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**Dr. Mehrnoosh Ahmadi actively contributed to preparing the contents used in this report till 30/09/2021.

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# 1 Executive Summary


The objective of this report is to present the establishment, monitoring of and initial results of the Italian demonstrator. This deliverable D5.4, with introductive information on E-DYCE demonstrators and their methodological organization reported in D5.1, defines the current state of Italian demo buildings and prepares the subsequent data analysis step that would be collected in the deliverable D5.6.

The Italian demonstrator comprises five buildings: two schools and three residential buildings. All buildings are located at Torre Pellice, a medium-to-small municipality situated northwest of Italy, Piedmont Region, in the Pellice's valley. General referring names for the five demos are reported in Section 2. Section 3, elaborated by TPM, introduces the broad local context of the Italian demonstrator by describing the Torre Pellice Municipality and shortly introducing architectural aspects of the five buildings. Finally, the following technical sections elaborated by POLITO describe in detail the five demo buildings and the Italian demonstrator, including monitoring specifications and modelling actions.

In particular, Section 4 describes the establishment of the five Italian demo cases. It mainly focuses on the inspection processes and basic information retrieval, including geometrical data and basic building information.

Section 5 reports basic information about all demo buildings planned and installed monitoring systems. Specifically used sensors are described in detail, including their localization in all demos. Additional information on short-term monitoring campaigns (e.g., U-value detection) is also provided. An initial sample of monitored data outputs is also given in this section.

Section 6 focuses on the developed EnergyPlus building models. It describes the chosen modelling methodology for all Italian demos. Additionally, it reports model calibration processes mainly concentrating on the free-running mode during the summer months. During the subsequent project phases, an extra upgrade of these verifications is expected, including heating consumption data that are currently limited due to delays in the installation phase. Nevertheless, all demo buildings have an EnergyPlus model, verified for summer seasons, and already organized to be run in the E-DYCE dynamic energy simulation platform (PREDYCE) by also potentially using the E-DYCE middleware (FusiX). Developed models use zone naming to connect simulation results of the digital twin model with physical monitoring data integrating building spaces and related sensors.

Section 7 describes extra content, including resulting demo improvements performed by end-users thanks to E-DYCE's continuous exchange of information between technical partners and building tenants and owners. Additionally, the development of a local educational activity performed at POLITO to develop an initial android application supporting monitored data visualization for Italian demo end-users is described. Finally, in paragraph 7.3, TPM describes the ongoing education activities driven by the Municipality and involving local school children.

Finally, Section 8 concludes this deliverable followed by the mentioned list of references.

# 2 Introduction

The Italian demonstrator is composed of five buildings in Torre Pellice – see Section 3 introducing the local context. The selected buildings are two schools, i.e., a public municipal building hosting an infantry school and a middle school, the Liceo Valdese high school, and three private houses, i.e., a single-family house, a flat in a bi-family house, and a flat in a terraced house. The following image Figure 1, see D5.1, introduces the five demos.

| B2.1 | B2.2 | B2.3 | B2.4 | B2.5 |
|---|---|---|---|---|
| Kindergarten and Middle school building | High school Liceo Valdese | Private residential building | Private residential building | Private residential building (flat) |
|  |  |  |  |  |
| **Built**: 1975 (not renovated) | **Built**: 1836 | **Built**: about 1950 (light renovation in 2015) | **Built**: about 1900 (light renovation in 2019) | **Built**: before XX century (renewed about 1940, small recent renovation – heater and spaces) |
| **Heated area**: 2150 m² | **Heated area**: 800 m² (gross, about 550 m² net) | **Heated area**: 135 m² | **Heated area**: 190 m² | **Heated area**: about 90 m² |
| **Data available - Building level:** energy bills<br>**Data available - Apartment level:**<br>**Idea** to renovate it toward NZEB during next 10 years<br>**Potential** to increase IEQ and IAQ due to monitoring data and informed user actions | **Data available - Building level:** general map, energy bills<br>**Data available - Apartment level:** plan and bills<br>**Potential** to increase IEQ due to monitoring data, identification of light retrofitting scenarios impacts | **Data available - Building level: N/A**<br>**Data available - Apartment level:** energy bills, EPC before light renovation<br>**Definition** of light retrofitting impacts and reduction in performance gap optimisation<br>**Suggesting** full renovation roadmap | **Data available - Building level: N/A**<br>**Data available - Apartment level:** energy bills, EPC before light renovation<br>**Definition** of light retrofitting impacts<br>**Reduction** in performance gap thanks to optimisation | **Data available - Building level: N/A**<br>**Data available - Apartment level:** energy bills.<br>**Definition** of light retrofitting impacts<br>**Reduction** IEQ suggestions, definition of light retrofitting scenario impacts; reduction in EPC performance gap |
| **EPC**: N/A | **EPC**: N/A | **EPC** - Class E - 11/06/2015 | **EPC** - Class E - 06/29/2018 | **EPC**: N/A |

**Figure 1 The five Italian demo buildings**

In this deliverable there is principally treated information regarding stage 1 and part of stage 2 of the E-DYCE rationale described in Deliverable D1.2 – see D1.2 Figure 25 – focusing on inputs and data collection and monitoring and implementation of dynamic energy models to support further the elaboration of KPIs and outputs for DEPC analyses. Specific aspects connected to stage 2 and stage 3, including data elaborations, DEPC studies, and end-user involvements using the E-DYCE application, are not described here but will be elaborated for the last WP5 deliverable (D5.6). Additionally, information related to the inspection plan and basic building input retrieval are reported in D5.1 and are not re-discussed here.

# 3 Torre Pellice (ITA) demonstrator: context and building introduction[1]

## 3.1 General context

The Italian Demo Cases are located in Torre Pellice, in Piedmont Region. Torre Pellice is a small town in the Pellice mountain Valley, with a population of about 4.500: that means that Torre Pellice is in line with most of Italian municipalities. **Figure 2**

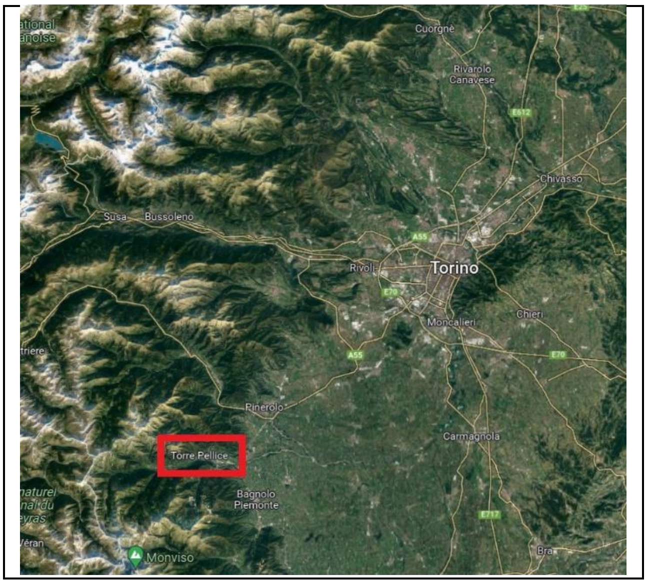



**Figure 2 Location of Torre Pellice**

Torre Pellice was founded approximately in 1186 along the way between Turin and the Queyras, in France; what is moreover, it was located at the confluence of two streams, Angrogna and Pellice: this is because that was the perfect place to control the whole valley.
From the Middle Ages to about 1750, there were only few houses built along the road to France and clusters of houses – called *borgate* - on the slopes of the mountains. (Figure 3 and Demo Case n. 3).
At the end of the 12th Century Waldensian, who were sent away from France because of their faith, settled in some valleys in the west of Piedmont - including the Pellice Valley - because they considered these valleys as a safe place ~~where~~ to practice their faith. Over the centuries, many Waldensian foundations and organisations settled in town, and that is the reason why, Torre Pellice is known as the "centre of the Waldensian world".

[1] Section 3 is developed by TPM.

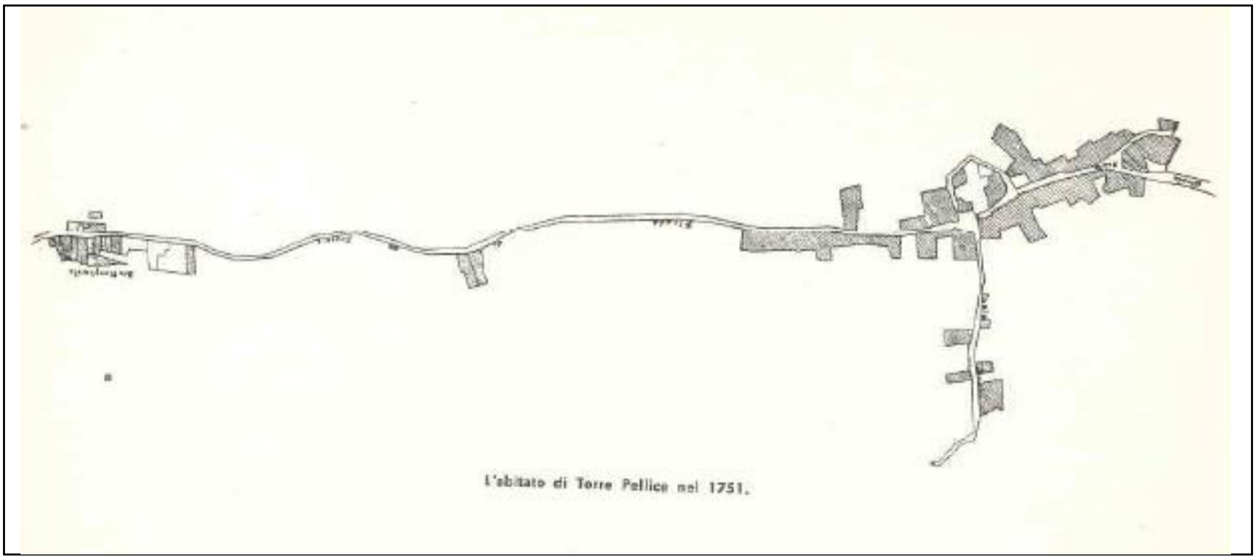



**Figure 3 Torre Pellice in 1751.**

During the second half of the 18th century, manufacturing industries (silk and felt industry) were settled along the Pellice. Consequently, Torre Pellice expanded: residential multiapartment blocks were built for the workers near the industries.
At 5:43 pm on Saturday 2 April 1808, a 5.7 magnitude earthquake destroyed almost all the houses in town. Nevertheless, Torre Pellice rose quickly: unstable buildings were torn down and new ones were built following the nineteenth-century urban planning conventions. (**Figure 4**) A new road was drawn south of the city centre, more suitable for vehicular traffic moving to Turin or France, leaving the old way going through the town centre for the pedestrian.

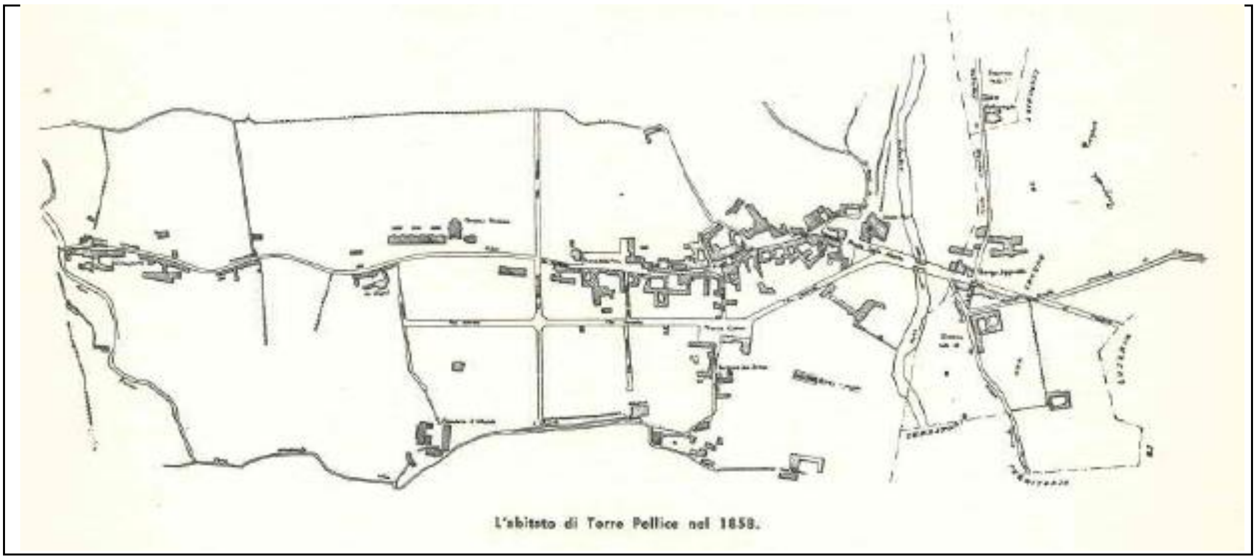



**Figure 4 Torre Pellice in 1859.**

Because of this, the town expanded along the new road and in the space between this and the old one, following a checkerboard pattern. That was the highest point of the history of Torre Pellice: it became a renowned holiday resort visited not only by the Piedmontese but also European bourgeoisie. They appreciated cool weather, especially in summer, and the lively cultural life of the town. Members of bourgeoisie stayed in the hotels in Torre Pellice or, more often, built there their own "holiday residences": usually single or double family houses surrounded by private gardens.

Besides this, in the 19th Century the Waldensian Neighbourhood started to develop: the Collegio – also known as the Liceo Valdese (demo case n. 2) – was built in 1832. The hospital was built few years later, thanks to the Russian Tzar's and the Prussian King's contributions; in addition to this, 2 more buildings were also constructed the temple and the Casa Valdese.
On 20 December 1882, the railway line between Pinerolo and Torre Pellice was inaugurated, making the connection with Turin faster.
Due to the failures of the manufacturing industries and the outbreak of the First World War, in 1915 began a decline that ended only in the second post-war period: some inhabitants migrated to Turin in search of work, others were called to the front.
The forecasts of the urban plan approved in 1914 (**Figure 5**) were not carried out until the second half of the 20th Century.

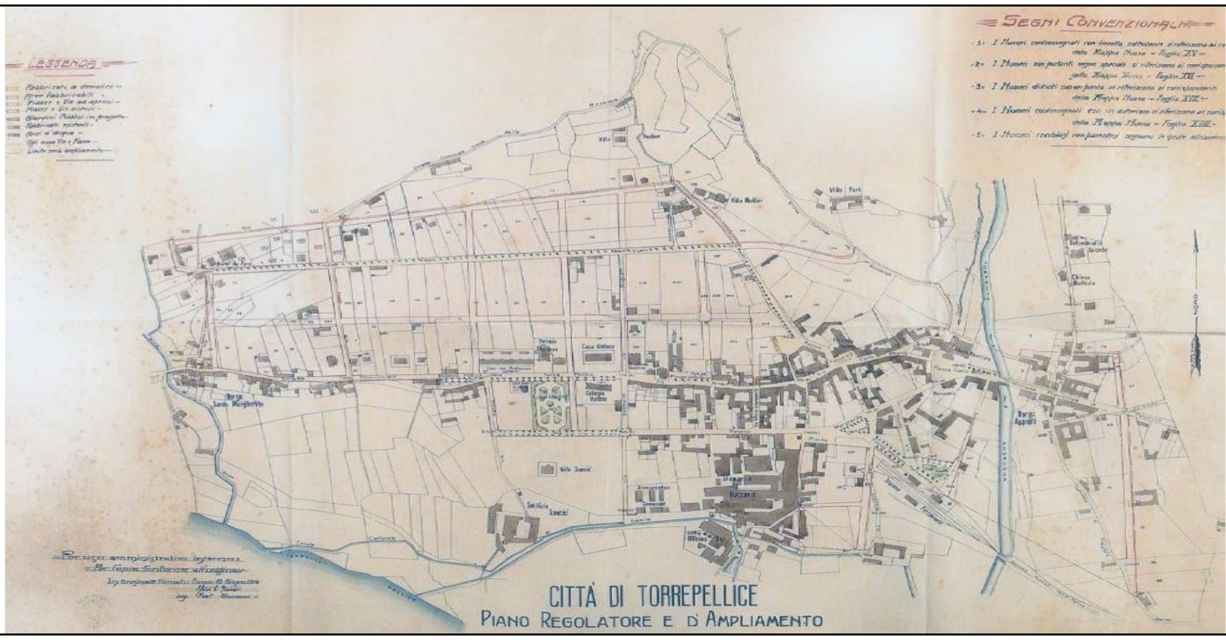



**Figure 5 Torre Pellice in 1914.**

Nowadays, Torre Pellice has a historic centre lying on the ancient road to France with, on each side, two rows of houses connected to each other; perpendicular streets, opened in the last century, cut them to make the historic centre healthier (Figure 6 and Figure 7). Buildings in this part of the city usually develop over three floors: on the ground floor there are often shops, while the apartments are located on the other floors.
North of the historic centre, tree-lined streets create a checkerboard pattern suitable for settlement of low-density building; in fact, this expansion area is full of detached houses, all surrounded by private gardens. Houses usually developed over two floors with one or two apartments.
Almost all the facilities are located there: schools, library, museum, sports centre etc. in the '50 the elementary school was built while the Kindergarten and Middle School Building (demo case n. 1) was inaugurated in 1975.

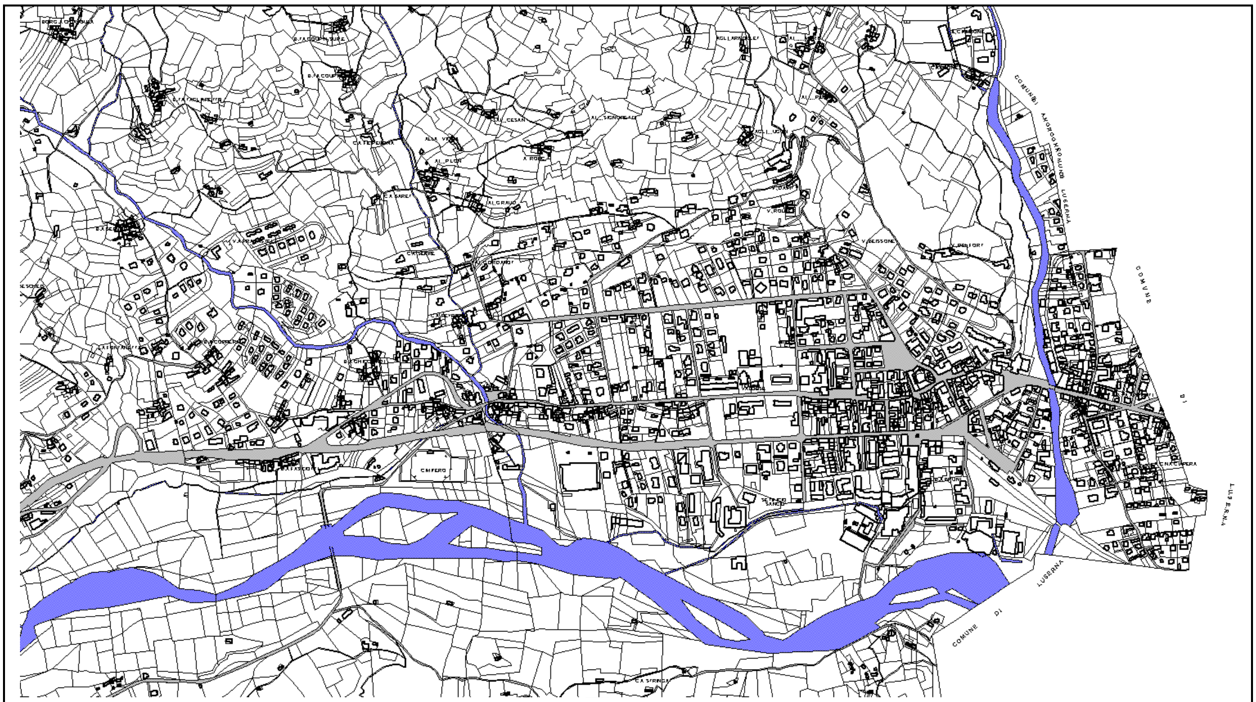


**Figure 6 Urban Plan of Torre Pellice approved in 2012**

**Figure 7 Torre Pellice nowadays.**

## *3.2 Local context*

### 3.2.1 Demo Case n. 1 – Kindergarten and Middle School Building

**Figure 8 Kindergarten and Middle School Building**

The building has a well-defined rectangular shape with a curved metal roof; it consists of three floors, plus an additional semi-buried floor. The structure is composed with a skeleton of reinforced concrete with brick curtain wall. In facades it is possible to see the presence of strip windows in every floor.
The internal floors are characterised as follows: a stairwell in the northeast corner and a distribution corridor along the north side of all floors, giving the access to school rooms facing south. The kindergarten is located in the basement, divided into two sections, including spaces for the canteen, common activities and toilets. The ground floor is divided into offices, classrooms and laboratories in addition to toilets, the two remaining floors are organized with five classrooms per floor ad toilets.

