside)[°C], GHI[W/m^2], Delta Tin-Te[°C], Min indoor Temp [°C],	13.33 132.13 0.26 12.51 20.37 36.51 28.07	Dist Acm 0.95

	Min outdoor Temp [°C], Max indoor Temp [°C], Max outdoor Temp [°C]		
iv. combined - MC	Te (outside)[°C], GHI[W/m[2]], Delta Tin-Te[°C], Min indoor Temp [°C], Min outdoor Temp [°C], Max indoor Temp [°C], Max outdoor Temp [°C]	13.11 54.34 0.26 12.51 14.43 36.44 26.37 14.01 54.33 0.10 19.83 14.42 36.43 26.36 13.29 54.33 0.26 12.50 14.38 36.43 26.29	Qc 14.64 POR 0.56 Qc 14.65 POR 0.56 Qc 14.64 POR 0.56

4.4. Occupancy module

4.4.1. Overview of the proposed solution

The occupancy module developed in Task 3.3 has been presented in Deliverable D3.3.

The occupancy module has been first tested in the Living Lab Energetikum (LLE), validating its application in an office building. To test and validate the module in a residential building, it is under implementation in the single-family house of Ry, Denmark. This house has a high level of automation technologies. In complement, the occupancy module will be tested in a residential building, with a low level of automatic actuators. Turin demonstration building perfectly represents this category. Therefore, the occupancy and behaviour module will be implemented there.

The occupancy module has been developed in MATLAB and translated in Python, for integration in the FusiX platform. Both versions will be used for adjustment of the module to the Turin demo case.

The Turin demonstration building has CO_2 measurements but no mechanical ventilation, which means the approach used in the LLE cannot be applied as is. Indeed, the CO_2 balance calculated in the LLE, is based on the calculation of the CO_2 coming in and out of the room through the mechanical ventilation air flow. The difference provides an estimation of the CO_2 production rate in the building, related to the occupants' metabolism. Many buildings are in the configuration of the Turin demonstration building, with natural ventilation. It is therefore important to propose a solution for such cases. In Turin, other approaches developed and tested in LLE, as described in the deliverable D3.3, will be applied. Solutions based on feature-based machine learning algorithms are expected to perform best in this context.

The occupancy module will be tested in combination with the energy optimiser developed by STAM. The module will therefore deliver a weekly forecast of the presence probability, based on historical measurements. The module will also provide an indirect information of occupancy, with a weekly forecast of the internal gains from the occupants. These internal thermal gains will be estimated based on indirect measurements of occupancy in the flats. This approach will be tested with the available data from Turin.

4.4.2. Model development and integration

Concrete implementation of the occupancy module has not started yet. The planned development and integration steps are described here.

The monitoring data will be accessed via FusiX. It will be integrated easily, following the same procedure already validated in LLE and Ry. The occupancy module implemented with Python takes direct measurements from the PRELUDE database as input to perform its calculations. It is designed to run once a week by retrieving 90-day measurements and processing them to feed a machine learning algorithm to provide one week of occupancy forecast. The module can provide results at either an apartment or a room level, depending on the availability of data and the structure of each demo site.

For the feature-based machine learning algorithms, the following measurements and information are of relevance:

- Indoor air properties: operative temperature, CO_2 concentration, relative humidity, …
- Electricity: power consumption overall, details from sub-meters.
- Date and time: eight typical days, with the seven days of the week plus national holidays of the corresponding country. The time of dusk and dawn at the building location are also considered.

In addition, for validation of the occupancy model, a source of ground truth information would be beneficial, even from a limited period. For example, one week of detailed occupancy schedule could be recorded manually from an apartment. This will be organised in agreement with the partners.

The module will be tested and validated in at least one apartment. The benefit of the occupancy module will be assessed, in particular when operating in combination with the energy optimiser from STAM.

4.5. Measurement and Verification Framework

4.5.1. Overview of the proposed solution

The M&V framework developed by LIBRA, as outlined in D4.3, encompasses the M&V methodology and its module. Its primary focus is to assess and quantify the thermal energy savings achieved through DPC (EE optimizer/En-power) by STAM, offering valuable insights for enhancing energy efficiency. The implementation of M&V 1.0 approaches will be utilized, enabling the module to develop an adjusted baseline model that predicts monthly energy consumption, monitors energy savings, and facilitates the quantification and monitoring of achieved energy savings. The resulting output can be easily accessed through the Graphic User Interface of the PRELUDE Decision Support System upon request.