### 3.2.2 Demo Case n. 2 – Liceo Valdese Building

**Figure 9 Liceo Valdese Building**

The Liceo Valdese is a brick building, having a well-defined rectangular shape and consists of two floors plus an additional buried floor.
Its facades are characterized, at each floor, by a regular sequence of rectangular wooden windows with green shutters; on the top, there is a pitched roof with Luserna stone cover.
The interiors are distributed around the main entrance, placed in the middle of the building: two corridors start from it and move to the left and to the right, giving access to the classrooms. A staircase leads to the

other floors. Corridors are located along the north side of all floors, while the classrooms facing south. The building typology is in line with the majority of schools built in Italy in the 20th Century.

### 3.2.3 Demo Case n. 3 – Residential house n. 1


**Figure 10 Residential house n. 1**

This residential demo case is located in one of the ancient cluster of houses (*borgata*) typical of Italian mountain. It is a stone and brick building with an irregular shape, following coarse ground; it develops over a ground floor and a semi-buried one. On the ground floor the living room, the kitchen, two bedrooms and a toilet are placed, while all the utility rooms are on the basement. In recent years, the building has gone through a total renovation.

### 3.2.4 Demo Case n. 4 – Residential house n. 2


**Figure 11 Residential house n. 2**

This residential demo case is located in one of the expansion areas already expected by the zoning regulation approved by the Municipality in 1914. The structure is composed with a skeleton of reinforced concrete with brick curtain wall. The Liberty-style house was built in the 20$^{th}$ Century, as a detached double-family house with a private garden all around. It develops over three floors with one apartment at each floor, and a cellar. It could be considered as a typical Italian detached house built over the 20$^{th}$ Century.

### 3.2.5 Demo Case n. 5 – Residential house n. 3

**Figure 12 Residential house n. 3**

This demo case in an apartment in a residential multiapartment block. The building has a well-defined shape and is developed in three floors that follow the slops of the ground. The apartment occupies the north wing and is spread over a single floor where the living room, kitchen, bedrooms and bathroom are located.

# 4 Establishing the demonstrator

Section 4 describes basic actions performed to support the initialization of Stage 1 of the E-DYCE rationale – see E-DYCE Deliverable 1.2 [1], Fig. 25. Concerning mentioned actions, this section focuses on demo end-user contacts and the retrieval of existing basic information. When this information is unavailable, such as in several cases, the followed methodology for data production is shortly introduced.

## *4.1 Establishing the demonstrator*

To follow the E-DYCE proposed methodology and correlated analyses in the buildings mentioned above – see also E-DYCE Deliverable 5.1 [REF], several issues have been performed, starting with establishing the demonstrator. The latter includes a series of actions devoted to connect building owners and tenants/users to communicate project advancements, access demo cases, retrieve information and support inspection plan definitions. In the following step – see Section 4.2 –, each pilot is preliminary studied to define the expected applications of DEPC analyses and define potential specific outcomes and analyses correlated to E-DYCE functionalities, e.g., energy signature, IEQ (indoor environmental quality) studies, performance gap detection via the project platform, etc.

### 4.1.1 Engaging with building owners and tenants

Defined the five buildings composing the Italian demonstrator, building users have been contacted to support a deeper explanation of the project and discuss each specific demo's objectives. Additionally, a first inspection has been performed to collect initial information and define the monitoring plan. The latter has been communicated to end-users to facilitate the following installation phases and increase user engagement while limiting potential misunderstanding issues. A second inspection phase has been performed to support sensor installation. During these two phases, privacy and GDPR documents have been submitted to residential users. A geometrical relief was accomplished for all buildings to finalise the geometrical data collection for building modelling purposes. A third phase followed the sensor installation supporting the continuous exchange of information and end-user engagement during monitoring, modelling and initial restitution phases. A fourth phase of building user engagement is expected during the last project year to support the positive usage of the E-DYCE GUI interface to improve energy and environmental user consciousness and building management and to support the data analysis (monitored and simulated data). At present, all users report very positive feedbacks regarding the project. We have underlined a growing interest in improving the energy efficiency in demo residential buildings by including some retrofitting actions.

### 4.1.2 Accessing building/apartment information, relief, and inspection

During the initial inspection, existing geometrical information has been collected by demo end-users, including cadaster geometrical data and/or maps and other information. For residential buildings, cadaster and, when existing, maps used during the presentation of authorization requests are the identified existing sources, and all the three demo buildings show one of this information. Due to their specific usage, upgraded maps are also available for the schools. Nevertheless, to perform further modelling steps, additional information is needed, e.g., window dimensions and positioning, potential building technological data (composition of the walls, roofs, slabs; building installed systems; etc.). Additionally, all geometrical data have been checked with an in-situ relief using a Leica Disto X4 P2P pack with the Bluetooth 3D Leica DST 360 instrument that allows point-to-point measurements and smartphone-driven data collection – see Figure 13. Reliefs allow to limit geometrical errors and collect information about building elevations that are not present in existing maps – see Figure 14. An additional inspection phase supports the collection of extra information to fill missing data needed to define the current semi-steady state national APE (the Italian EPC), such as specific information on the installed heaters, the number and distribution of artificial lights in B2.1 (Municipality school building), and the number and general dimensions of radiators in the same demo building. The compatibility of provided inspections with the inspection protocol provided in the E-DYCE deliverable D2.2 is shown in D5.1, where three inspection protocol sheets are also available for selected Italian demo buildings. Although, for all demos, several inspections have been conducted collecting the above-mentioned geometrical data, together with several extra information, like potential wall compositions, building system data, user behaviors, and others. These inspections also supported the project's final definition of monitoring protocols and acted as discussion moments with the end-users to discuss the planned sensor installations and increase user involvement. Some of the collected data are summarized below, while additional information on building envelope data is discussed in the modelling verification section – see Section 6.

School 1 (B2.1) is inhabited, for what it concerns the middle school part, by about 170 children and 30 teachers, plus 4-5 scholastic operators. The kindergarten hosts about 45 small children (3 to 5 years old) and 5 teachers, plus supporting scholastic operators. The standard usage profile for lectures is Monday-to-Friday from 8:10 to 14:10, while the infantry part is used from 8:00 to 16:30, even if some children go home earlier in the afternoon.

School 2 (B2.2) is primarily used as a high school, with morning and afternoon lectures. Some other specific activities may also be conducted. Students following the high school are about 14-19 years old, and the school has about 10-15 teachers.

Two of the residential buildings are inhabited by families with young children, while one person inhabits the other one. In these buildings, it is not easy to organize an occupancy profile being not subject to rigid time schedules. In one of the buildings, office space is also present, supporting a continuous occupancy profile for part of the building. Nevertheless, all demos are generally occupied for at least half a day during the daytime.

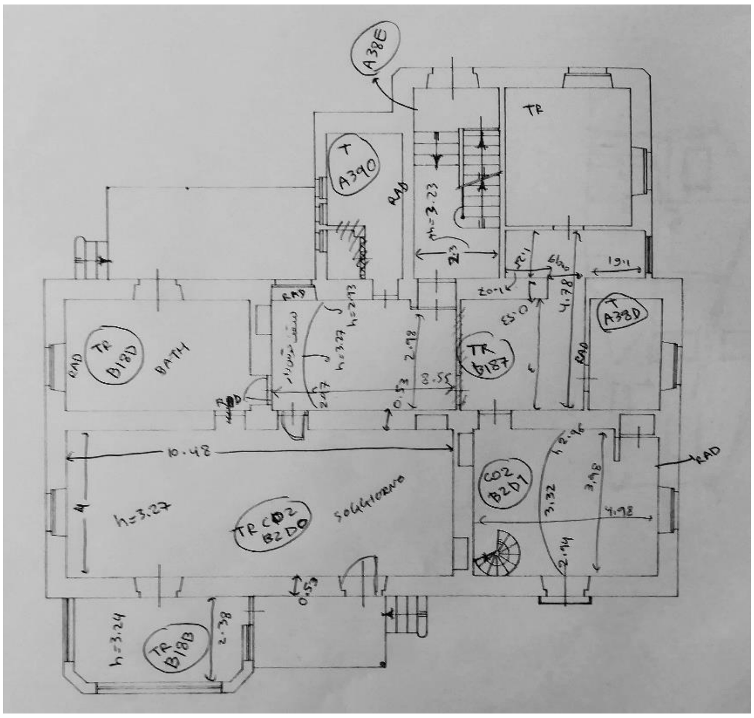


**Figure 13 A sample picture of one of the relief campaign draft papers**

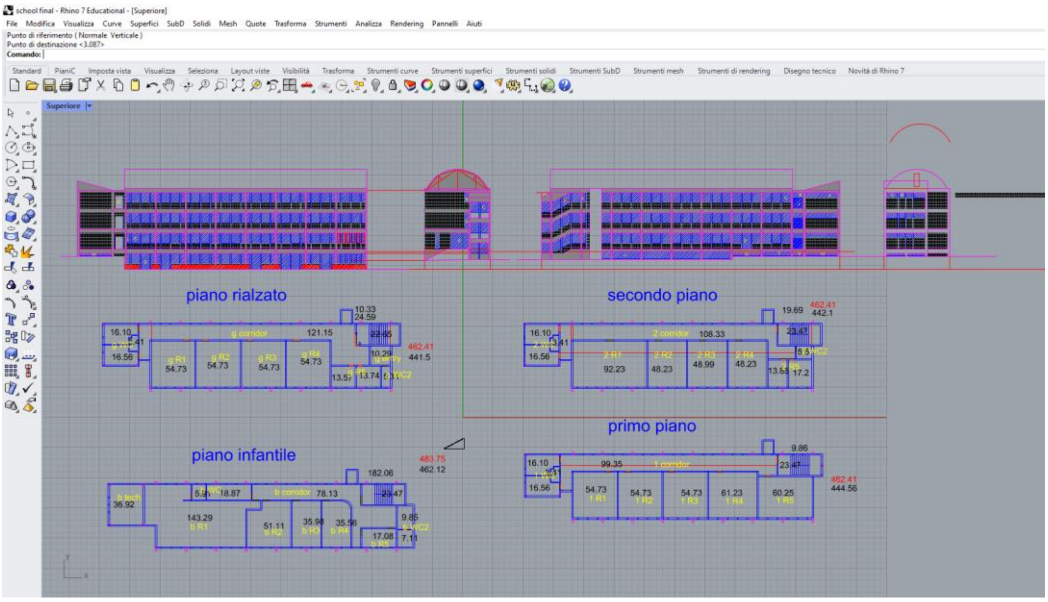


**Figure 14 One of the developed CAD files (here B2.1) to internally restitute the geometrical information verified during the in-situ relief phase to further establish the EnergyPlus building models.**

### Buildings: composition of the walls

School building one was initially expected to be without insulations. Nevertheless, thanks to both in-situ measurements of the U-value via a movable kit, and the holes done in walls during the installation of the mechanical ventilation units, it is now clear that the school has an insulation layer positioned in the cavity wall. Coherently, it can be possible to imagine that the last slab may also have a limited insulation layer and that, for this reason, the U-value of this horizontal component may vary in a larger range during the verification process. Windows are all the same, characterized by a double glass and a wooden frame. As is underlined in Figure 15, walls are composed of the following layer:

- (outermost) a 2 cm of plaster (cement);
- a bricklayer (a typical Italian 6-hole brick) horizontally positioned – 12 cm;
- an insulation layer positioned in the cavity wall composed of semi-rigid panels of glass wool (6 to 7 cm);
- a bricklayer (typical Italian 6-hole brick) vertically positioned – 8 cm;
- (innermost) a 2 cm of plaster (cement+gypsum).

Each layer is thermally characterised in EnergyPlus using plasters and insulation fundamental suggested values by DesignBuilder. For bricks, typical Italian values merge UNI 10351 and wall components indicated in EPC Italian tools. Similarly, initial values for slabs (*laterocemento* – bricks and concrete) and windows are also defined.

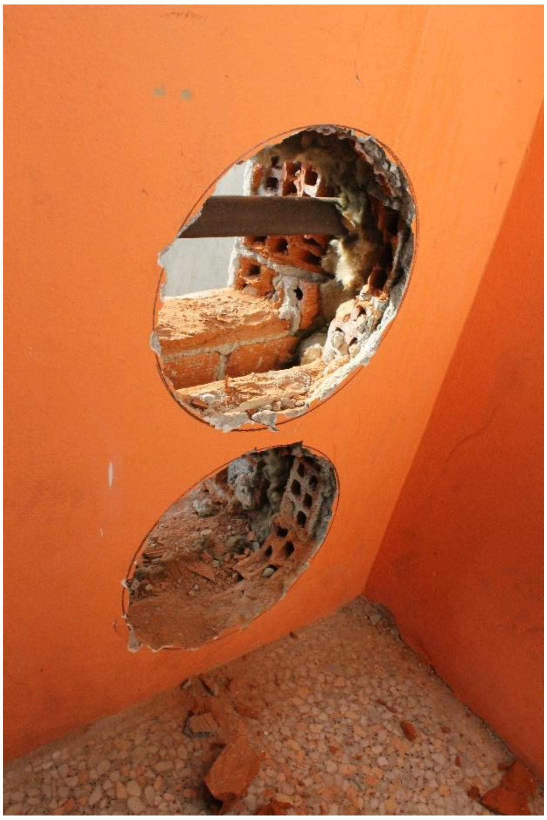


**Figure 15 Internal layer distribution in vertical walls of the school building 1. The horizontal tube is part of the heating distribution system reaching radiators**

School building 2 (B2.2) is a historical building with walls of about 4-5 cm of plaster (different layers) on both sides and an internal structural masonry wall made of local rock blocks and aggregates. The external thickness reaches 70 cm. Also, interior walls are composed of the same materials, excluding minor changes that arrived in more recent years (potentially in bricks or brick blocks), such as bathroom walls. Different thicknesses have been observed and reproduced in the basic EnergyPlus model, opening some modelling issues. The roof has an under-roof not inhabited and non-heated space, while the roof pitches have the typical Luserna's flat stones (typical flagstone roofing solutions adopting a local gneiss). Windows are double glazing with wooden frames.

Residential building 1 (B2.3) shows two main types of walls. The original core of the building is made of rock structural walls with aggregates and plaster layers on both sides. Differently, the more recent parts of the building are made of a cavity wall with and without insufflated insulation (depending on the specific wall) composed of two layers of bricks and plastering finishing on both sides. Most slabs are made here in brick hollow flat blocks (*tavella*) and concrete, while some original slabs are also present. Windows are double glass.

Residential building 2 (B2.4) is a typical house from the beginning of the 20$^{th}$ century with a roof in typical local stones. Slab and wall materials are assumed from the Italian Tabula database – see [2,3]. Windows were substituted a few years ago and are triple glazing. In some rooms, the new windows have been installed living the old original ones (single glazing and wooden frame). No insulation is expected in walls and original slabs – See Section 7.1 about the inclusion of a new insulation layer on the outermost slab. The roof is a cold roof composed of wooden rafters and typical local flagstone.

Residential building 3 (B2.5) is composed of an original wing with rock and aggregate typical walls with finishing plasters and a new part with an armored concrete anti-seismic structure and Poroton blocks. The new part has a pavement facing the ground with igloos and concrete layers. The old building part has a cold roof with an under-roof space not heated and not inhabited. The roof has typical local flagstone. The new roof is a warm roof with an outermost layer of flagstones. The roof includes wooden coatings, including the innermost one composed of a tongue-and-groove layer and thermal insulation. Windows and external doors are all double glazing with wooden frames.

**Building systems.**

During inspections, primary data concerning building heating and other specific systems have been collected. In particular, school 1 (B2.1) has a large heater positioned in a buried space near the school and is dimensioned to cover in addition to the demo building, also another school building (elementary school), a public library and a public art gallery. The heater is a Viessman Vitocrossal 200 CM2-620, a gas condensing boiler with 620 kW of nominal power – see Figure 16(a). The school heating distribution is based on three circuits connected to the same heater mentioned above (Figure 17). The first serves the kindergarten semi-buried floor, the second serving the former "segreteria" composed of the small two rooms at the middle school entrance and the ones on the last floor, and the third serving all other spaces of the middle school. Each distribution system has a zone temperature sensor, but any control is given at room level. Radiators are used as heat emitters, and they do not have any thermo-valves. Five small electrical boilers are localized in female bathrooms and the ground floor male one, directly serving a connected sink. These boilers are Ariston VID 10R (1200 W) (Figure 16(b)), but most of them are not activated. To support the EPC disposal, radiators and electrical lighting systems have been catalogued- see sample Figure 18. The school lighting system uses neon lamps with a power of 36W in classrooms (single and double lamps) and 58W in the corridors (single lamps). In the main corridors, half of the lights have been substituted by LED tubes of 20 W. In the kindergarten, the same lamps mentioned above are used, with the addition of smaller double lamps composed of two neon tubes. Each couple of small tubes reach 36 W. Emergency lights are composed of both original lighting systems using 18W lamps and new

LED lights using 10 LEDs of 0.16 W each (1.6W per light). Figure 19 shows one radiator and one of the lighting components used in classrooms.