4.5.2. Technical specifications of the proposed solutions

According to the current plan, the PRELUDE solution for validation by M&V is the DPC (Comfort-EE optimizer) by STAM, which offers two types of action initiation based on automation levels. The first type is fully automated, requiring no user involvement, while the second type relies on user engagement for manual application of suggestions provided by the PRELUDE application.

In line with the M&V methodology, it is necessary to define the data points required for calculating energy consumption. Figure 46 illustrates the mapping of different sources (data points) from Iren-Turin. However, due to the absence of energy-measuring sensors, it is not feasible to specify the data points of interest and the energy flux using real data. According to Table 17, there are variables in forms of historical time series which will be provided by FusiX and can be used to calculate the adjusted baseline model. When they will be available, the tree map will be updated and the identification of the necessary datapoints for computing the thermal energy consumption will follow.

As an alternative, simulated energy consumption data will be generated for the baseline and reporting periods based on the building's energy profile and the ECM being evaluated. Also, the weather data utilized in the simulations is sourced from the Meteostat Python library[12].

Consequently, the data used for developing the adjusted baseline model is still being reviewed, and all alternative options are being taken into consideration.

Figure 46: Sensors mapping per apartment in Iren-Turin.

4.5.3. Implementation plan

For the project, the measurement boundary will focus on 8 selected dwellings out of a total of 30. As proposed in D4.3, the option of the IPMVP methodology to be applied is D (Simulation). However, since the level of automation varies across apartments, leading to potential changes in the measurement boundary based on available historical and monitoring data.

At present, there are no energy consumption sensors integrated into FusiX concerning the apartment level. Thus, the thermal energy consumption cannot be monitored, and the baseline and the reporting period will be based on simulated data calibrated on the building's characteristics. It is worth mentioning that if the monitoring status of the demo site will be modified, in the sense that energy consumption data will be provided, then the M&V methodology to be followed will be modified accordingly. There is a possibility for datapoints related to internal and external temperatures, HVAC energy consumption and global horizontal irradiation, in forms of historical time series to be available in FusiX. If this happens, the necessary changes will take place and LIBRA will study the different variable sand their relation to the temperature and other factors, as presented in D4.3. Accordingly, the reporting period is subject to change as it depends on the available data, as presented in the following Table 25.

Table 25 Potential reporting periods

	Input for adjusted baseline model development	Reporting period
1	Simulated data by STAM	Use of the latest 12 months of monitoring data after/during the ECM is applied.
2	Historical data (provided by FusiX or asynchronous as a csv file)	
3	Specific period from historical data(e.g., months, weeks, days)	Use the corresponding period (e.g., months, weeks, days) after/during the application of ECM

[12] "Python Library | Meteostat Developers." https://dev.meteostat.net/python/#installation (accessed Mar. 13, 2023

4.5.4. Performance assessment of the implemented solutions

In order to ensure accuracy in both the model and the results of the methodology, the M&V methodology is tailored to the specific characteristics of Turin. This involves utilizing statistical models to develop an adjusted baseline model that is suitable for the evaluation. To determine the most accurate model, two metrics are employed: the Coefficient of Variation of Root Mean Square Error (CV-RMSE) and the Normalized Mean Bias Error (NMBE). The CV-RMSE value is used to assess the level of uncertainty introduced, with lower values indicating better model performance. The NMBE serves as an additional metric for evaluating the model, but it is not utilized for selecting the model since positive and negative biases can cancel each other out. The primary focus remains on minimizing uncertainty throughout the modelling process.

4.5.5. Energy savings and reduction of gas emissions

The M&V module will produce 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. On a monthly basis, the module will retrieve the required input data from FusiX, allowing for the generation of a time series of estimated energy consumption and savings. It is important to note that the output is provided monthly and covers the period up until the previous month, offering a retrospective estimate rather than future energy consumption predictions while enabling end-users to evaluate the effectiveness of the intervention implemented.

4.6. EPIQR analysis

An EPIQR+ diagnosis of the Turin demo-case building was performed through the new EPIQRweb platform in order to determine the costs of two different renovation scenarios. The first one or « Reference scenario» corresponds to the renovation works required to rehabilitate the building according to its current standard. The second one, named “Optimization”, lists in addition to the interventions of the first scenario other ones corresponding to upgrades in terms of thermal envelope, summer comfort and use of local renewable energy.

The dimensional and cost coefficients, necessary inputs for the diagnosis, are mentioned in Figure 47.