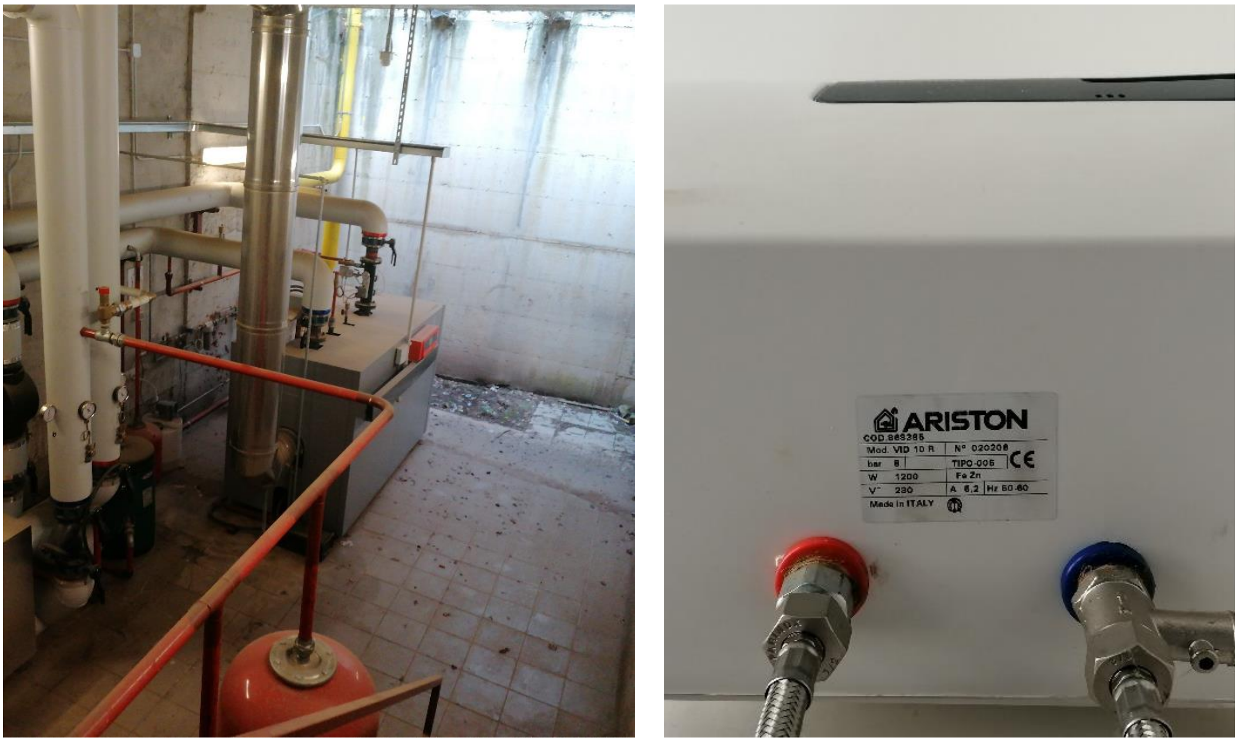



**Figure 16 (a) the heater, and (b) one of the DHW electrical boilers.**

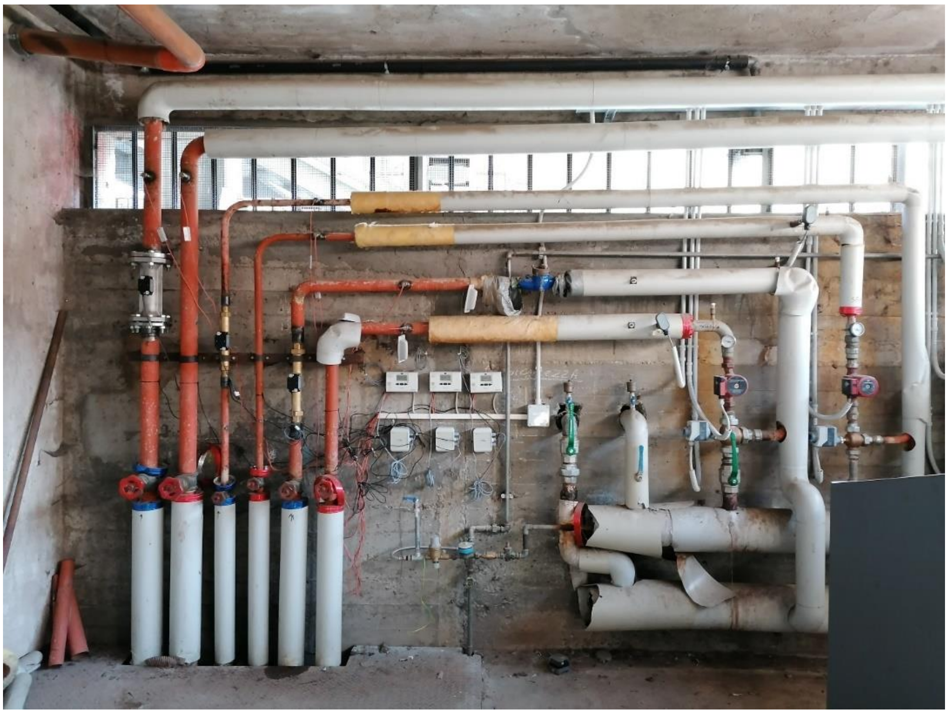


**Figure 17 The three heating distribution lines – it is also possible to see the E-DYCE installed heat meters.**

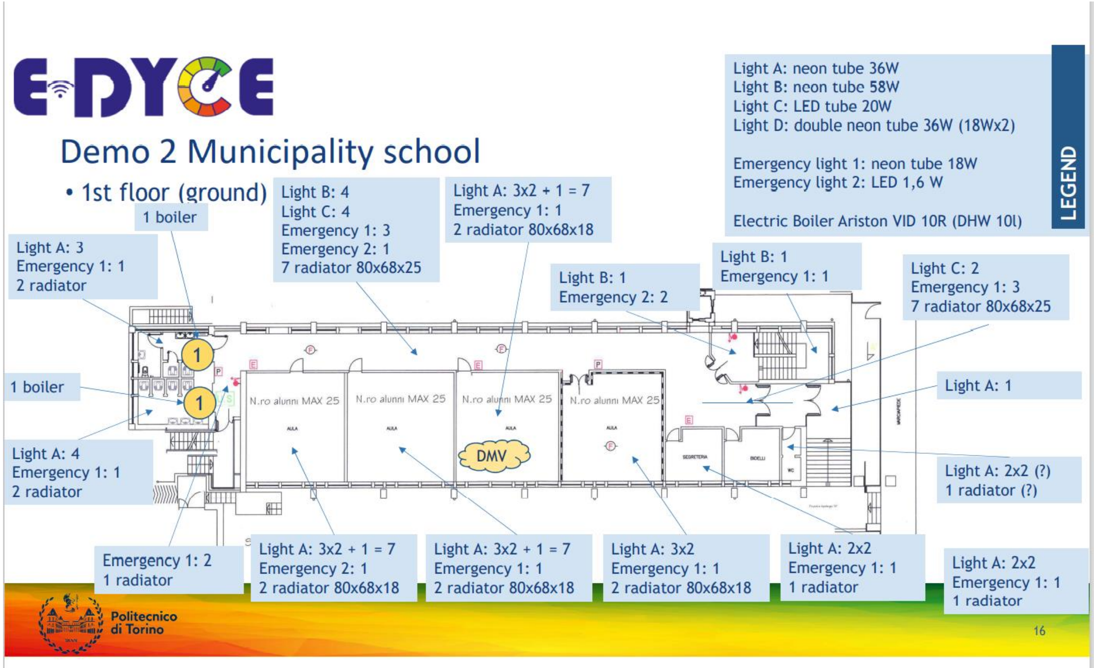



**Figure 18 One of the post-relief restitutions shows lighting and radiator positionings.**

**Figure 19 (a) one of the school radiators; (b) one of the lighting systems installed in classrooms**

School 2 (B2.2) has a devoted heater serving the entire building, which is positioned in a technical room in the basement. The heater is a gas condenser boiler Remeha B V NL-7300 AA, model GAS 210-ECO, with a nominal power of 120 kW – see Figure 20. All rooms have radiators with thermo-valves. In corridors, thermo-valves may be manually operated with a limitation in the maximum number (3 over 5) to reach about 18-20°C, while in rooms, the control is more intelligent. A few years ago, a room control system was integrated based on a Honeywell thermostat remotely connected to a BMS able to actuate the room's relative radiators via automatic thermo-valves- see Figure 21 and Figure 22. Thermostats are remotely controlled by one of the school operators limiting the system's activation to those rooms that are expected to be used in the following hours. DHW is provided via electrical boilers directly connected to near sinks. These boilers are of different models, i.e. Like mod. ER/510 and Styleboiler mod. Pony 10 SP SE, both with 10l of capacity.


**Figure 20 The heater of B2.2.**

**Figure 21 (a – top-left) the thermos-valves of radiators in common spaces, including corridors; (b – top-right) the thermos-valves with remote controller installed in the classrooms**


**Figure 22 One of the thermostats installed in classrooms.**

Residential house 1 (B2.3) has a gas condenser boiler serving the heating system based on radiators and the DHW system. The heating generator is a Beretta gas condenser boiler. The heating system is divided into two lines, one serving those rooms used during the daytime and one serving bedrooms. Nevertheless, during 2022, this system has been substituted by a new heater (gas condenser boiler), a Buderus Logamax plus GB122-24 (installed during the first months of 2022), and a fireplace insert with intelligent control (installed during summer 2022) and connected to the heating system begin able to heat the radiator fluid.

Residential house 2 (D2.4) has a pellet heater: a GRA30ROS - 30kW thermal efficiency of 91%. Pellets are automatically charged to the heater. The system uses radiators. A traditional fireplace is positioned in the living room but is rarely activated. A solar panel system by BUDERUS is also installed with ample storage (290l) to produce the DHW.

Residential building 3 (D2.5) has a gas condenser boiler producing the DHW and the heating power for two circuits: the first serving radiators with thermo-valves positioned in the older part of the house, and the second serving the new wing of the house that has an underfloor heating system. Each circuit has a proper thermostat. The heater is a Viessman Vitodens 200-W installed in 2015 with 23 kW of useful power. A traditional wooden stove is also installed in the kitchen space and is used in winter when the tenant is at home.

### 4.1.3 APE (EPC)

Such as mentioned in D5.1, an EPC has been retrieved for three of the five Italian demos, although some of these certifications may have some discrepancies with current building situations. This issue is because EPC is mainly produced when a building is sold or rented. It is generally not updated when changes arrive without being supported by national incentives, e.g., installing a new heater, changing a window with a more performative one, etc. Nevertheless, the three acquired APEs – an APE 'Attestato di Prestazione

Energetica' is the Italian EPC – are here assumed. For the two buildings that do not have an EPC, a professional was asked to develop them.

In particular, B2.1 does not have an EPC. Confirmed that the owner is not interested in developing it, POLITO has assumed the need to support a professional to create the APE-correlated information for E-DYCE purposes. The developed APE, even if not transmitted to the SIAPE Regional portal, includes heating, DHW, and lighting information. POLITO performed the needed inspection and data collection while an external professional elaborated the data to represent an actual EPC development process. School building 1 resulted in being in energy class E.

B2.2 have a valid APE released in 2014. After this release, the heating regulation changed since thermo-valves were installed for all radiators. Corridors have thermo-valve control with a limitation on the maximum that can be set up (up to 3, instead of up to 5). Differently, classrooms and other rooms have a thermostat that is remotely controlled to support via intelligent-thermo-valves the management of radiator heat flows. Although these changes, the original APE already shows a by-zone thermostat control. B2.2 is classified as energy class C.

The first residential building (B2.3) has an APE released in 2015. After this date, minor changes arrive in the building, although the retrieved EPC is here assumed as a reference. This building is labelled as energy class E. Considering that in summer 2022, a change in the heating system has been performed – see also Section 7.1 –, including a new heater, the integration of a new intelligent fireplace insert in the heating system, and some extra thermal insulation between the basement and the first inhabited floor, a new APE is expected to be released during the 2022-23 period.

Residential building 2 (B2.4) has an APE released in 2018. Still, since the heating system is composed of an automatic pellet heater not labelled, this certification is officially expired (valid for one year only). Nevertheless, we assumed these data as basic information for EPC-correlated analyses. After releasing this certification, the building envisaged some energy improvements, including changes in windows and, in January 2022, the inclusion of an insulation layer between the unheated under-roof space and the underlying heating rooms (first floors) – see also Section 7.1. The original energy class of the building is E, even if these recent changes suggest an improvement.

The third residential building (B2.5) has been renewed, with the inclusion of a new building wing, the substitution of the heater and windows, and, in the new-built part, the inclusion of thermal insulation layers. For this reason, any valid EPC is available. In 2015 an APE was released for a change in the building ownership, but it included only the old building part (half of the current heated net area), classified in energy class F. The present demo case under investigation is different from the one in 2015. Hence, the old APE is not valid. For this reason, POLITO has assumed the need to support a professional to develop the APE of this demo building for E-DYCE purposes. The upgraded EPC labels this building as class F.

Extra information on building EPC is reported in D5.1, which is complementary to the abovementioned data.

## *4.2 Expected values from the DEPC*

Expected uses of each pilot concerning DEPC analysis are already reported in the Deliverable D5.1. For this reason, the specific KPIs lists, based on the E-DYCE DEPC approach described in the Deliverable D2.4, are not here repeated but can be retrieved in the mentioned D5.1. Although, it can be reminded that all

Italian demos allow performing environmental and IEQ (Indoor Environmental Quality) analyses, including thermal comfort (both Fanger and adaptive models – see EN 16798-1, ISO 7730 and other references, e.g. [4–7]) and IAQ (indoor air quality) studies. For these variables, more than one year of monitored data is already available in all demo buildings. Hence, we can expect to analyse more than two years of data during the data analyses scheduled for the final deliverable D5.6. In addition to environmental variables, electricity and thermal uses are also monitored, even if the latter is currently limited in the already available data due to a delay in the heat meter installations. Nevertheless, all sensors are now positioned to collect the future 2022-23 heating season. All demo buildings have a correlated EnergyPlus multi-zonal model that has been checked and verified for summer free-running behaviours. All models will be re-checked during the last project year for heating consumption indicators, thanks to the progressive collection of monitored data during the future heating season. This improvement will also be reflected during the calculation of the 1D and 2D energy signatures. Models have already been built to allow to be run via the PREDYCE tool and the FusiX connected PREDYCE API facility. This allows to run sensitivity analyses and potentially performance gap studies (PG), having already aligned the zone names with correlated sensors. Nevertheless, additional efforts are expected during the following months to better support this action by improving the definition of the current standard and especially standard-modified model inputs – see the following Section 6. For all demos is possible to run fictitious cooling calculations. Italian demo buildings are characterised by a continuous exchange of information with the end-users to increase their involvement, collect feedbacks and missing information, and prepare the next project phase focussed on demo data analyses. Such as underlined in Section 7.2, users currently can look at monitored data via the mobile application developed during an educational activity connected to POLITO dissemination actions. Although, this student-developed app will be substituted in the following months by the official E-DYCE solution that includes several additional functionalities. It is possible to summarise that IEQ aspects may be calculated together with fictitious cooling and comfort correlated KPIs with different time aggregation analyses for all demo buildings. Concerning energy needs, it will be possible to analyse the heating needs in all demos. At the same time, DHW will not be a priority for Italian demo buildings and is not monitored with the exclusion of one residential building. Electrical consumptions are observed, but no analyses are expected for final KPIs. Differently, energy signatures would be defined for all demos.

# 5 Monitoring (Technical aspects of the data collection)

## 5.1 Monitoring Plan requirements and sensor technologies used in the demonstration

Such as introduced in D5.1, the Italian demo monitoring is based on two solutions: the first regarding building data collection and based on the Capetti Electronics WINECAP® system, and the second regarding meteorological data collection and based on a cloud-connected weather station. Technical and functional requirements identified during the monitoring planning phase are reported in D5.1, while here below are the detailed chosen systems, specific probe information, and sensor installation. Figure 23 shows the Italian demo data-logic flow, including sensor connections to FusiX and POLITO server facilities. On the left, installed probes transmit data to their gateways, allowing remote cloud connections with intermediate cloud storage and graph production for initial analyses. Furthermore, both solutions allow for direct communication with the E-DYCE middleware (based on FusiX) and the local POLITO server. The connections with the dynamic simulation platforms (PREDYCE) for data analyses, including the EnergyPlus input (IDF) and weather data on the right part of the figure.

Additionally, in this section there are also detailed additional solutions adopted in the Italian demonstrator, including the description of the three detached mechanical ventilation units installed, thanks to E-DYCE, in the municipality middle school building (B2.1) and describing some of the low-term monitoring actions (e.g., U-value monitoring) to support data feasibility.

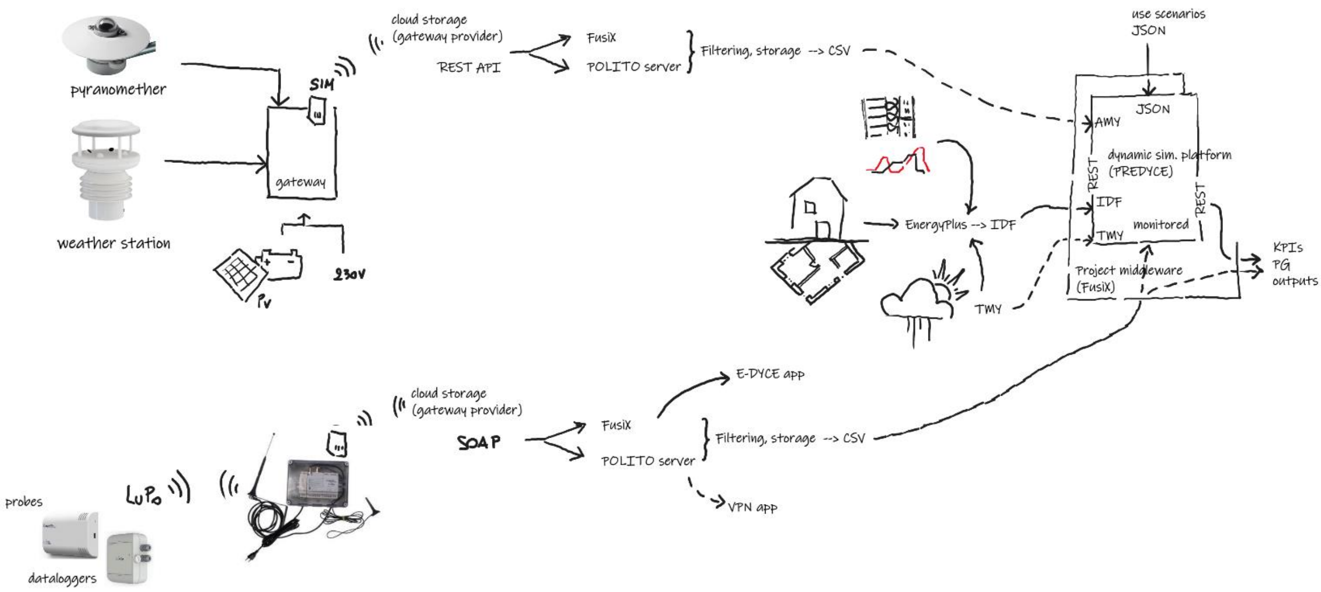



**Figure 23 The logical monitoring scheme of the Italian demos.**

## 5.2 The Capetti system for environmental and energy monitoring

The Capetti WINECAP is a monitoring system that provides tools to monitor environmental variables and energy in one or more buildings via remote connectivity. The system comprises many battery-powered dataloggers with sensors and a single AC-powered gateway that collects and stores data from the dataloggers and sends them to the Internet via GSM/GPRS. The gateway automatically creates and maintains the network by simple sensor pairing operations. Its range can be extended by using battery-powered routers to reach remote areas of the building. The pairing operations are done by bringing a magnet close to the side of the datalogger devices to send input commands that follow a pattern based on several LED indicator blinks. Since the datalogger does not require an electrical connection, they can be placed almost anywhere in the building and guarantee about five years of battery operation – even if window sensors show a short life during project monitoring phases. Moreover, each sensor-logger also works as a datalogger so that if the gateway is temporarily inaccessible, e.g., during a blackout, collected data are not lost. Still, data will be sent as soon as the gateway comes back online. The high redundancy and continuity of collected data make the system very reliable. Data can be downloaded using the Capetti Web interface. Additional ways of retrieving data from the system include USB and RS232 connections, RTU Modbus via RS485 protocol, and a SOAP API. The following Figure 24 shows some installation moments.


**Figure 24 During sensor Installation**

The core of the system is composed of the mentioned gateways, formed by a modular wireless datalogger gateway (MWDG GSM B – see the following Figure 25) – able to memorise and export data. Each gateway can manage till 40 wireless connected probe/dataloggers and has an internal storage able to retrieve 2500000 data points. Gateways have a WSN and a GSM antenna with an RS485 interface using the MODBUS RTU protocol and a GSM internal module for point-to-point connections and GPRS for data uploading toward the Capetti Service. The system is also able to send data to an FTP server.

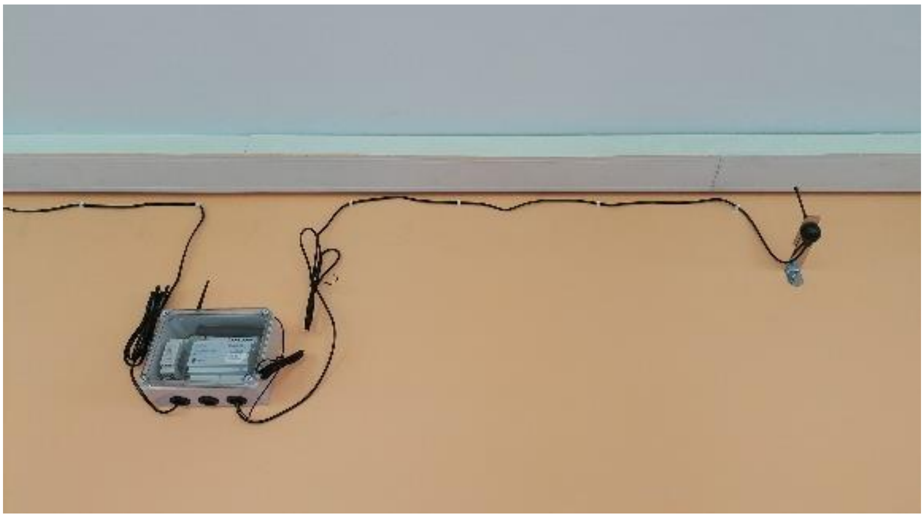


**Figure 25 A Capetti's MWDG GSM B gateway**

Specific datalogger and sensor descriptions:

- **Temperature** (WSD00T_LD)**:** a wireless smart datalogger including a sensor which monitors temperature.

**Table 1 WSD00T_LD**

| | |
|---|---|
| **Connection** | Wireless, USB. |
| **Indoor Temperature – transducer type** | NTC10KΩ |
| **Indoor Temperature – measure range** | -10°C ÷ +60°C |
| **Indoor Temperature – measure precision** | ±0,2°C whole range |
| **Indoor Temperature – measure resolution** | 0,01°C |

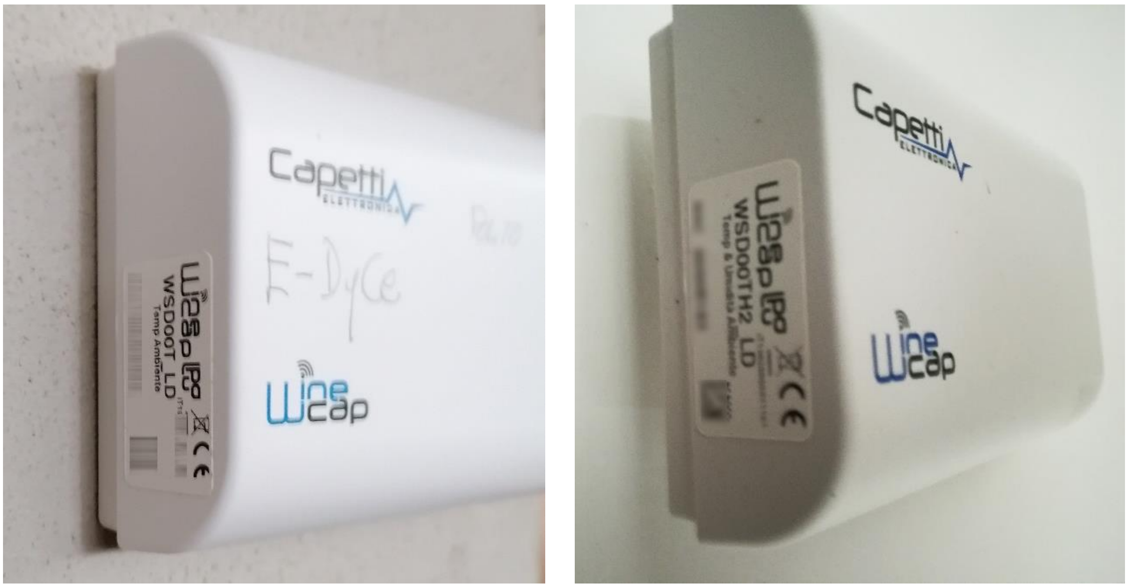



**Figure 26 (a – left) A WSD00T_LD probe/logger, and (b – right) a WSD00TH2_LD**

- **Temperature and relative humidity** (WSD00TH2_LD): a wireless smart datalogger with two channels, including sensors which monitor temperature and relative humidity.