Dimensional coefficients		
ERS Energy reference surface	2833	m²
Wso Wall surface against the outside	1863	m²
Ws Window surface	512	m²
BS Built surface	283	m²
LSS Landscaped surroundings surface	0	m²
FS Floor surface	3116	m²
Number of lift shaft modules	20	U
HS Habitable surface	2238	m²
SS Secondary Surface	283	m²
Main circulation surface	586	m²
Dwelling count	30	U
Surface of viewed facades	0	m²

Cost coefficients		
Complexity Coefficient: Size of building	98	%
Complexity Coefficient: Working condit…	102	%
Complexity Coefficient: Access	102	%
Building Cost Index	90	%
Engineering Fees	8	%
VAT	10	%
Miscellaneous and unforeseen	0	%

Figure 47 - dimensional & cost coefficients - diagnosis inputs

The results of the proposed interventions with their related costs for the two different scenarios are detailed in reports extracted from the web platform. Since the reports are extracted in pdf format, they are attached to the deliverable in two additional documents attacked to the Deliverable D7.3.

To summarize, the «Reference scenario» mainly takes into account the following works:

- Light repairs of balconies plaster
- Replacement of old single and double-glazing windows as well as the roller shutters if damaged
- Cleaning of the tiles and maintenance works on the roof structure
- Painting of walls and doors of the interior distribution
- Maintenance of the main surfaces (floor coverings, interior walls, ceiling, kitchen and sanitary facilities)
- Maintenance of the electrical, heating and sanitary technical installations
- Maintenance of the elevator

The optimized scenario, in addition to the previous works, also considers:

- The replacement of roller shutters by slatted blinds in parallel with the renovation of windows to help maintain a pleasant indoor climate during heat waves by decreasing the heat flow before it enters the building and allowing in parallel some natural ventilation
- Interior insulation of the facades
- Loft insulation
- The implementation of a photovoltaic installation on the roof for local renewable energy

Approximately one eighth of the old single or double-glazing windows has already been replaced by recent triple glazing ones. The double wall masonry facades are not insulated and mechanical ventilation is not present in the building. Different smart sensors like environmental ones, smart thermovalves, electrical meters or other smart plugs have been recently installed.

All taxes included, the optimized scenario costs about 1'811'000 euros which is approximately 1.6 times more expensive than the first one. However, it allows to increase indoor comfort and energy autonomy. A complementary study could permit to specify the photovoltaic project including its self-consumption rate as well as the cost effectiveness of this second scenario over time.

5. SUMMARY OF EXPECTED IMPACTS AND CONCLUSIONS

Such as mentioned above, this report introduces the first PRELUED technology integration works done for the Turin demonstrator. The latter is composed by 8 flats in a typical multi-floor residential building strongly representative of a large series of buildings in the specific territorial context. Being the building not having previous monitoring or smart solutions, the demo is organised in order to allow monitoring of energy and environmental variables – to perform the minimal monitoring requirements of tested technologies – but the choice of installed solutions is based on the need to integrate commercial solutions and especially end-user ready systems like the Aircare kits. In one of the flat an additional professional monitoring solution is also integrated to perform a deeper analysis and compare simple solutions developed for tenants with a system developed for building-performance experts. Main integrated sensoring solutions are described in Section 3. Several technologies are integrated in the demo, considering that in Turin the activation of end-users will be based on self-actions supported by information alerting supported by the project middleware. Among the PRELUDE technologies which are under test, it is possible to mention the STAM and POLITO ones, the occupancy module by FB, the M&V module by LIBRA and the renovation roadmap based on EPIQR+ by ESTIA – see Section 4. Some initial analyses of monitored environmental data retrieved in one of the flats are also given in Section 3, while during the next months the various tests will start and correlated results will be included in the final WP7 report.

APPENDIX A

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APPENDIX B

Attached documents reporting EPIQR+ results:

- 230526_Turin demo-case_Optimization scenario EPIQRweb results.pdf
- 230526_Turin demo-case_Reference scenario EPIQRweb results.pdf

Work cost Estimation

Optimization	Cost index : 90.00

Optimization

Summary of cost

Wa Facades and balcony	888 800
Wi Windows and doors	1 057 500
Ro Roofs	80 500
Ss Common and secondary surfaces	238 100
Ms Main surface	373 700
El Electricity	161 100
He Heating	88 000
Ve Ventilation and Air conditioning	0
Sa Sanitary	172 500
Mi Security, transport, miscellaneous	19 900
Works cost (without fees and without VAT)	**3 080 000**
Architect's fees (without VAT) calculated on the basis of 8 % of the works cost	246 000
Sub-total of works and fees (without VAT)	**3 327 000**
Misc. and unexpected's fees (without VAT) calculated on the basis of 0% of the sub-total	0
VAT on the basis of 10% of the sub-total and misc. and unexpected	333 000
Total cost for renovation (with VAT)	**3 659 000**