**Table 2 WSD00TH2_LD**

| | |
|---|---|
| **Connection** | Wireless, USB. |
| **Indoor Temperature – transducer type** | NTC10KΩ |
| **Indoor Temperature – measure range** | -10°C ÷ +60°C |
| **Indoor Temperature – measure precision** | ±0,2°C whole range |
| **Indoor Temperature – measure resolution** | 0,01°C |
| **Relative humidity – transducer type** | CMOSens® technology |
| **Relative humidity – measure range** | 0 ÷ 100% |
| **Relative humidity – measure precision** | ±2,0% (*typical*) from 0% to 100%<br>Precisions are guaranteed in the range of 0°C ÷ 50°C |
| **Relative humidity – measure resolution** | 0,05%RH |

- **Temperature, relative humidity, and $CO_2$** (WSD00TH2CO) and (WSD00TH2CO_S)**:** this wireless smart datalogger has an additional $CO_2$ concentration meter (3 channels) measuring CO2, relative humidity and air temperature. Some of them also feature a LED indicator (_S model) which can be turned on if the $CO_2$ exceeds a settable threshold.

**Table 3 WSD00TH2CO_S**

| | |
|---|---|
| **Connection** | Wireless, USB. |
| **Indoor Temperature – transducer type** | NTC10KΩ |
| **Indoor Temperature – measure range** | -10°C ÷ +60°C |
| **Indoor Temperature – measure precision** | ±0,2°C whole range |
| **Indoor Temperature – measure resolution** | 0,01°C |
| **Relative humidity – transducer type** | CMOSens® technology |
| **Relative humidity – measure range** | 0 ÷ 100% |
| **Relative humidity – measure precision** | ±2,0% (*typical*) from 0% to 90% |
| **Relative humidity – measure resolution** | 0,05%RH |
| **$CO_2$ concentration - Measure Range** | 0÷5,000ppm |
| **$CO_2$ concentration - Measure Resolution** | 1 ppm |
| **$CO_2$ concentration - Measure Accuracy** | 0÷5,000ppm: < ± 50ppm (*+3% of measured value*) |


**Figure 27 One of the installed WSD00TH2CO_S probes/dataloggers**

- **Temperature, relative humidity and TVOC** (WSD00TH2VOC)**:** Advanced sensor, with an additional total volatile organic compounds meter.

**Table 4 WSD00TH2CO_S**

| | |
|---|---|
| **Connection** | Wireless, USB. |
| **Indoor Temperature – transducer type** | NTC10KΩ |
| **Indoor Temperature – measure range** | -10°C ÷ +60°C |
| **Indoor Temperature – measure precision** | ±0,2°C whole range |
| **Indoor Temperature – measure resolution** | 0,01°C |
| **Relative humidity – transducer type** | CMOSens® technology |
| **Relative humidity – measure range** | 0 ÷ 100% |
| **Relative humidity – measure precision** | ±2,0% (*typical*) from 0% to 100% |
| **Relative humidity – measure resolution** | 0,05%RH |
| **Voc - Transducer type** | CMOSens® Technology |
| **Voc - Measure range** | 0÷60,000ppb |
| **Voc - Testing gas** | Ethanol and H2 |
| **Voc - Measure resolution** | 1ppb from 0÷2,000ppb |


**Figure 28 One of the installed WSD00TH2VOC probes/dataloggers.**

- **Window opening and temperature** (WSD02T-KK)**:** Sensor which returns the opening state of a window by evaluating the contact of two magnetic pieces. It also has a temperature sensor, which may be used to analyse radiant temperature inhomogeneity since it is placed on the window wall.

**Table 5 WSD02T-KK**

| | |
|---|---|
| **Connection** | Wireless, USB. |
| **NC/NO (*Status integration*) - Measure range** | 1 change every 3 seconds |
| **NC/NO (*Status integration*) - Output voltage** | 3V (*pull-up 10KΩ*) |
| **Indoor Temperature – transducer type** | NTC10KΩ |
| **Indoor Temperature – measure range** | -10°C ÷ +60°C |
| **Indoor Temperature – measure precision** | ±0,2°C whole range |
| **Indoor Temperature – measure resolution** | 0,01°C |


**Figure 29 One of the installed WSD02T-KK probes/dataloggers.**

- **Temperature, humidity and lux** (WSD00TH2L)**:** Sensor with additional lux meter; the positioning of the sensor is critical for correct lux reading. In this case, it is positioned vertically in line with the other sensors giving a general idea of the luminance but not reading the standard horizontal values to be maintained on the working plan.

**Table 6 WSD00TH2L**

| | |
|---|---|
| **Connection** | Wireless, USB. |
| **Indoor Temperature – transducer type** | NTC10KΩ |
| **Indoor Temperature – measure range** | -10°C ÷ +60°C |
| **Indoor Temperature – measure precision** | ±0,2°C whole range |
| **Indoor Temperature – measure resolution** | 0,01°C |
| **Relative humidity – transducer type** | CMOSens® technology |
| **Relative humidity – measure range** | 0 ÷ 100% |
| **Relative humidity – measure precision** | ±2,0% (*typical*) from 0% to 90% |
| **Relative humidity – measure resolution** | 0,05%RH |
| **Light intensity - Transducer type** | Photodiode array |
| **Light intensity - Measure range** | 0 ÷ 16KLux |
| **Light intensity - Measure resolution** | 1Lux |

**Figure 30 One of the installed WSD00TH2L probes/dataloggers.**

- **Temperature contact probes** (WSD12-TT1K): a wireless smart datalogger with two channels devoted to collect data from two external temperature PT1000 probes. Probes detect radiator and fireplace temperatures by analysing when end-users activate their fireplaces and if this will influence the radiator temperature. For Res.3 (B2.5), the fireplace temperature probe was modified, being the fireplace was substituted by a wood stove reaching very high surface temperatures. For this reason, the PT1000 has been adapted by building a globe thermometer based on a ping-pong ball externally treated to get a known emissivity value (grey coating) – see the methodology described in [8–10]. The globe thermometer has been positioned near the stove (high stove view-factor) and shaded concerning the radiator (no direct view-factor) to detect the period of turning-on of this manual heat source.

**Figure 31 One of the installed temperature contact probe dataloggers.**

- **Heat meter** (WSD12-EVTT)**:** the installed heat meters are composted by external probes connected to a Capetti wireless smart datalogger with four channels (WD12-EVTT). Together with the datalogger, different heat counters by Kamstrup have been installed by ACEA (a public energy provider and manager company) under the TPM budget, including the Kamstrup meter plunged supply and return water temperature probes. Additional supply and return temperature probes are also positioned on the external surface of the supply and return tube (not insulated parts) (NTC10K). Each datalogger receives data from the Kamstrup meter (heat and flow) plus the outermost surface temperatures. Each demo building may have more than one heat meter according to the specific system organisation – See the sample in Figure 32.

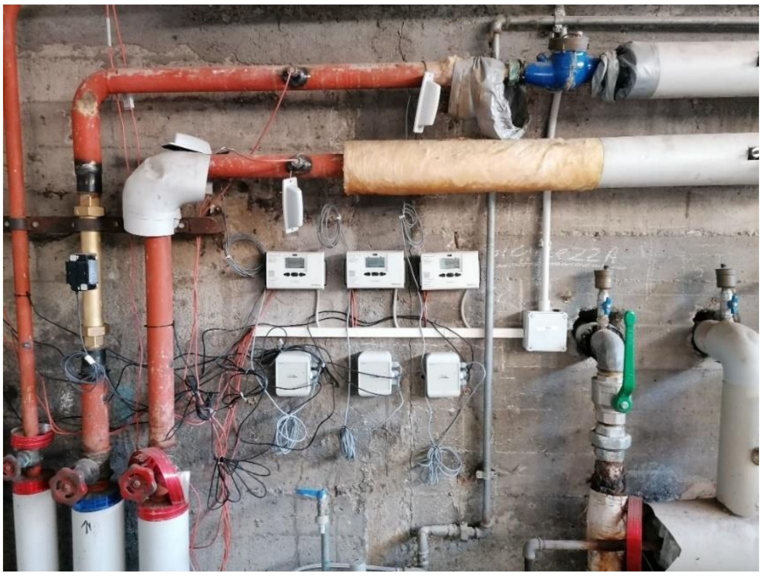


**Figure 32 One of the installed heat meter monitoring systems (B2.1).** ***It is possible to see the three heat meters including the three Kamstrup meters and the correlated Capetti 4-channel loggers. On the left it is possible to see***

***one of the flowmeters and on the top two of the immersed temperature probes connected to the Kamstrup (one for the supply and one for the return).***

- **Electric energy consumption** (WSD12-2DI)**:** Two different typologies of electrical meters have been installed. For demos B2.1, a three-phase meter (EC-6TA MID) 6A with three closed amperemeters 100A/5A (TAC) has been connected to a WSD12-2DI impulse counter wireless smart datalogger. The meter and the amperemeters have been included in the school electrical panel. This operation required extra time before fully operational and transmitting the desired input data. Differently, all the other four demo buildings have an optical interface (EXP2PUL) based on phototransistors to read the light pulse on most Italian domestic electrical meters, e.g., provided by ENEL or other distributors. This optical interface does not interfere with the official meter, which cannot be touched or modified for law, but is externally coupled with its end-user monitor. The interface is connected to a Capetti pulse reader (WSD12-2DI), transmitting the active and reactive power.


**Figure 33 One of the installed electrical meters with the EXP2PUL probe.**

- **Degree day and external temperature** (WSD10MiGG)**:** A wireless smart datalogger with four channels that is weather resistant (IP65). It monitors degree-days in line with the Italian D.P.R.412, degree-days on the base of a set base temperature, and the environmental temperature. The sensor can be certified in line with ACCREDIA.

**Table 7 WSD10MiGG**

| | |
|---|---|
| **Connection** | Wireless, USB. |
| **Outdoor temperature - Transducer type** | "A" class PT1000 |
| **Outdoor temperature - Measure range** | -30°C ÷ +50°C |
| **Outdoor temperature - Measure precision** | ± 0.25°C whole range |
| **Outdoor temperature - Measure resolution** | 0.01°C |
| **Outdoor temperature - Time constant** | 3 minutes |

**Figure 34 One of the WSD10MiGG installed probes/dataloggers**

- **External $CO_2$ and temperature** (WSD12T-CO*)**:** Weather-resistant datalogger (IP65) with two channels. It monitors external $CO_2$ concentration and environmental temperature. This specific sensor uses an external CO2 probe – (*EE82) and an NDIR infrared probe (IP54) – connected to the datalogger-free channel. The external probe requires a continuous electrical plug; this datalogger is connected to the 220V school electrical system.

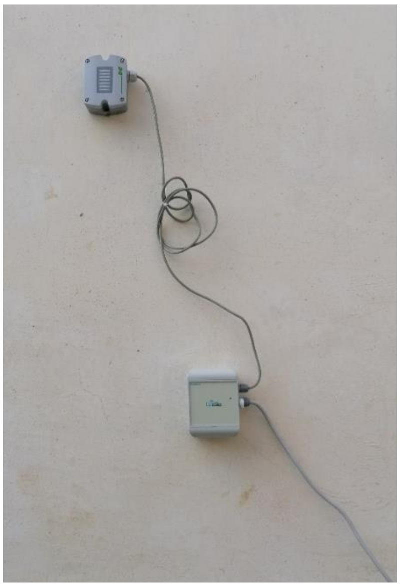


**Figure 35 The installed outdoor CO2 probe**

- **Router** (WR12)**:** Device which extends the coverage of the WINECAP wireless sensor network. It is also managed as a datalogger allowing one to see it remotely and know its battery level, the quality of the radio signal, and the quantify of collected data). This device has an environmental protection IP 65.


**Figure 36 One of the installed WR12 routers**

## 5.3 Meteorological station

A meteorological station assembled by Netsens is placed near the high school; it is powered by an electrical plug connected to the school electrical system and a small accumulator (24V battery) powered by a PV panel to guarantee data continuity. The gateway includes a SIM slot for cloud data connections and management.

The station features two main components: a Clima Sensor US made by Thies, which performs several measurements, including dry-bulb and wet-bulb temperatures (derived), relative humidity, wind speed and direction, degree-days, atmospheric pressure, precipitation, and brightness; and a Spectrally Flat Class B (First Class) pyranometer (LPPYRA02) made by Delta OHM which measures global solar radiation. The Thies sensor specifications are reported here below.

**Table 8 Thies Clima Sensor US**

| **Precipitation** | | **Temperature** | |
|---|---|---|---|
| Measuring range | 0.001 ... 10 mm/min | Measuring range | -50 ... +80 °C |
| Accuracy | typ. 95% | Accuracy | ±0,3 K (@ 25 °C) |
| **Relative humidity** | | **Brightness** | |
| Measuring range | 0 ... 100 % rel. h. | Measuring range | 0 ... 150 kLux |
| Accuracy | ± 1.8 % rel. h. (10 ... 90 % rel. Humidity) | Accuracy | 3 % of rel. measuring value |
| **Wind direction** | | **Wind speed** | |
| Measuring range | 0 ... 360 ° | Measuring range | 0.01 ... 75 m/s |
| Accuracy | ±2 ° WS > 2 m/s | Accuracy | ±0,3 m/s rms (< 5 m/s)<br>±3 % rms (5 m/s... 60 m/s) |
| **Air pressure** | | | |
| Measuring range | 260 ... 1260 hPa | | |

| | |
|---|---|
| Accuracy | ±0.25 hPa @ - 20 ... +80 °C @ 800 ... 1100 hPa<br>±0.50 hPa @ - 20 ... +80 °C @ 600 ... 800 hPa<br>±1.00 hPa @ - 50 ... -20 °C @ 600 ... 1100 hPa |

This sensor has digital outputs via Modbus RTU protocol and analogue outputs (wind speed, wind direction, brightness, precipitation, relative humidity, air temperature, air pressure and others). The sensor has a GPS allowing it to define sun positions. Other derived or calculated values may also be retrieved by the Climate Sensor US using potential free Modbus channels. In this specific case, it is possible to read the following variables: degree-days; ETP; Brightness (East, North, West, South); wind direction; wind velocity; precipitation; atmospheric pressure; air temperature; precipitation type; air relative humidity; and absolute air humidity.

Measured data by both sensors can be viewed via Netsens Live Web page and then exported to XLS files, or they can be directly downloaded via REST API in an XML format. The station was installed on the 13th of April 2021.

**Figure 37 The installed meteorological station for the E-DYCE Italian demos**

## *5.4 Building-specific monitoring plan and sensor installation*

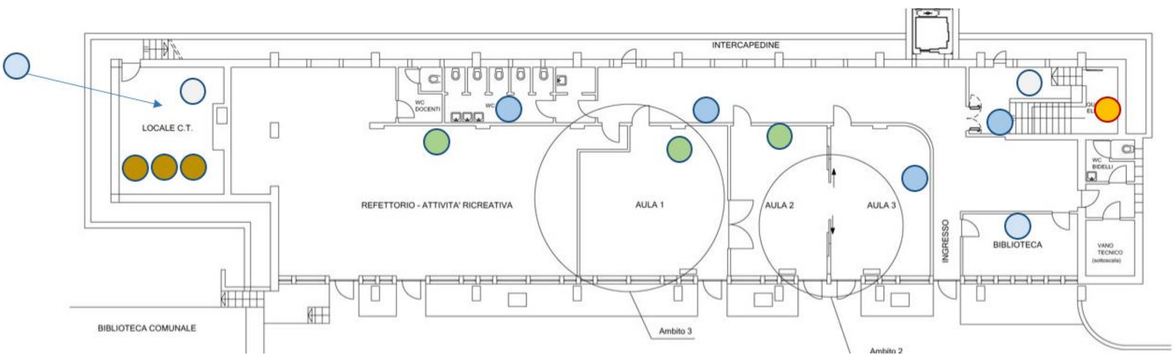
An initial data transmission date for all sensors is given in D5.1, together with the list of all installed sensors per demo. Generally speaking, environmental sensors are transmitting since April/May 2021, while the electricity meter since the same date for residential buildings and since November 2021 for schools. The heat meters have been installed secondly due to microchip availability delays. They have been transmitting since the end of February/March 2022, excluding Res. 1 (B2.3), which starts monitoring in summer 2022. Here below are described sensor positioning in all the five demo buildings. Some routes have been moved during the monitoring campaign to increase sensor signals, so not all routers are represented here in the following maps.

In B2.1 (the municipality school), sensors have been arranged to get the temperature and relative humidity values from all classrooms, teachers' rooms, laboratories, and corridors. Advanced sensors that monitor $CO_2$ concentration and TVOCs have been placed in rooms generally used for lessons and characterised by full-occupancy use. For each floor of the middle school part, a classroom has also been chosen to host window opening sensors, which in turn were placed on sashes that occupants typically use to create random natural ventilation. Moreover, degree day and external $CO_2$ are measured on the exterior north-faced facade. Global electric consumptions are retrieved by the three-phase meter, while heating uses are monitored via three heat meters. The first is collecting data from the semi-buried floor occupied by the infantry school. The second collecting data from the 'secretary', an old subdivision of the system including office rooms near the entrance of each floor (from ground to last one). The third is collecting all other heating users from the middle school. To analyse the whole school building, data monitored by all three meters need to be summed. Differently, the infantry consumptions relate to the devoted heat meter, and the middle school ones to the sum of the other two meters.

The following maps describe datalogger/sensor localisations on the four floors of the municipality school. Colours represent a different type of probe/datalogger in line with the legend reported in Table 9. In particular, Figure 38 shows the infantry semi-buried floor, while Figures 39, 40, and 41 illustrate the middle school's first, second and third floors, respectively. In addition to sensor localisations, schools also reported the correlated activities' names used to combine PREDYCE and FusiX functionalities monitored with simulated data and perform different results aggregations (e.g., by room types). The same is not here reported for residential buildings considering privacy issues.

**Table 9 colour legend describing installed dataloggers/sensors.**

| color | types | color | types |
|---|---|---|---|
| | DBT | | Electrical consumption (pulse) |
| | DBT+RH% | | Heat flow |
| | DBT+RH%+CO2 | | DBT+CO2 (external) |
| | DD | | State (window open) |
| | DBT+RH%+Lux | | gateway |
| | DBT+RH%+VOCs | | routers |



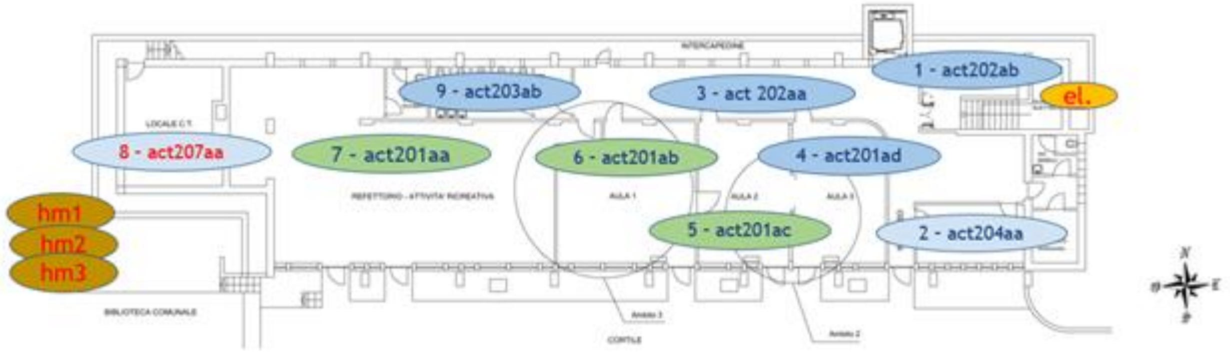



**Figure 38 The semi-buried floor – Kindergarten school**

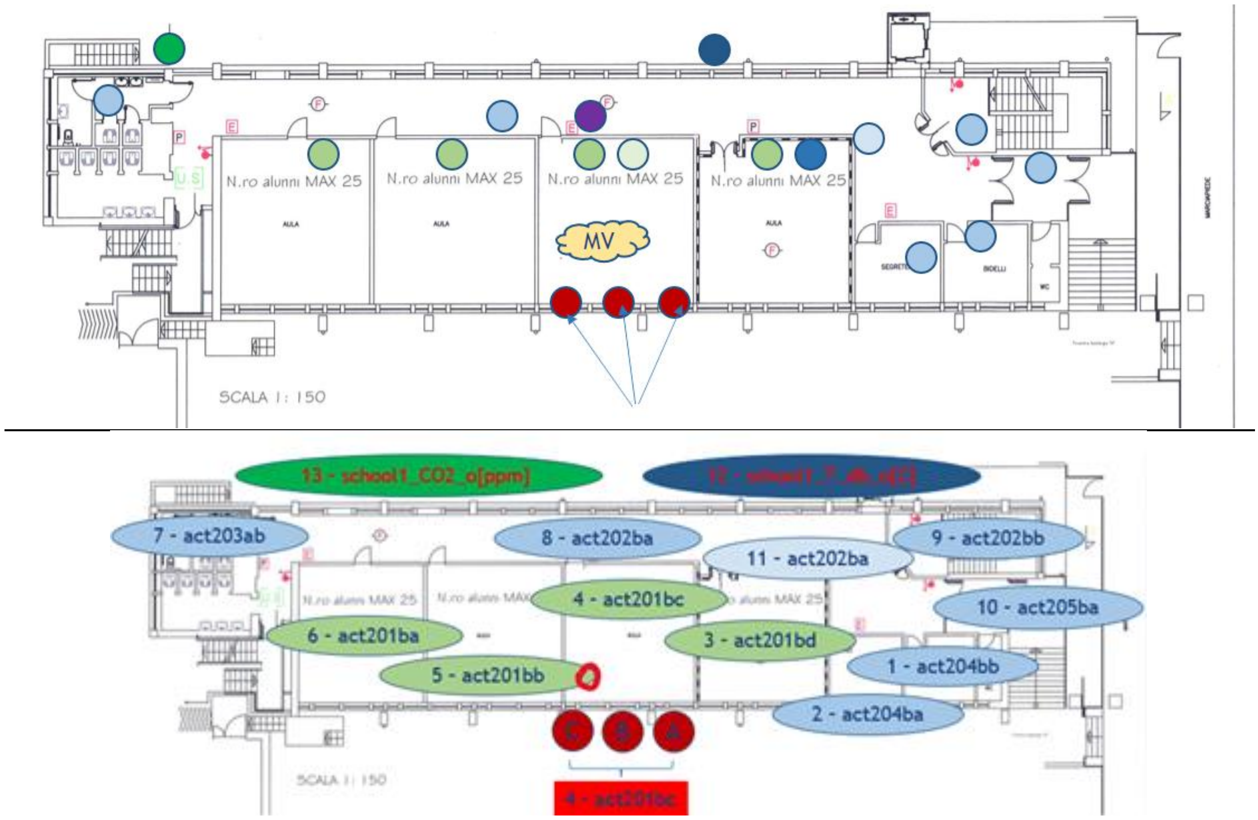



**Figure 39 The ground floor – Middle school first floor (entrance)**

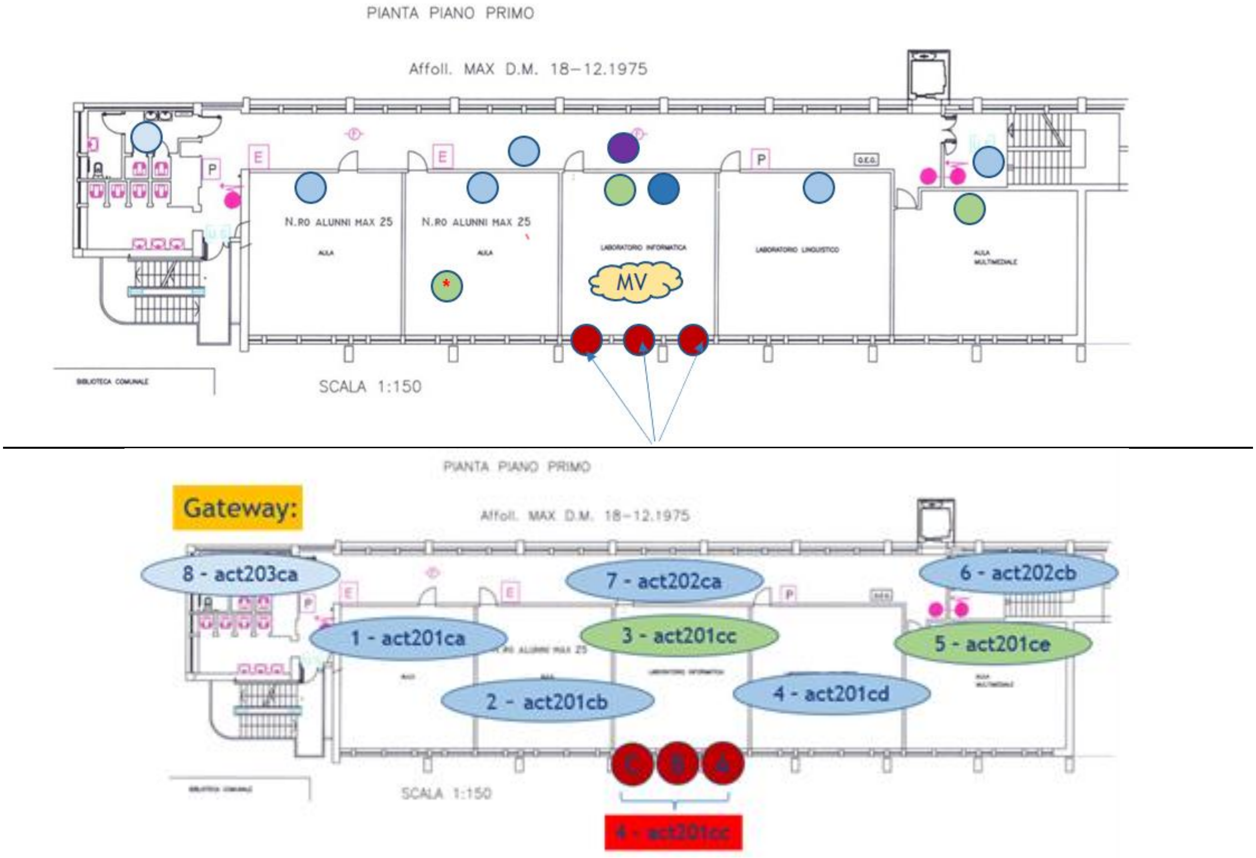



**Figure 40 The first floor – Middle school second floor**

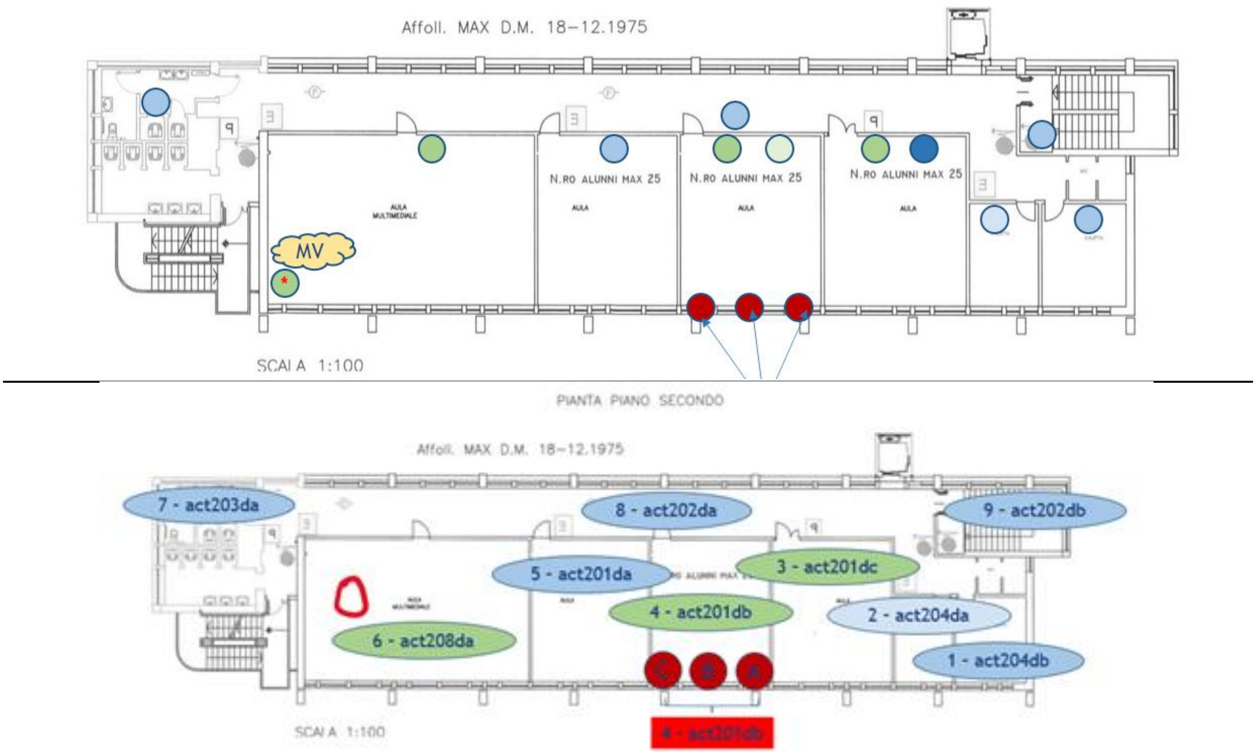



**Figure 41 The second floor – Middle school third floor**

As mentioned above, in the middle school we also have performed a series of short-term monitoring actions using the LSI U-value monitoring kits. U-value monitoring includes the positioning, for a period of 7-10 days, of two external wall-surface temperature probes, an internal wall-surface temperature sensor, and an internal heat flow sensor. The following Figure 42 shows a sample positioning of the two internal probes during one of the monitoring periods ranging from late 2021 and 2022.


**Figure 42 sample images representing one of the U-value monitoring tests.**

In school 2 (High school, B2.2), all classrooms are covered with temperature, relative humidity, and $CO_2$ concentration sensors, while corridors are provided with temperature and relative humidity sensors. Degree days (DD) and the external temperature are measured from a DD sensor placed on the emergency stairs behind the building. Electric consumptions have been monitored since 24/11/2021, while a heat meter has been installed to monitor heating uses (02/03/2022). A short-term U-value measurement was also conducted in high school in late 2021.

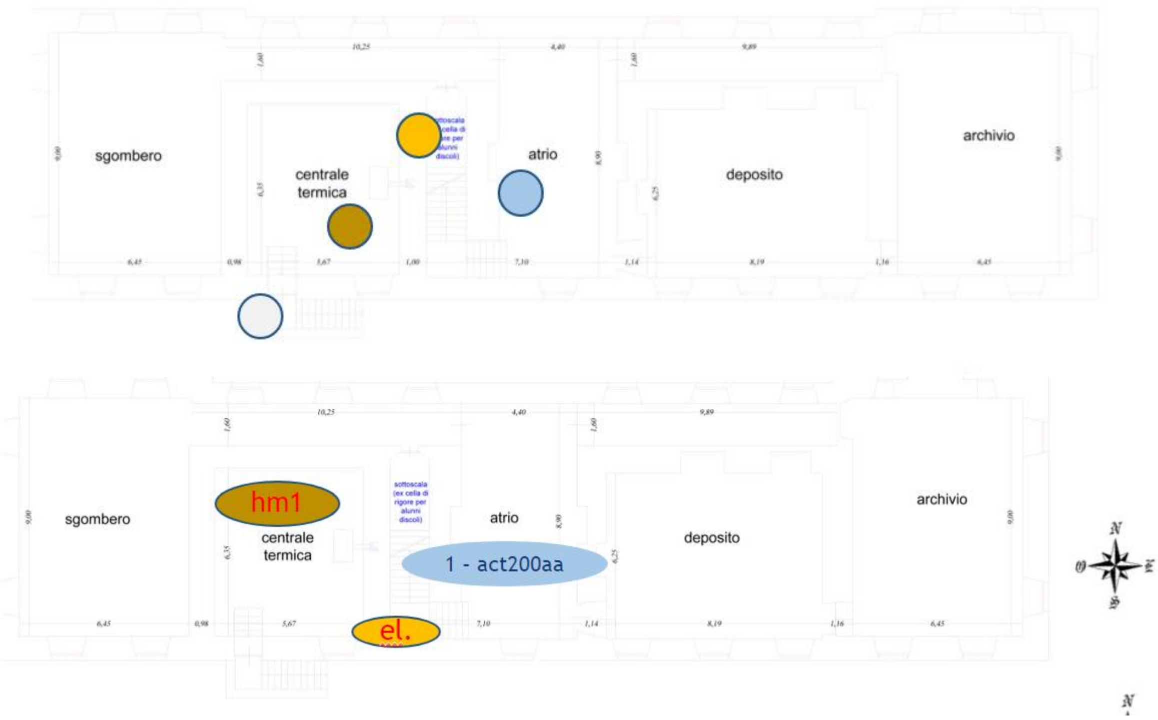



**Figure 43 Valdese high school basement**

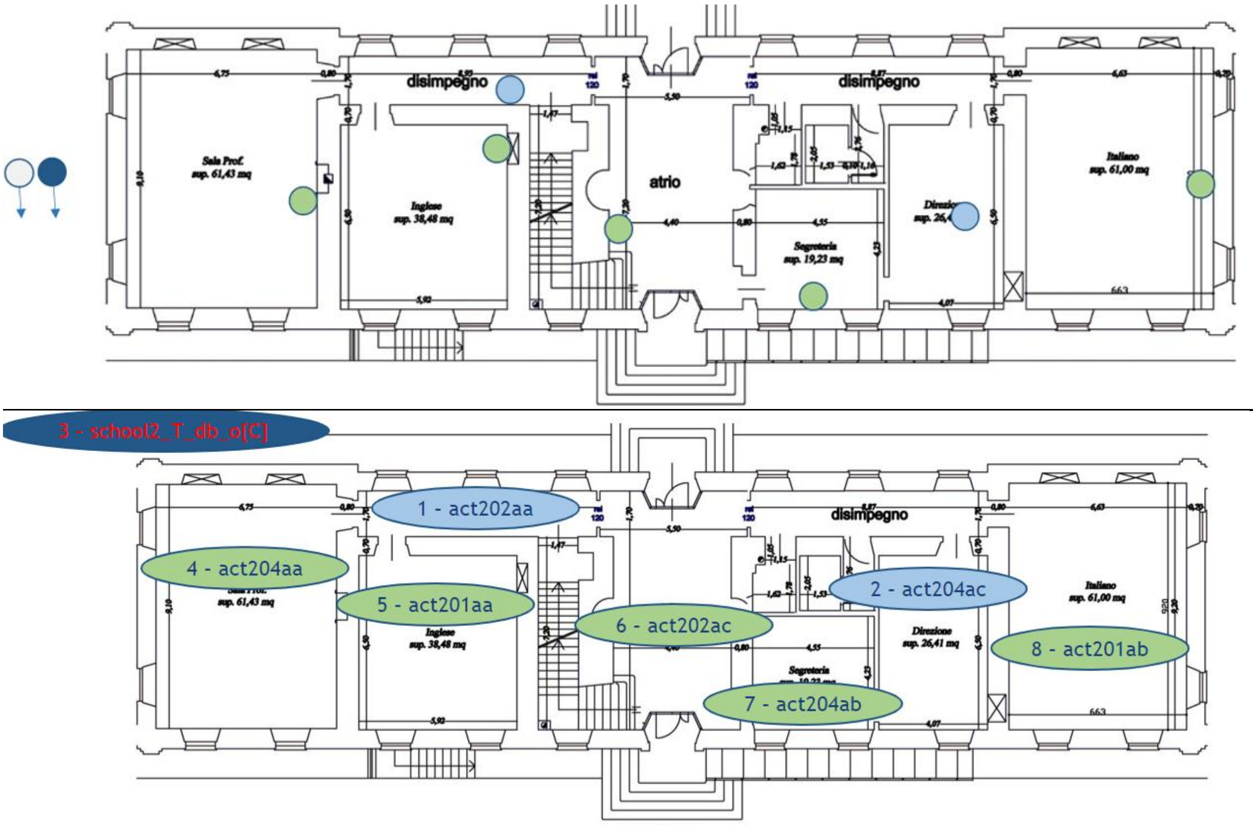



**Figure 44 Valdese high school ground floor – entrance**

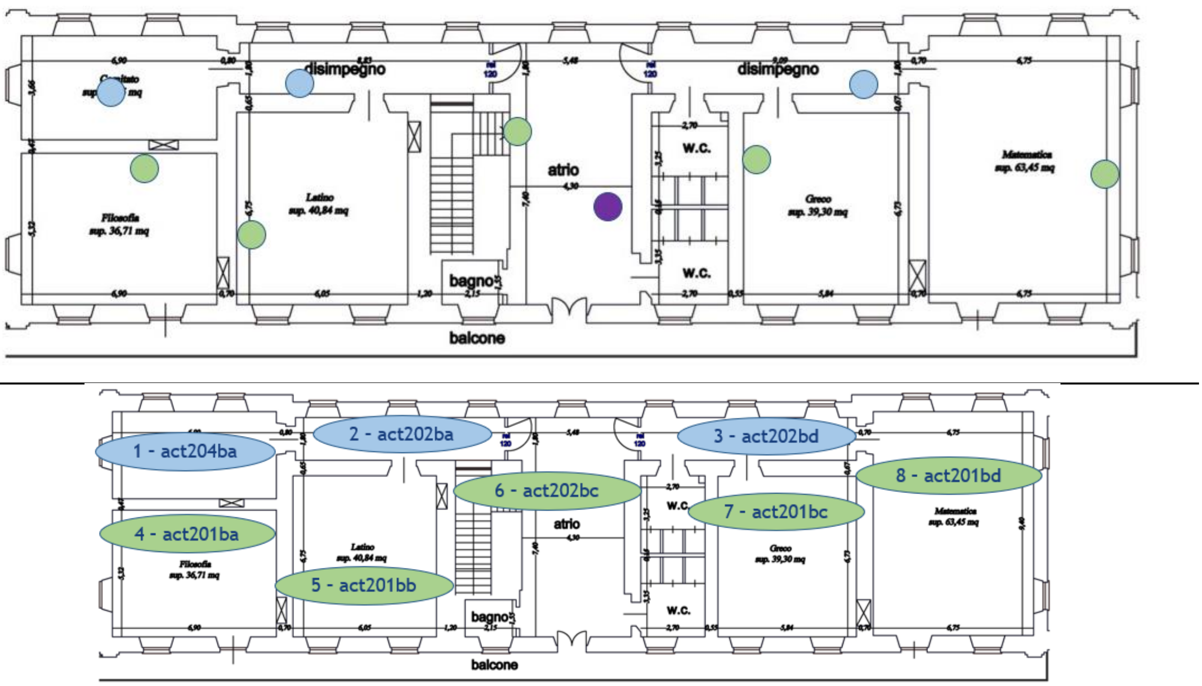
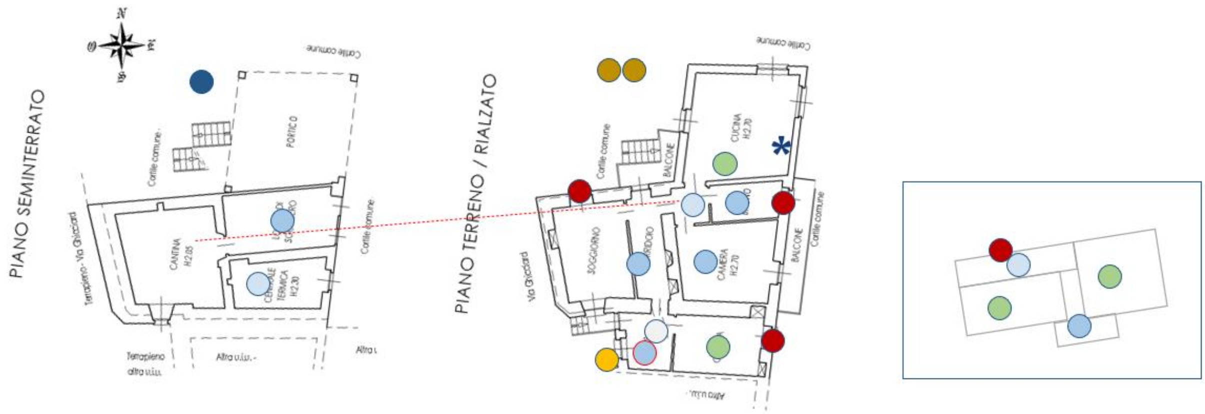



**Figure 45 Valdese high school first floor (in this floor is hosted the demo gateway – central space)**

On residential 1 (B2.3), temperature and relative humidity are measured in the bathroom, corridors, and double bedroom; advanced sensors with an additional $CO_2$ concentration meter are placed in the kitchen and the office. Three windows on the raised ground floor are covered with opening sensors. The thermal power plant room is equipped with temperature and heat flow sensors, while relative humidity and temperature of the basement are measured from the storage room. A degree day sensor is placed on a nearer awing opened structure, exposed to external air but protected by direct solar radiation. On the first flow, the window on the corridor is equipped with an opening sensor as well; the bathroom is provided with a temperature and relative humidity sensor; the other two bedrooms are equipped with $CO_2$ sensors. Electric energy consumption is also measured, while heat meters have been positioned in delay (summer 2022) due to the heating system change. Two heat meters have been installed: one acquiring the heating data from a natural gas condensation heater, and the other collecting the data from a fireplace insert integrated into the new house heating system. The sum of the two heat meters is expected to give the total heating uses, splitting non-renewable and renewable (biomass) components.