Work cost Estimation

Optimization

Cost index : 90.00

Wa		Facades and balcony	0		888 800
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.1	66%	External wall - Rendering	○⓪○	□□□	0
1.6	34%	External wall - Artificial stone	○⓪○	□□□	0
3.1		External wall thermal insulation - Absence of thermal insulation	○○❸	□□□	0
		Replacement with internal insulation			792 700
5.2		Balconies and galleries - Metal / wood railing	❶○○	■□□	96 000

Wi		Windows and doors	0.00		1 057 500
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.1	88%	Windows - Wood windows	○○❸	■■■	856 800
3.1		External doors - Generic	○❷○	□□□	0
2.3		Shutters and solar protection - Roller shutters	❶○○	□□□	0
2.5		Shutters and solar protection - External blinds	○○❸	■■■	200 700

Ro		Roofs	0.00		80 500
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
2.2		Roof structure - Metal structure	❶○○	■□□	29 400
1.1		Roof covering - Pitched roof	❶○○	■□□	19 600
3.2		Roof thermal insulation - Sloped roof, attic without amenities	○○❸	■■■	31 500

Ss		Common and secondary surfaces	0		238 100
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
2.6		Interior doors - Generic	❶○○	■□□	16 400
1.1		Main distribution - Interior distribution - housing	❶○○	■□□	221 700

Ms	Main surface		0	373 700
%	Element-Type	Degradation	Intervention	Cost excl. taxes
4.1	Kitchen - Equipped kitchen	❶ ○ ○	■ □ □	53 600
5.1	Sanitary premisses - Toilets in bathroom	❶ ○ ○	■ □ □	24 900
7.1	Interior carpentry - Interior carpentry	❶ ○ ○	■ □ □	45 100
1.5	Floor finishings - Generic	❶ ○ ○	■ □ □	24 100
2.8	Interior walls and wall finishings - Generic	❶ ○ ○	■ □ □	153 800
3.8	Ceiling coating - Generic	❶ ○ ○	■ □ □	72 200

El	Electricity		0.00	161 100
%	Element-Type	Degradation	Intervention	Cost excl. taxes
5.1	Lighting appliances - Lighting Fixtures	○ ○ ❸	■ □ □	3 200
6.1	Individual electricity production - Photo-voltaic panels	○ ○ ❸	■ ■ ■	119 200
1.1	Electrical power supply and main electrical panel - Without induction current compan-sation	❶ ○ ○	■ □ □	6 000
2.1	Pannels and secondary electrical distribu-tion - Low power distribution pannels	❶ ○ ○	■ □ □	11 900
4.2	Lighting wiring and plugs - Wiring sockets and fixtures - dwellings	❶ ○ ○	■ □ □	20 800

He	Heating		0	88 000
%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.6	Heating central production plant - Substa-tion without heat production	❶ ○ ○	■ □ □	2 100
2.1	Sanitary hot water production - Central boil-er with heat exchanger	❶ ○ ○	■ □ □	1 700
3.1	Heating distribution network - Apparent heat distribution	❶ ○ ○	■ □ □	67 600
4.2	Heating and cooling terminal units - Radia-tors - generic	❶ ○ ○	■ □ □	16 500

Ve	Ventilation and Air conditioning		0	0
%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.1		○ ⓪ ○	□ □ □	0

		Ventilation system without air handling - Natural ventilation (opening windows)			

Sa		**Sanitary**		**0**	**172 500**
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.1		Water connection and metering - Connection and water distribution battery	1	■□□	4 300
2.1		Sewage pipes - Wastewater pipes	1	■□□	2 200
3.1		Sanitary water distribution - Cold water and hot water pipes	1	■□□	166 100

Mi		**Security, transport, miscellaneous**		**0**	**19 900**
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.1		Lifts - Lift	1	■□□	19 900

Works cost (without fees and without VAT)	**3 080 000**
Architect's fees (without VAT) calculated on the basis of 8 % of the works cost	**246 000**
Sub-total of works and fees (without VAT)	**3 327 000**
Misc. and unexpected's fees (without VAT) calculated on the basis of 0% of the sub-total	**0**
VAT on the basis of 10% of the sub-total and misc. and unexpected	**333 000**
Total cost for renovation (with VAT)	**3 659 000**