A b c

**Figure 46 Residential house n. 1 basement (a), ground floor (b) and first floor (c)**

On residential 2 (B2.4), temperature, relative humidity and $CO_2$ concentration are measured in the living room, children's bedroom, and double bedroom. The kitchen and other most used spaces have a temperature and relative humidity probe. In contrast, less used rooms and boundary-not-heated areas, i.e., the under-roof and the basement, have a temperature probe. Electrical consumptions are monitored for the home electrical line. Additionally, two heat meters are positioned to monitor the heating uses.

(a) (b) (c) (d)

**Figure 47 Residential house n. 2 basement (a), ground floor (b), first floor (c) and roof (d)**

On residential 3 (B2.5), sensors have been arranged to cover each room of the house by paying particular attention to monitor the difference in temperature and relative humidity between the new part of the building and the old one. The $CO_2$ concentration is observed only in the kitchen room; window opening sensors have been placed on two glazed doors that outlook a balcony. The electrical meter reads the electrical counter near the house but uses a router supporting the signal. Two heat meters are also installed, reading heating and DHW energy used by the natural gas condensation heater. The building also has a detached wooden stove in the kitchen. To generally know the period of usage of the latter and the effect of the stove on the radiator temperature – radiators have thermo-valves – a two-channel surface temperature probe has been positioned in the kitchen. This datalogger reads the surface temperature of the stove-nearer radiator and a globe thermometer temperature near the stove – see the description in Section 5.2. In this demo, the U-value kit was also positioned for the first measurements performed near the end of the heating season in 2022.

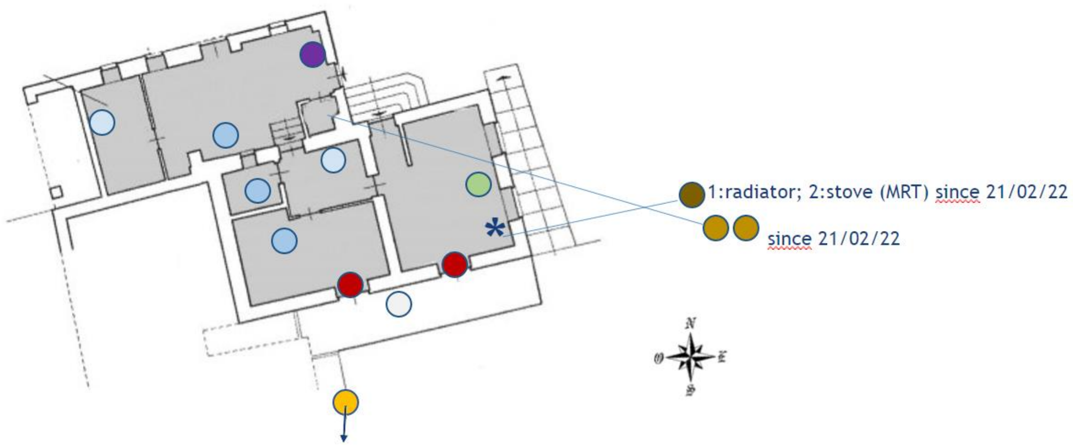



**Figure 48 Residential house n. 3**

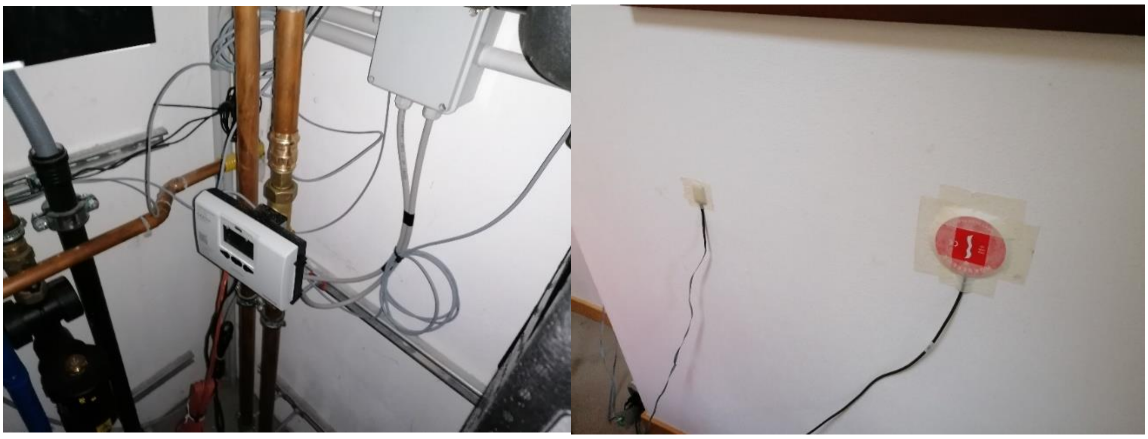


**Figure 49 (a-left) one of the two installed heat meters, (b) sample image representing one of the U-value monitoring tests.**

## 5.5 *Building actuator: detached mechanical ventilation unit*

Inside E-DYCE actions, the installation of three detached mechanical ventilation units (DMV) in the middle school building (B2.1) are included. Like most Italian schools, any ventilation system is installed in the two E-DYCE school demo buildings. This specific test was considered highly interesting to analyse IAQ and eventually free-cooling potentialities by providing controlled night ventilation in summer. During the project, the unexpected pandemic situation impacted this original action. The need to ensure high ventilation rates in schools and public spaces is, in fact, a priority. The Italian Ministry of Education has promoted during Covid several regulations asking for continuous ventilation in classrooms to reduce the pandemic-correlated risks. This was first translated into the need to leave the window opened for more extended periods with a consequent increase in heat losses in winter. Nevertheless, this original request is now supporting a substantial interest in installing mechanical ventilation systems in schools. The same Ministry and local authorities are studying potential instruments to fund and support this action. This new context positioned the E-DYCE test on mechanical ventilation solutions in the B2.1 demo in a more extensive background with a potentially higher interest in disseminating results in local and national communities.

Focussing on technical aspects, after a general check on local market solutions proposed for schools and other public spaces with a high occupancy rate, three Helty VMC Flow 800 machines have been installed – see Figures 50 and 51. The choice focussed on devices able among the other identified specifications, to:

i.) allow a flow-rate compatible with high occupancy levels,

ii.) support simple installations based on detached MV approaches and not requiring long channels,

allow a full integration in school spaces to avoid directly visible machines with tubes and cables in classrooms,

iii.) support different control possibilities, including

iv.) the potential integration of $CO_2$ sensors, and

v.) the option of adding remote control of the system at least for project purposes.

The chosen solution requires a two-channel connection with the outside, but the same may arrive directly in the installation space. Additionally, the system is integrated into a wardrobe with the typical dimension of a classroom wardrobe, assuring a high integration level. Finally, the solution allows being controlled via $CO_2$ sensors by acquiring the compatible probes (not available at present) and can be connected via Modbus to support remote controls.

DMV units have been positioned for floor in middle school classrooms chosen among the ones with continuous usage and higher $CO_2$ peaks. The chosen model controls the ventilation flow reaching 800 m3/h in both inlet and outlet flows. Noise can reach 42 dB at higher flow rates, while the system is labelled class A+ for energy needs, showing a nominal power of 188 W that during operation varies according to the set level of airflow. For example, excluding grid and channel pressure losses, the electrical power for an airflow of 370 m3/h is about 30 W but reaches 50 W at 540 m3/h, 84 W at 700 m3/h, and 178 W at 950 m3/h (producer data). The installed units were produced in 2021, a new model recently developed by the providing company. Additionally, a heat recovery system is installed but can be bypassed during the summer season to allow the ventilation units to support ventilative cooling. The installation started in January 2022.

Initial usages are based on a planned operational schedule supporting fixed ventilation rates from 8:00 to 14:00 (occupation period). This control has been tested during the first months with manual turning on and off operated by the school operators, and further by using the panel directly, allowing for manual setting of defined schedules. Nevertheless, in late June 2022, thanks to a POLITO master's degree thesis, remote-control solutions using Modbus were implemented by installing three RaspberryPi 4 with correlated Modbus adapters. The Raspberry modules are connected to the school's Wi-Fi, and software to allow remote control has been implemented. These remote-control solutions are expected to be used for the E-DYCE last year's tests. During the summer season of 2022, different tests to verify the ventilative cooling potentiality of these systems are planned, including, among the others, various night scheduling activations and temperature setpoint controls. During the 2022-23 educational year, these tests are expected to compare different strategies to control CO2 levels with single flow rates and to modulate the activation schedules or with multiple flow rates modulating schedules and flows. In parallel, the EnergyPlus model of the school – see Section 6 – has been modified to define another version of the same devoted to test DMV control solutions via EMS coding. This model, calibrated for this specific purpose, will be used to verify the impact of different control strategies before trying them or enlarging testing possibilities. The same will also be used to check the effect of DMV and controlling approach to the whole school building.

**Figure 50 (a-left) one of the installed DMV units; (b) the system controlling board**

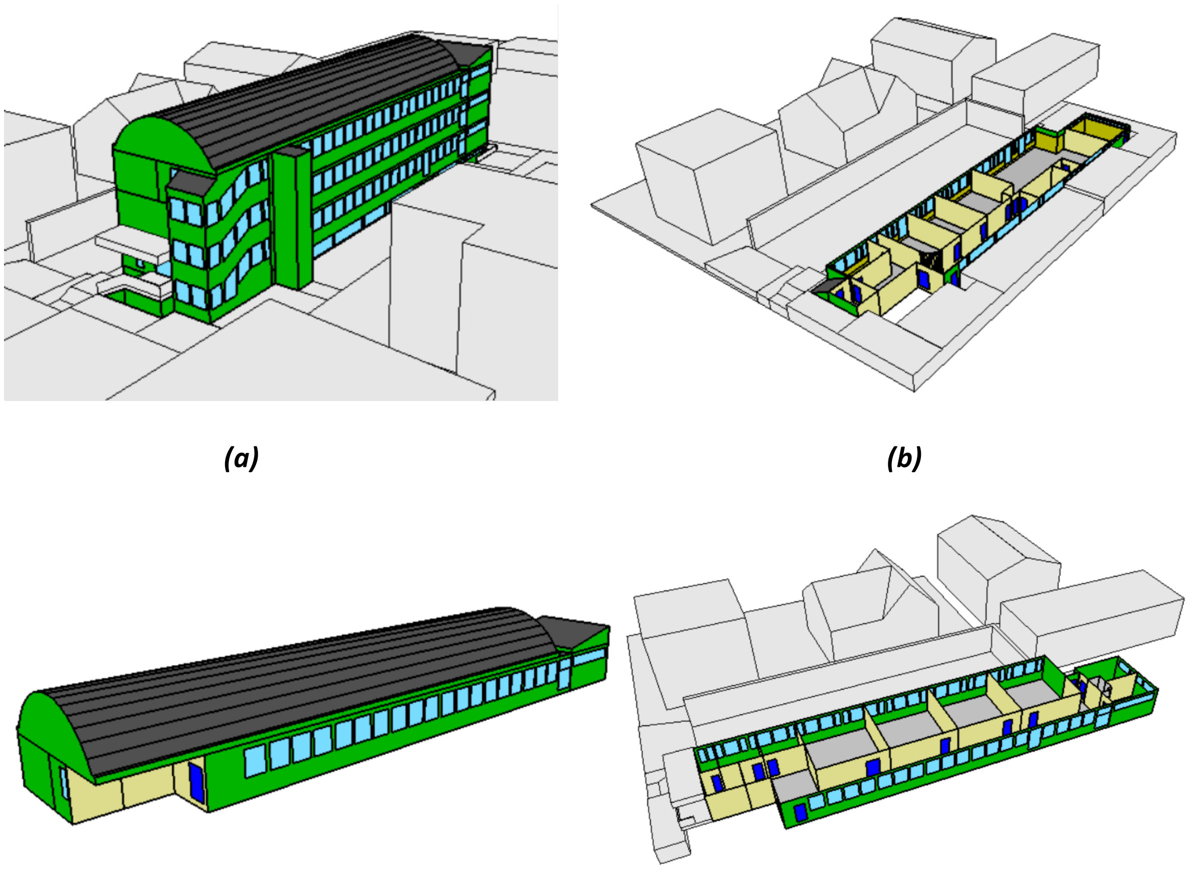
**Figure 51 During the DMV installation**

# 6 Modelling

## *6.1 Models' development*

Models for building dynamic simulations were realised for all Torre Pellice demo cases by using DesignBuilder Software [11], which allows exporting IDF files to input EnergyPlus simulations through the PREDYCE platform described in E-DYCE deliverables 3.1 [12] and 3.2 [13]. Further modifications to various aspects of the models (e.g., usage variations in occupancy schedules, HVAC setpoints, construction elements) can then be performed by exploiting PREDYCE functionalities, as described in previously mentioned deliverables, acting directly on the IDF file, in accordance to standard and standard-modified definitions included in the E-DYCE protocol described in deliverable D2.4 [14] or in agreement to actual building modifications for renovation purposes. In further paragraphs, the main model choices for all demo cases are highlighted, examples of needed changes following WP2 outcomes are presented, and finally, model verification procedures and results are deepened. As general rules, all models were realised with a multi-zone approach with room detail to try giving feedback to specific usages together with averaged results. However, the HVAC system was modelled through simplified EnergyPlus objects, which allow the definition of setpoints and the retrievement of net-envelope energies, named in EnegyPlus 'District Heating' and 'District Cooling' results, to which furtherly apply defined COP; also, lights were not modelled in detail. All buildings are characterised by random natural ventilation usage driven by end-users. Initially, schedule ventilation is assumed, even if the IDF's ZoneVentilation:WindandStackOpenArea object may be tested. The latter works with simple ventilation reducing model complexity. Additional information regarding the followed model methodology is reported in D5.1.

Torre Pellice Municipality school (B2,1) is quite a big building, developing over four floors, one of which is partially underground. The school has a north-oriented façade devoted to common circulation areas, while teaching areas are all built on the southern façade in line with basic bioclimatic principles. As a first approach, a complete model representing the whole building unit and surroundings was developed, as shown in Figure 52 (a). Still, the simulation time was considerable (almost 20 minutes for each simulation). Consequently, smaller models for each floor were realised separately, keeping for each of them significative surrounding elements, e.g., basement and ground floor, were highly impacted, especially on the southern façade, by shadowing buildings and nature, as shown in Figures 52 (b) and (c). In contrast, the last floor was impacted mainly by the roof structure, Figure 52 (d). In the smaller models, surfaces that should be in contact with other building elements were considered adiabatic to limit un-existing heat exchanges with the surrounding. Besides floors and ceilings, walls originally adjacent to stairs and the elevator were treated similarly. In addition to surrounding, other elements of a significant impact considering simulation results are the concrete elements positioned between windows that are solved in the model by adding fictitious shadowing elements (mainly fixed lateral fins) simulating the brought shadows. The subdivision of the school into four separate models, despite leading to significative benefits in terms of simulation time without leading to loss of accuracy in calibration results (see next section 6.2), makes more complex heating consumption analysis and calibration since two of the three radiator distributional lines presented in the school (the ones devoted to middle school and those dedicated to the former secretary) operate on three of the four floors. Hence, the total consumption of the floors has to be considered to be compared with monitored data.



*(a)* *(b)*

*(c)* *(d)*

**Figure 52 Building model of demo case n. 1, Torre Pellice Municipality school: (a) complete school model, (b) kindergarten model (basement floor), (c) ground floor model, (d) last floor model**

Figure 53 instead shows standard and standard modified schedules used for municipality school teaching areas considering occupancy and appliances. Standard modified schedules are mainly characterized by shorter daily usages especially in the middle school classrooms, with the afternoon mainly dedicated to cleaning activities. Moreover, middle school classrooms standard modified schedule (see Figure 53 (b)) was made more static (0.9 in occupied hours) and considering also (in the People object inside IDF file) the real number of students in that area, which was usually significantly higher than those considered by the standard, e.g., 0.185 people/m$^2$ versus 0.3 people/m$^2$. Concerning instead the kindergarten, adjusting occupancy standard modified schedules was a more difficult task which could lead also to future improvements in the next year data analysis: difficulties come mainly from the very irregular use of the teaching areas and from the different daily exit hours of the different children. In fact, not all children stay in the school till 16:30, but some go home for lunch and others after lunch, before the sleeping time, reducing the total number of children of almost half during the day. Also, the big room shown in Figure 53 (b) at the end of the corridor is mainly used in the afternoon for lunch and sleeping time, while the three smaller rooms (the first two of which are actually communicating through a mobile wall) are mainly used in the morning for playing activities together with the adjacent courtyard facing south. However, usages patterns (analysed through $CO_2$ monitored data in the room and inspection) were not so regular, consequently the final choice for now was to consider as if children (around 50) were distributed simultaneously in half of the teaching area space (corresponding to the three rooms, and separately the bigger room), such modifying the standard 0.26 people/m$^2$ to 0.35 people/m$^2$. Another difficult point, that could be also subject to further improvement, was the definition of ventilation schedules, to calibrate both temperatures and $CO_2$ emissions. In fact, due to government indications to face the covid-19 pandemic situation, teachers were invited to keep the windows always open, even in wintertime. This made difficult the definition of clear HVAC setpoints, especially in the kindergarten, and to balance $CO_2$ emissions. Also, the real behaviour was quite dependent from individuals and different classrooms in different hours behaved in different ways. Hence, for now, it was chosen to individuate average ACH values and acting on the outdoor temperature as activation threshold, as if windows were always open during occupied hours, giving preference to calibrate temperatures with respect to $CO_2$. However, since mechanical ventilation units have been recently installed in the building and equipped with possibility of fully remote control (June/July 2022), further analysis on $CO_2$ trends will be made in the last year of the project. Concerning instead appliances, shown in Figure 53 (c), schedules were not modified to standard modified profiles, since retrieving realistic information was too difficult.

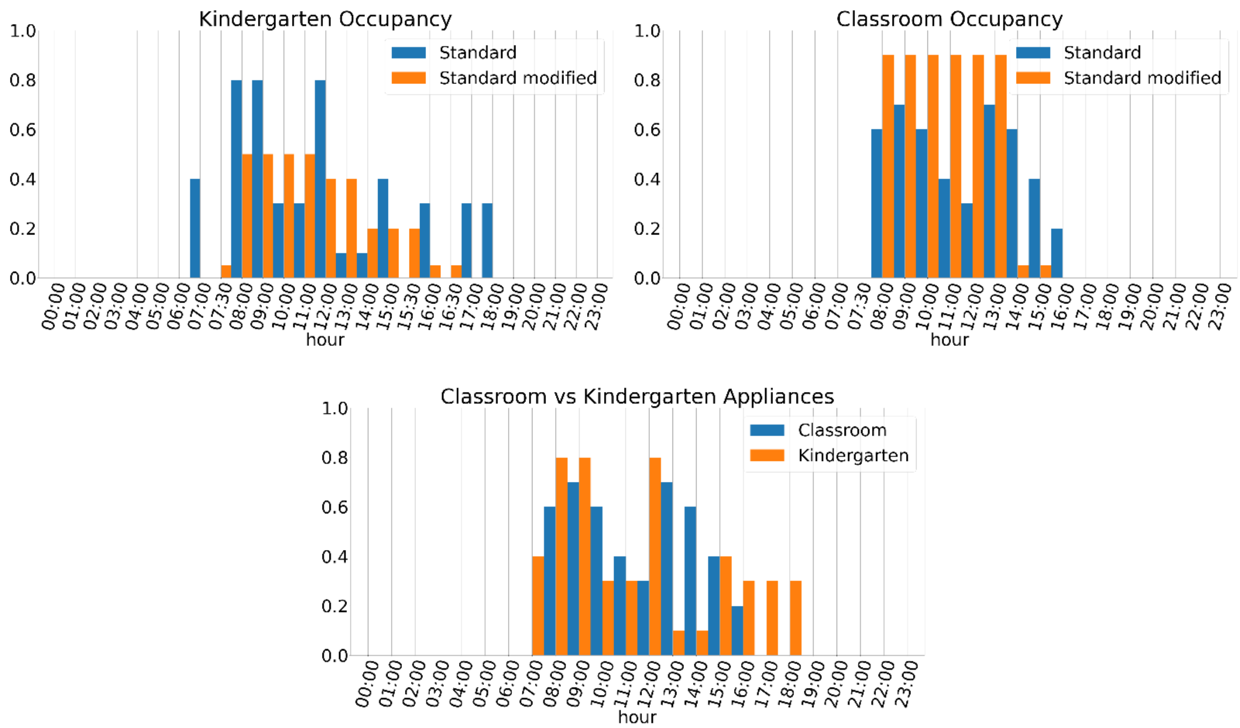
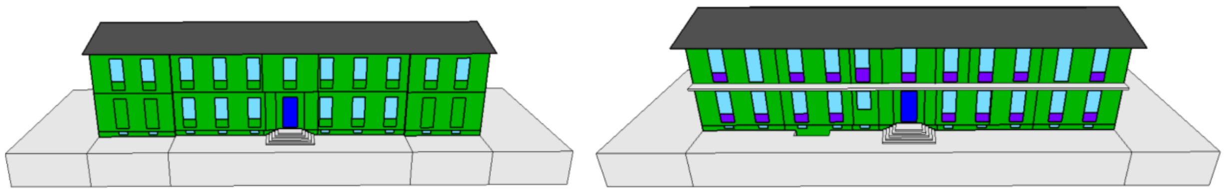



**Figure 53 Standard and standard modified usage schedules used for the municipality school (B2.1)**

The Liceo Valdese high school (B2.2) instead is composed of two floors shown in Figure 54, where (a) is the school entrance, while (b) is facing a big courtyard. All facades, except the southern one, are faced with high trees shadowing almost entirely the windows, particularly on the north and west sides. Instead, the east and south sides are provided with curtains to all windows to reduce the high solar contribution in hotter periods. Inside, the school is organised differently from a typical Italian high school, following a more American style: mainly, there are a few more significant teaching areas devoted to the study of different subjects (e.g., science, philosophy, English), which occupy especially the first floor and lateral parts of the ground floor, while central parts of the ground floor are partially devoted to offices and secretary spaces. The building is a historical building, characterised by very thick walls (almost 80 cm). However, it was recently lightly renovated by substituting all windows with double glazing systems maintaining the wooden frames, except for the three higher window doors facing south. A significant vertical air exchange also characterises the school because the stairs are located at the centre of the building and are not separated by any door from the rest of the distributional spaces.

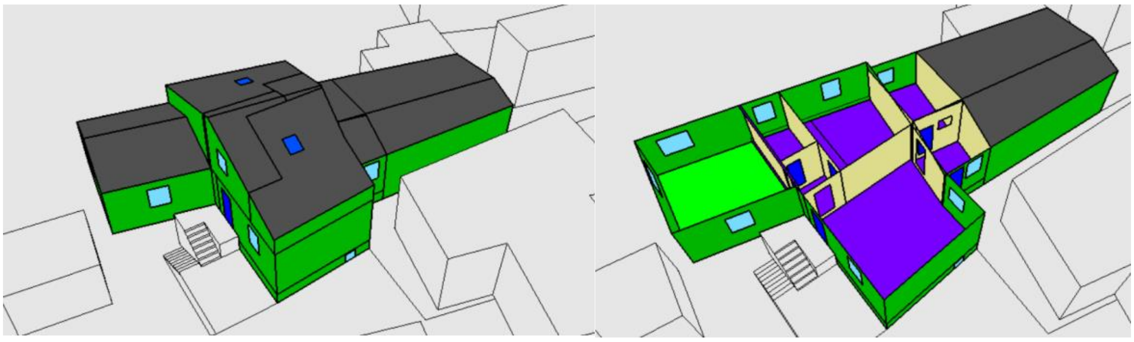
As reported in section 6.2, some problems occurred in calibrating the high school because of the very peculiar and complex internal geometry, needing further improvements and revision by re-defining the model using a different approach to manage wall-thickness. Hence, standard, modified schedules were still not defined in detail and needed additional post-elaboration studies of monitored CO2 data to determine the spaces' actual usages. However, standard schedules defined by WP2 in line with EN 16798-1 are not different from middle school classroom schedules shown in Figure 53.



*(a)* *(b)*

**Figure 54 Building model of demo case n. 2 (Valdese Highschool) north view (a) and south view (b)**

Concerning the residential demo cases instead, demo case B2.3 is a very particularly shaped single-family house (see Figure 55 (a)), developing over three main areas: a ground floor devoted mainly to family daily activities, a small area on the right part of the house composed only by a room and a separate entrance being dedicated to a working office, and small additional spaces with bedrooms. On the ground floor, Figure 55 (b), it is worth noticing the area with the green floor, which is the living room: it is suspended, and the area below is used as an open cars parking; moreover, it is the only part of the house with insulated walls, while the rest of the ground floor still keeps original materials. The upper floor walls instead presented a slightly different construction being a taller under-roof area. Hence to calibrate U-factors, three different materials for walls were considered.



*(a)* *(b)*

**Figure 55 Building model of demo case n. 3 (residential house n. 1) external view (a), ground floor view (b)**

Some basic considerations were made for residential buildings. Concerning usage schedules, each room was originally assigned with standard schedules for occupancy and appliances as shown in Figure 56. Then reasonings about standard modified occupancy were made separately for each demo case. However, generally, it was not possible to define a stable usage pattern for the houses since people's habits were variable both over the different weekdays and over time. Also, it was considered a useless effort to define room detailed schedules (e.g., day and night activities), also considering that CO2 sensors are not located in every house room, preferring average behaviours over the whole house. Also, during 2021 working habits were deeply impacted by lockdown periods which led to more remote working days than usual over the year and long quarantine periods for children, staying consequently home from school.

Concerning residential house n.1 (B2.3), two main changes were made at present to define a standard, modified occupancy: the four people living in the house were considered to occupy most of the time simultaneously the same area (e.g., the living area on the ground floor or the night area at the upper floor). Hence, the number of people per square meter was modified from the standard value of 0.0235 to 0.03, but the schedule was not altered. However, the most significant change concerned the office area located on the right side of the house bordering another apartment: since in that area are used to work one of the parents and an assistant during daytime working hours, people per square meter were increased to 0.2, and the schedule pattern was modified to consider an office usage from 8:30 to 17:30 with fraction 0.9, but also considering a lunch break between 12:00 and 14:00 setting schedule fraction to 0.5.

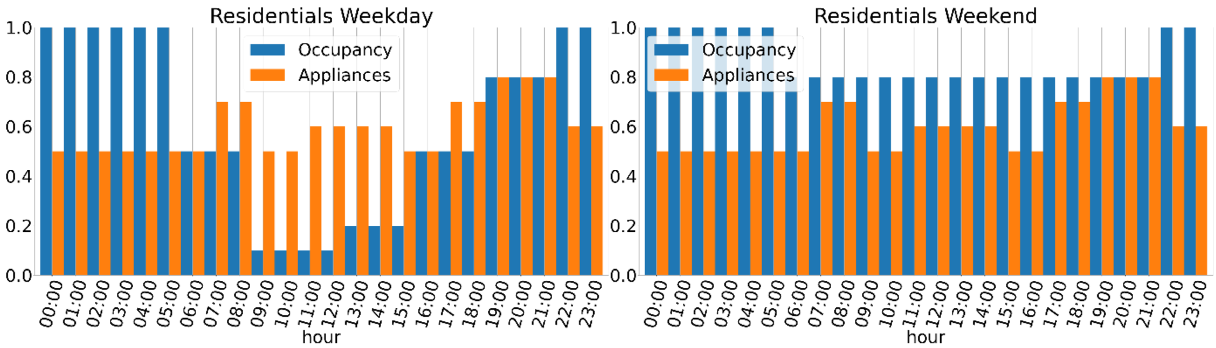
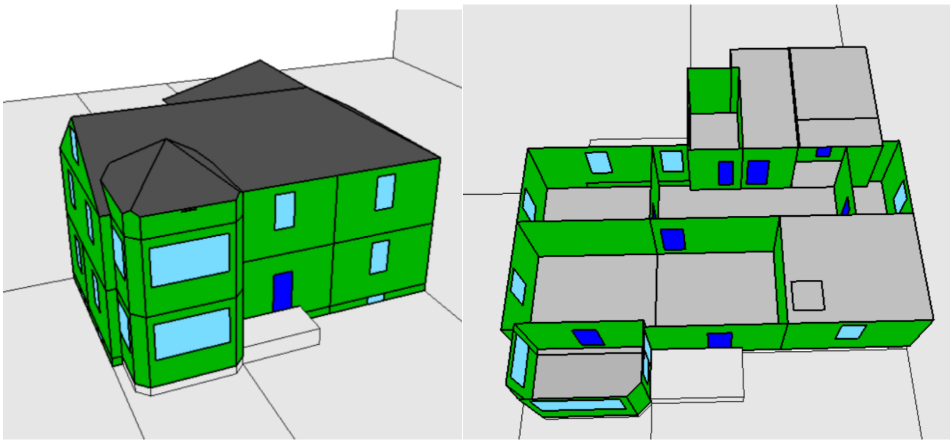



**Figure 56 Standard values for residential occupancy and appliances schedules over weekdays and weekends**

Regarding residential case n.2 (B2.4), it is a historical building (also subject to renovation limitations to preserve facades) partially inhabited by a family composed of four people. The parts of the house used by the family are the ground floor, shown in Figure 57 (b), and a bedroom and a bathroom on the upper floor above the room on the right corner. A small spiral staircase connects the two floors (see the small square on the corner room ceiling). The most important rooms are all facing south, while the ground floor bedroom also faces east but is partially shaded by a balcony. Internal rooms are mainly common circulation areas, bathrooms and small closets. Moreover, the main house staircase connecting the two floors faces north, but it is an unheated space. However, it is mainly unused as a circulation area but used as an additional closet. The kitchen has a bow-window shape, located on the ground floor inside the house tower: it is almost entirely windowed, and it is kept most of the time open to the living room, guaranteeing a visual connection with the front garden. The building was subject to renovation before EDYCE monitoring started, concerning the substitution of all windows with triple glazing low-E filled with Argon. However, some of the windows had to maintain also the original single glazing window for historical reasons, such as creating an air chamber between the two glazing systems. Moreover, at the end of January 2022, the ceiling above the southeast corner was insulated with the addition of 14 cm of glass wool rolls – see Section 7.1.



*(a)* *(b)*

**Figure 57 Building model of demo case n. 4 (residential house n. 2) external view (a), ground floor view (b)**

Concerning standard modified occupancy schedules, during weekdays, with children going to school and parents working outside the home, it was changed such that until 8:30, almost a full fraction (1) is kept. Differently, it is set to 0 until 16:30, then gradually until the evening, when it returns fully occupied. As also done for the previous demo case, it was considered that mainly the whole family stays in the same home area (kitchen and living room for daily activities, bedrooms during the night), so people per square meters number was set accordingly to 0.095. Also, HVAC setpoint schedules were adjusted to standard modified behaviour since they show a stable cyclic behaviour starting around 5:30 in the morning and stopping at 8:00, then starting at 5:30 p.m. and stopping at around 9:30 p.m.

The last residential demo case is composed of around 90 m$^2$ of inhabited area located inside a residential complex, see Figure 58. The house comprises two main areas: an older part belonging to the original complex and a newer part built ex-novo and devoted to living and office. The newer part of the building presents completely different construction materials from the older part, for what concerns roof and walls, being insulated and anti-seismic, and equipped with a floor heating system. The older part of the building is not thermally insulated and is heated with classic radiators. However, all the house windows were renovated with a double-glazing system. Another peculiarity of the house is that on the north side, the newer part faces a hill with a significant slope, such that it is rarely hit by the sun, even in summer during early morning or late afternoon. Also, a tree shadows practically all-day long the roof window. Below the house, instead, there is a garage, which is kept open most of the time in summer and is not heated in winter.

This demo case had the most irregular and complex pattern concerning standard modified occupancy. Also, only one room is equipped with a $CO_2$ sensor, but especially in summer, that room is kept most of the time completely open with high ventilation. Hence, defining a proper regular, modified schedule was impossible. Consequently, the final choice was to keep the standard schedule and change people per square meter to consider the only person living in the house (from 0.353 to 0.011 people/m$^2$). Also, further analyses are necessary to define an eventual heating schedule since heating the older part of the house is mainly performed through a wood stove.

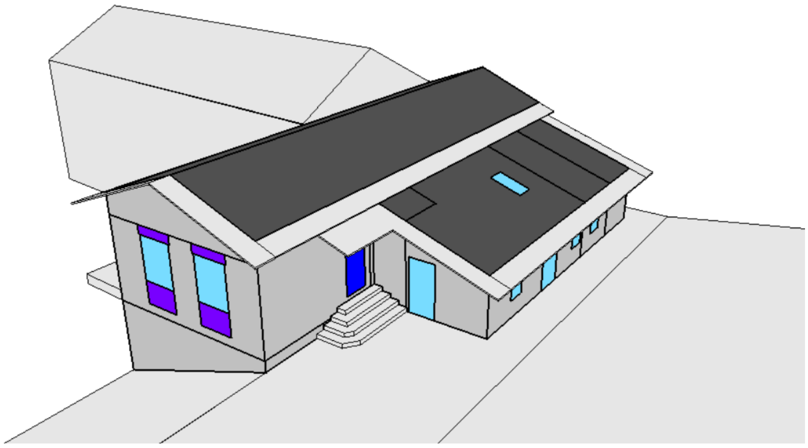


**Figure 58 Building model of demo case n. 5 (residential house n. 3) external view**

For all demo cases, other parameters considered in the definition of a standard, modified usage are the natural ventilation (ACH and schedule) and the presence of shadings: their definition is analysed separately for each demo case in the following section.

## *6.2 Verification process (calibration)[2]*

The model's verification process was performed exploiting PREDYCE functionalities described in deliverable 3.2. In particular, the adopted methodology has reference in [15]. It consists in minimizing a combined error measure, including RMSE (Root Mean Square Error) and MBE (Mean Bias Error) on a given variable (e.g., indoor dry bulb temperature), see eq 1.

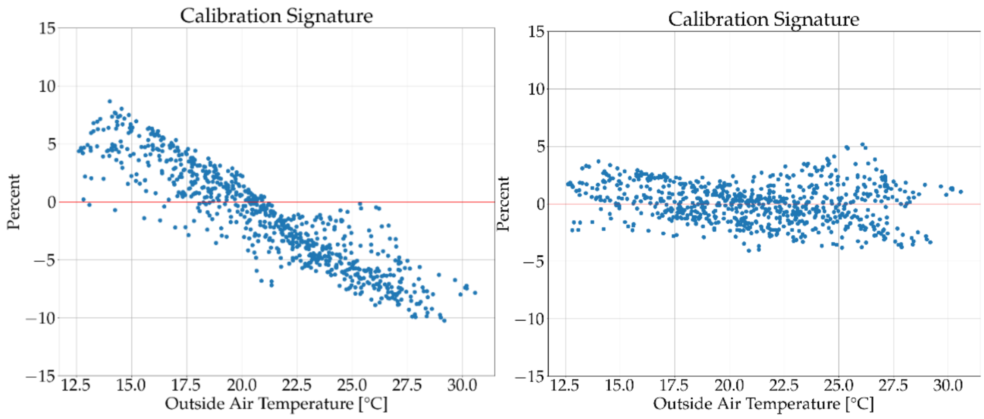
$$\mathrm{Error}_{\mathrm{tot}} = \sqrt{RMSE^2 + MBE^2} \quad (1)$$

The calibration signature, also described in [15], is computed according to eq 2, in which indoor dry bulb temperature is considered the objective variable.

$$\text{Calibration signature} = \frac{\text{measured } T_{\mathrm{db}}^{\mathrm{i}} - \text{simulated } T_{\mathrm{db}}^{\mathrm{i}}}{\max \text{measured } T_{\mathrm{db}}^{\mathrm{i}}} \cdot 100\% \quad (2)$$

Different IDF editing actions are applied parametrically to the models allowing to both shift the curve (e.g., acting on ACH, internal gains), change coefficient and inclination and modify amplitude variations (e.g., working on internal mass) to reach an almost flat line inside a 5% error range, which is in line with reference suggestions for model calibration – see for example ASHRAE Guideline 14-2014 for calibration criteria [16]. Figure 59 shows a generic example of calibration signatures plots before and after the calibration process.

[2] *NOTE: monitored data referred to 2022 are here considered till mid of July 2022, in line with the timeline of the development of this Deliverable.*




***(a)*** ***(b)***

**Figure 59 Example of calibration signatures: (a) starting point and (b) after model verification**

For now, the model verification process was mainly devoted to indoor temperatures, considering that the summer period (from mid-May to September) in the considered buildings is an entirely free-running period without any mechanical cooling or ventilation system. Moreover, as underlined above, heating data are only available from March 2022, requiring further analysis and adjustments to be performed during the 2022-23 winter season to also calibrate HVAC consumptions. First trials have also been made to calibrate $CO_2$ emissions in the municipality school, where occupancy patterns are better definable, but further improvements and analysis will be needed during the next project year, thanks also to the possibility of remote controlling the mechanical ventilation units' newly installed. Concerning residential $CO_2$ emissions instead, after different trials and tests, it was chosen not to calibrate this variable because it was impossible to define a formal room usage schedule and even monitor it in all used rooms. Consequently, considering the practical usefulness of possible behavioural improvement suggestions, it is regarded as a significant utility to suggest correct optimised ventilation strategies for the school. It could be enough for residential tenants to report punctual CO2 dangerous peaks and systematic analysis. These outputs may be supported by simulation results from the PREDYCE sensitivity scenario to suggest IAQ control strategies under standard and standard modified conditions. As a general note, it has also to be considered that the addition of internal mass inside the different models' thermal zones (performed through the insertion of a material with properties conductivity = 1.4 [W/m-K], density = 2100 [kg/m3], specific heat = 840 [J/kg-K], thermal absorptance [emissivity] = 0.9) was considered as a way to absorb the impact of different phenomena, e.g., the presence of furniture, eventual errors in envelope materials and masses, to align temperature peaks amplitude and shift concerning monitored. As defined by EnergyPlus software, the internal mass inserted in the zone is expressed as a percentage of the floor area.

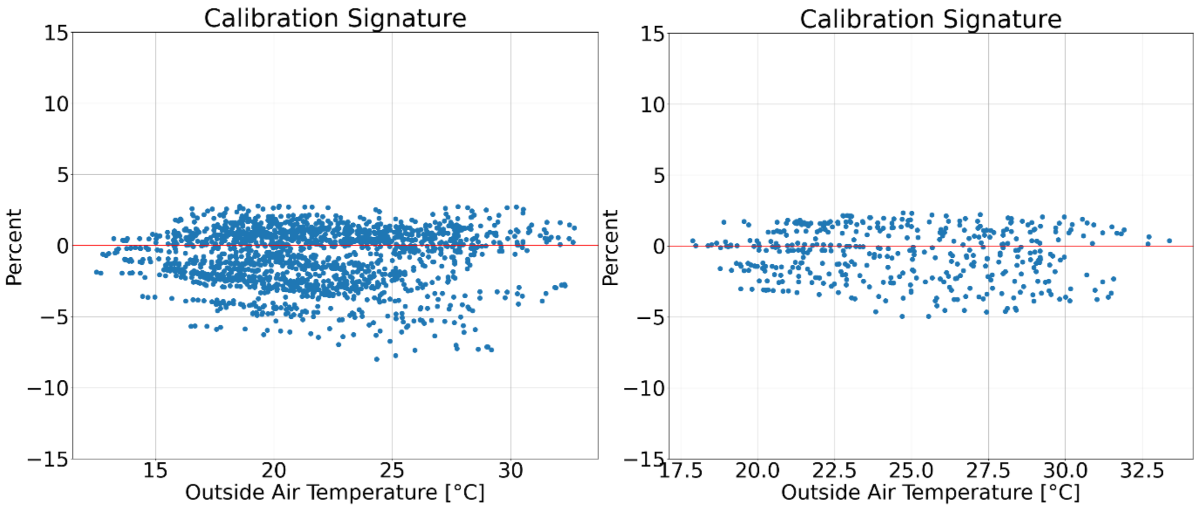
Moreover, for each model, we tried to optimise the error on averaged value over the whole building (or considering the most significant thermal zones) but without losing accuracy on the single rooms. The reasoning behind this approach was to understand the differences and complexity of a multi-zone approach with respect to a mono-zone and to try to maintain the possibility of giving room-related advice, especially in the school. Optimising the average, in fact, has the cons of having the opportunity to reach a balance without much physical meaning when looking at specific rooms. However, a wholly automated procedure is impossible if the shape of single rooms has to be maintained (despite what improves the average), hence human interpretation in each step, to choose which parameters to try, their range, which rooms to include and exclude, is significant. Although, if the sole mono-zonal approach (or building average) is maintained, such as in the current EPC, it is pretty simple to align building model behaviours via the PREDYCE semi-automatic scenario, even if this may lead to wrong local interpretation or verification assumptions that at building average can be balanced between zones. For this reason, and considering the interest in understanding this phenomenon, models have also been checked at room levels, such as mentioned above.

Current results of the performed calibration work led to the understanding that two of the eight analysed models still need a revision to obtain better results in terms of temperature. Notably, the Liceo Valdese high school gave good results in the average trend, but, when looking at room detail, this result lost in feasibility. The obtained average resulted from unbalances inside the simulated building concerning a more equilibrated measured behaviour. Hence, for this building, results will be only very shortly reported in the following. Although, future model upgrades will be needed and expected during the next project months. Moreover, the last floor of the municipality school (one of the four school models) gave several problems in maintaining a good trend for some of the tried time periods. In this case, the corridor (north faced) reached an optimal alignment, while the classrooms (south faced) were quite distant from monitored behaviour. Possible causes were found in wrong heat exchange with the roof and with the possibility of the presence of insulation on the ceiling, which did not result during the initial data collection phase. Hence, further improvements are needed for this model, considering that aligning classroom behaviour is considered of high importance.