Work cost Estimation

Reference scenario

Cost index : 90.00

Reference scenario

Summary of cost	
Wa Facades and balcony	96 000
Wi Windows and doors	897 300
Ro Roofs	49 000
Ss Common and secondary surfaces	238 100
Ms Main surface	373 700
El Electricity	41 900
He Heating	88 000
Ve Ventilation and Air conditioning	0
Sa Sanitary	172 500
Mi Security, transport, miscellaneous	19 900
Works cost (without fees and without VAT)	1 977 000
Architect's fees (without VAT) calculated on the basis of 8 % of the works cost	158 000
Sub-total of works and fees (without VAT)	2 135 000
Misc. and unexpected's fees (without VAT) calculated on the basis of 0% of the sub-total	0
VAT on the basis of 10% of the sub-total and misc. and unexpected	213 000
Total cost for renovation (with VAT)	2 348 000

Work cost Estimation

Reference scenario

Cost index : 90.00

Wa		Facades and balcony		0	96 000
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.1	66%	External wall - Rendering	○⓪○	□□□	0
1.6	34%	External wall - Artificial stone	○⓪○	□□□	0
3.1		External wall thermal insulation - Absence of thermal insulation	○○❸	□□□	0
5.2		Balconies and galleries - Metal / wood railing	❶○○	■□□	96 000

Wi		Windows and doors		0.00	897 300
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.1	88%	Windows - Wood windows	○○❸	■■■	856 800
3.1		External doors - Generic	○❷○	□□□	0
2.3		Shutters and solar protection - Roller shutters	❶○○	■□□	40 500
2.5		Shutters and solar protection - External blinds	○○❸	□□□	0

Ro		Roofs		0	49 000
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
2.2		Roof structure - Metal structure	❶○○	■□□	29 400
1.1		Roof covering - Pitched roof	❶○○	■□□	19 600
3.2		Roof thermal insulation - Sloped roof, attic without amenities	○○❸	□□□	0

Ss		Common and secondary surfaces		0	238 100
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
2.6		Interior doors - Generic	❶○○	■□□	16 400
1.1		Main distribution - Interior distribution - housing	❶○○	■□□	221 700

Ms		Main surface		0	373 700

	%	Element-Type	Degradation	Intervention	Cost excl. taxes
4.1		Kitchen - Equipped kitchen	❶ ○ ○	■ □ □	53 600
5.1		Sanitary premisses - Toilets in bathroom	❶ ○ ○	■ □ □	24 900
7.1		Interior carpentry - Interior carpentry	❶ ○ ○	■ □ □	45 100
1.5		Floor finishings - Generic	❶ ○ ○	■ □ □	24 100
2.8		Interior walls and wall finishings - Generic	❶ ○ ○	■ □ □	153 800
3.8		Ceiling coating - Generic	❶ ○ ○	■ □ □	72 200

El		**Electricity**		**0**	**41 900**
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
5.1		Lighting appliances - Lighting Fixtures	○ ○ ❸	■ □ □	3 200
6.1		Individual electricity production - Photo-voltaic panels	○ ○ ❸	□ □ □	0
1.1		Electrical power supply and main electrical panel - Without induction current compan-sation	❶ ○ ○	■ □ □	6 000
2.1		Pannels and secondary electrical distribu-tion - Low power distribution pannels	❶ ○ ○	■ □ □	11 900
4.2		Lighting wiring and plugs - Wiring sockets and fixtures - dwellings	❶ ○ ○	■ □ □	20 800

He		**Heating**		**0**	**88 000**
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.6		Heating central production plant - Substa-tion without heat production	❶ ○ ○	■ □ □	2 100
2.1		Sanitary hot water production - Central boil-er with heat exchanger	❶ ○ ○	■ □ □	1 700
3.1		Heating distribution network - Apparent heat distribution	❶ ○ ○	■ □ □	67 600
4.2		Heating and cooling terminal units - Radia-tors - generic	❶ ○ ○	■ □ □	16 500

Ve		**Ventilation and Air conditioning**		**0**	**0**
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.1		Ventilation system without air handling - Natural ventilation (opening windows)	○ ⓪ ○	□ □ □	0

Sa		Sanitary		0	172 500
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.1		Water connection and metering - Connection and water distribution battery	1	■□□	4 300
2.1		Sewage pipes - Wastewater pipes	1	■□□	2 200
3.1		Sanitary water distribution - Cold water and hot water pipes	1	■□□	166 100

Mi		Security, transport, miscellaneous		0	19 900
	%	Element-Type	Degradation	Intervention	Cost excl. taxes
1.1		Lifts - Lift	1	■□□	19 900

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