Entering in detail the model verification process, for demo B2.1 – the Torre Pellice municipality school – four models were calibrated separately for the four floors using as calibration period a part of the 2021 summer when the school was almost entirely unoccupied and hence natural ventilation off. Starting from the basement, where the kindergarten is located, the considered calibration period for indoor dry bulb temperature is from the 15$^{th}$ of July to the 15$^{th}$ of August 2021. This choice is because even if school ends officially at the end of June, at the beginning of July, a transition period not entirely in line with the simulated empty floor was found. Concerning the municipality school, although the four floors were calibrated separately, various elements were considered physical constraints. For example, windows are the same everywhere, and the U-value of external walls is the same for the three floors above ground. At the same time, since the kindergarten has different construction elements, it was treated as independent. For the whole school, it was also chosen to substitute the north surrounding obstacles with a fixed shade over the corridor since it is never interested in direct solar irradiation (except for 10 minutes in summer early mornings only on the last floor). At the end of the calibration process, the best-founded values for the municipality school basement are:

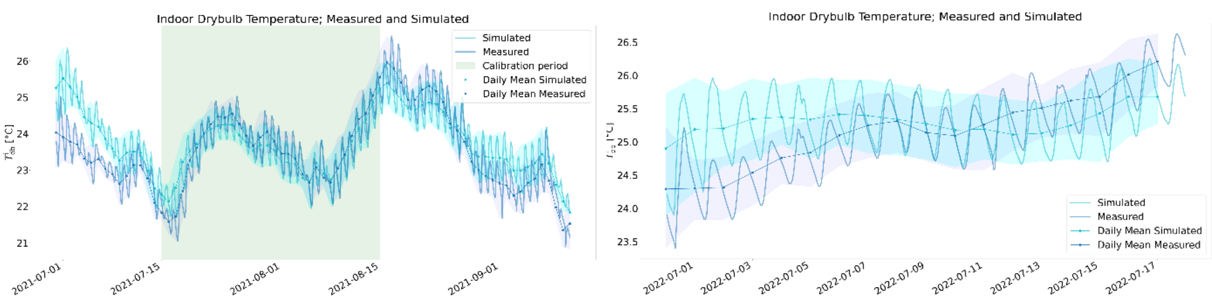
- Windows U-factor = 1.782 W/(m$^2$K) and SHGC = 0.5528;
- U-factor walls = 0.66 W/(m$^2$K), U-factor floor = 0.24 W/(m$^2$K);
- Average Infiltration ACH = 0.81;
- Internal mass in the different classrooms (with reference nomenclature to Figure 38): act201aa = 1000%, act201ab = 1500%, act201ac, act201ad = 2000%.

Figure 60 shows how the founded calibration values allow maintaining in terms of calibration signatures the obtained results over summertime (unoccupied periods), considering both summer 2021 and 2022. Figure 61 instead shows temperature trends over the same period: in both summer 2021 and 2022. The assessment period at the beginning of July is here visible. Figure 62 describes in detail classroom behaviours: not all of them show the same accuracy in maintaining the trend, but overall results are satisfying also in terms of the detailed multi-zone model.




*(a)* *(b)*

**Figure 60 Calibration signatures for B2.1 – municipality school basement floor (kindergarten) during unoccupied period summer 2021 in (a) and 2022 in (b)**




*(a)* *(b)*

**Figure 61 Simulated and measured average temperature trends for demo B2.1 – municipality school basement floor (kindergarten) in unoccupied period summer 2021 in (a) and 2022 in (b)**

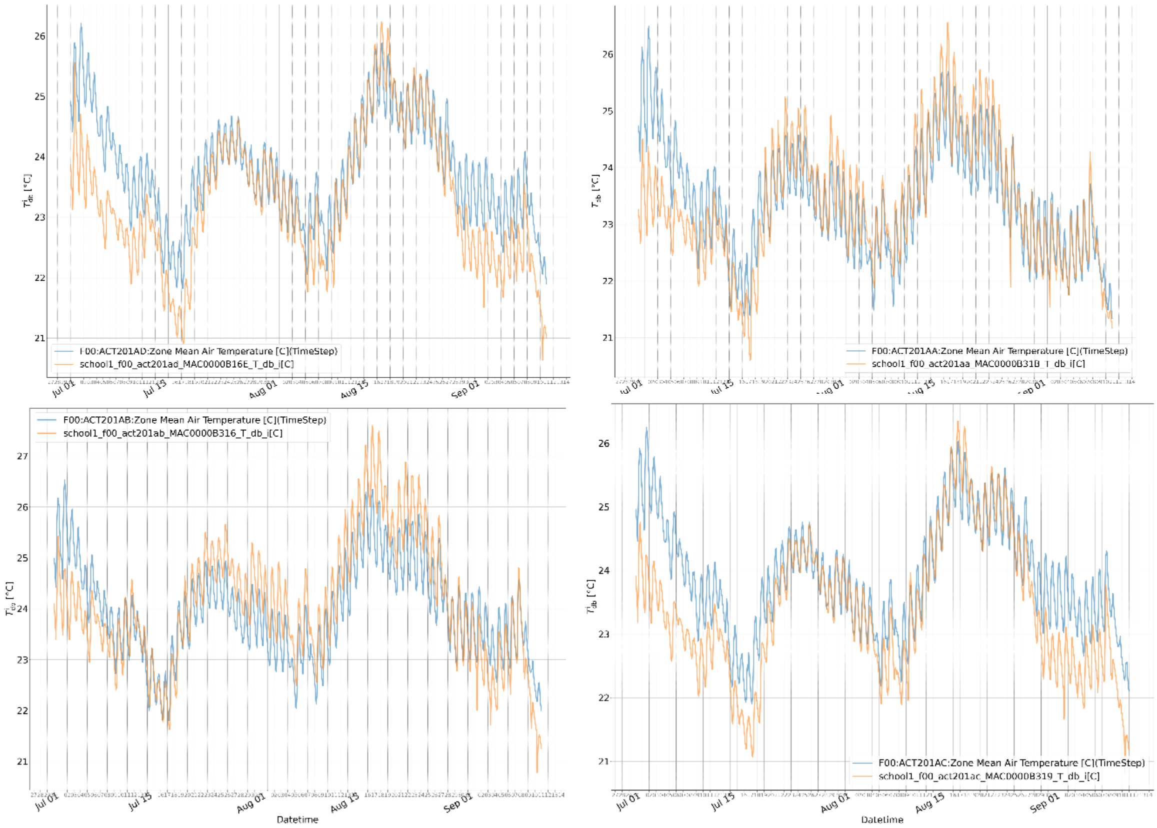
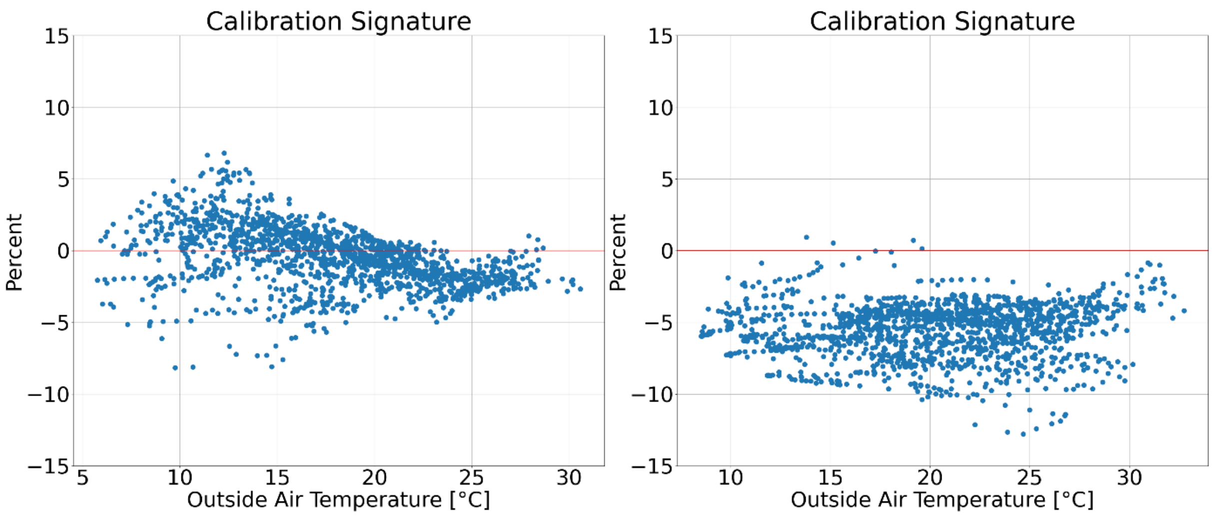


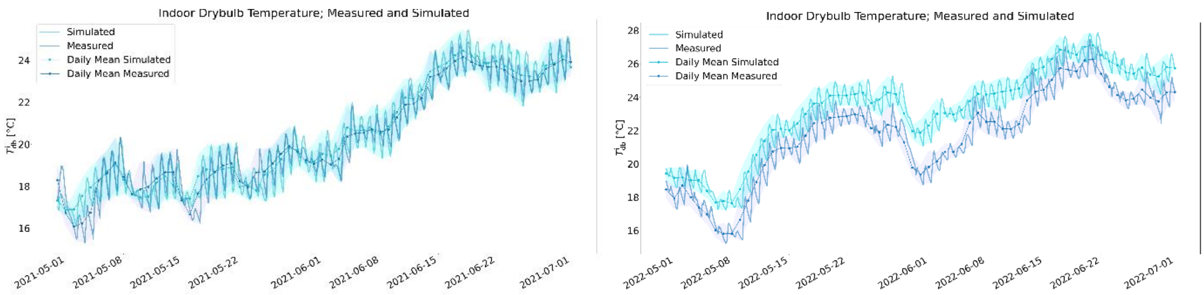

**Figure 62 Simulated and measured temperature trends with classrooms detail for demo B2.1 – municipality school kindergarten – during unoccupied period summer 2021 in (a) and 2022 in (b)**

In the further verification step, occupied periods were considered. May to June 2021 was used to test the validity of the standard modified model setting as described in the previous section. Also, an average value of 2.5 ACH in occupied hours was found to maintain the temperature trend in the considered period. However, although founded values allow following the trend very well in 2021 (also with classrooms detail), accuracy is not maintained in the same period in 2022. This is shown in Figure 63 in terms of calibration signature and in Figure 64 by analysing the average trend. In May-June 2022, measured temperatures result be significantly lower than simulated ones, with around 2°C of difference in worst cases. Some tests were made increasing ACH (from natural ventilation) impact on 2022, considering the implications of Covid-correlated window-suggested opening procedures. Nevertheless, even by doubling this value, the trend could not be re-aligned but only slightly approached. Consequently, further analysis on behavioural differences has to be performed in the following, especially if September 2022 will result in being poorly aligned.




*(a)* *(b)*

**Figure 63 Calibration signatures for demo case n.1 – municipality school basement floor (kindergarten) in occupied period May-June 2021 in (a) and 2022 in (b)**




*(a)* *(b)*

**Figure 64 Simulated and measured average temperature trends for demo case n.1 – municipality school basement floor (kindergarten) in occupied period May-June 2021 in (a) and 2022 in (b)**

Figure 65 shows the average temperature trend in the heating periods 2021 and 2022. Setpoint value and schedule were optimised considering 2021 data: setpoint was set at 17.5°C and setback at -50°C (heating off) while working hours were set from 7:00 to 17:00. Moreover, the outdoor temperature threshold for natural ventilation during occupied hours was set to 0°C. The trend is followed particularly well in all winter 2021, from October to December, and maintained in winter 2022, except in April, where, as it also happens in May and June 2022, monitored results start to appear significantly lower than simulated. In addition to this point, it can also be noticed that, especially on weekends, despite the heating being off, simulated temperatures do not reach as low as monitored ones. Hence, further analysis and inspection, also considering natural ventilation/infiltration, may be considered during the last project year.

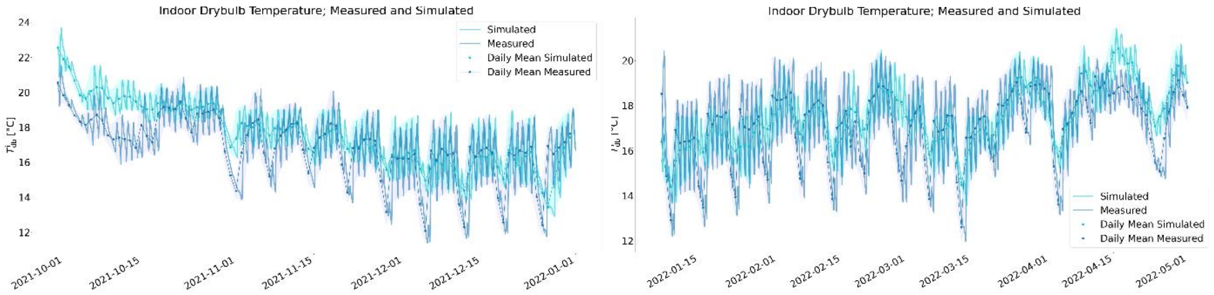



**Figure 65 Simulated and measured average temperature trends for demo case n.1 – municipality school basement floor (kindergarten) in heating period autumn-winter 2021 in (a) and winter-spring 2022 in (b)**

Considerations about the heating consumptions for all demos will follow in the further D5.6, considering that heat meters have been installed only in last months of the winter 2021-22 seasons. This check will start by setting room temperatures forcing measured values as local set-points to verify the simulated consumptions in respect to the monitored ones. This action may help in finalize specific values connected to user behaviours during the winter season and to verify average local emission, distribution and control losses.

Regarding $CO_2$, Figure 66 shows some performance gap tests over two weeks in summer 2021 for one of the classrooms. As visible, even actual behaviour (green dotted line) is very different in the two weeks, probably because of varying ventilation habits and the number of effective children in the room. However, these patterns are very difficultly to follow by standard and standard modified behaviours, even if the modified one performs slightly better.

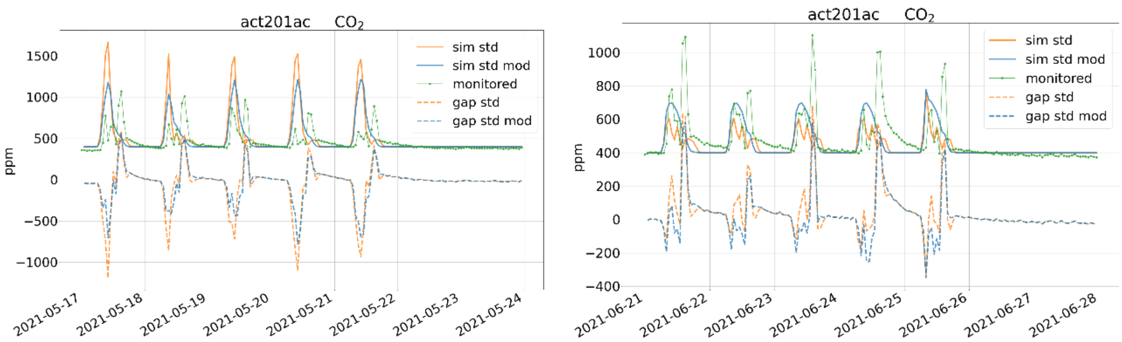
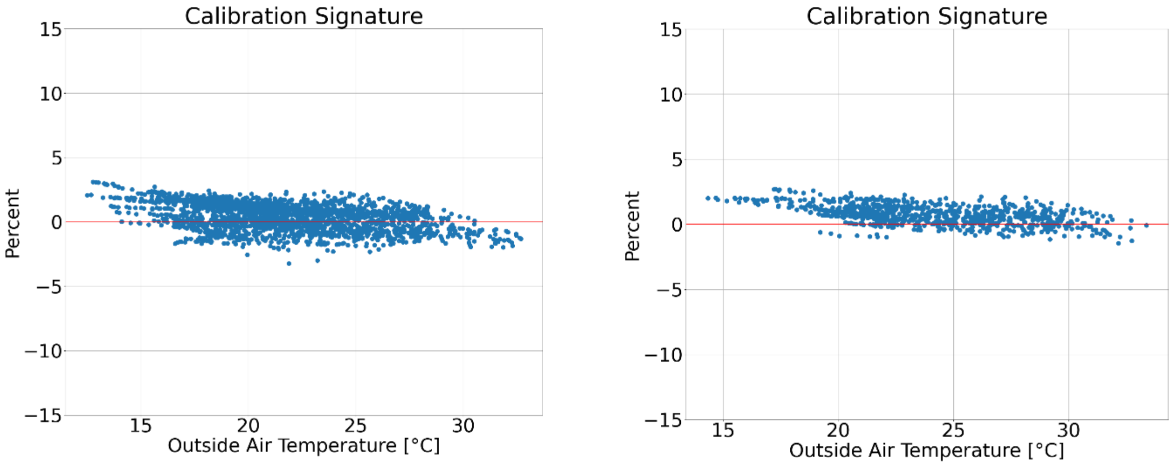



**Figure 66 Timeseries CO2 values in kindergarten act201ac thermal zone**

Considering the ground floor of the municipality school (Middle school) instead, the considered calibration period for temperature is from 15th of July to 15th of August 2021, since despite school ends in mid-June until July, this floor could still be used for final exams and then for administrative purposes and hence it could be randomly ventilated. Calibration results obtained on this floor were used as a starting point to analyse standard parameters on the other floors (e.g., for windows and opaque envelopes). Mainly obtained results are:

- Windows U-factor = 1.782 W/($m^2$K) and SHGC = 0.5528;
- U-factor walls = 0.64 W/($m^2$K);
- Average Infiltration ACH = 0.7;
- Internal mass in the classrooms: 1000%, corridor: 500%.

- Figures 67 and 68 show how obtained results maintain over summertime 2021 and 2022, in terms of calibration signature and trend: the trend is followed very well in both cases, getting more stable results concerning the basement floor.




(a) (a)

**Figure 67 Calibration signatures for demo case n.1 – municipality school ground floor in unoccupied period summer 2021 in (a) and 2022 in (b)**

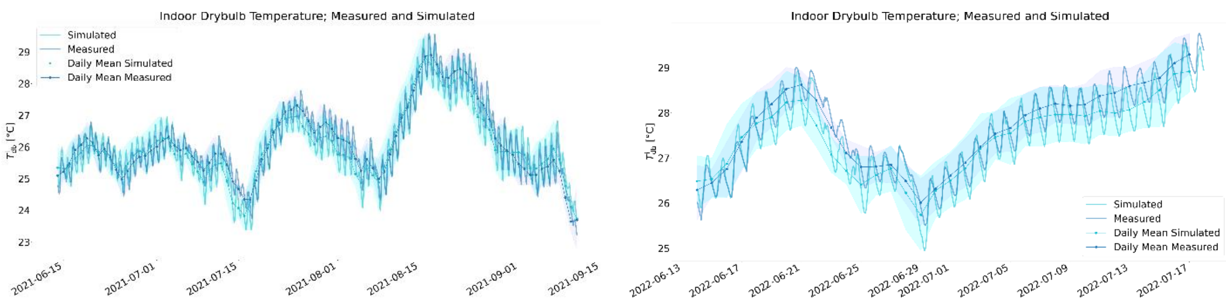
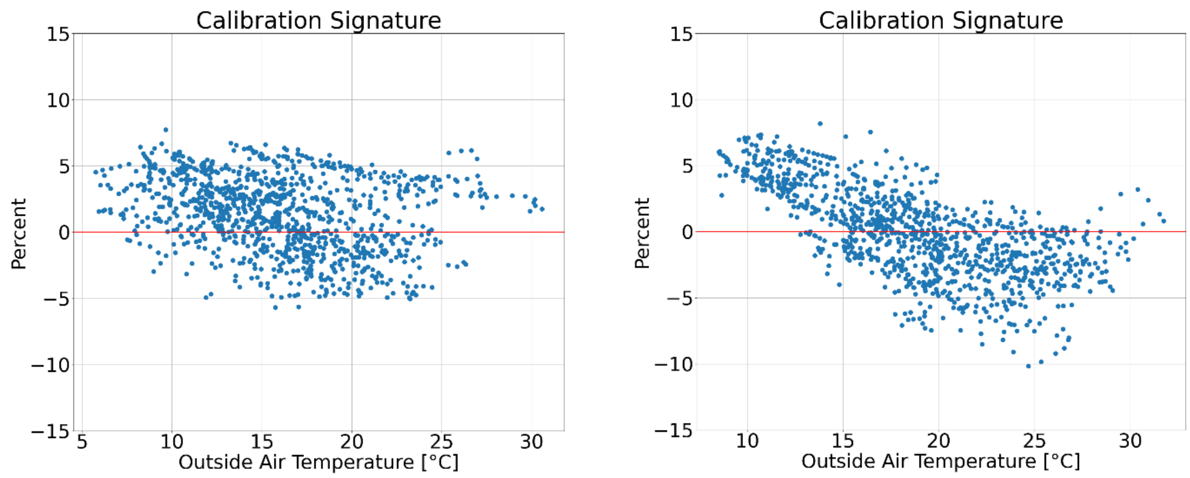


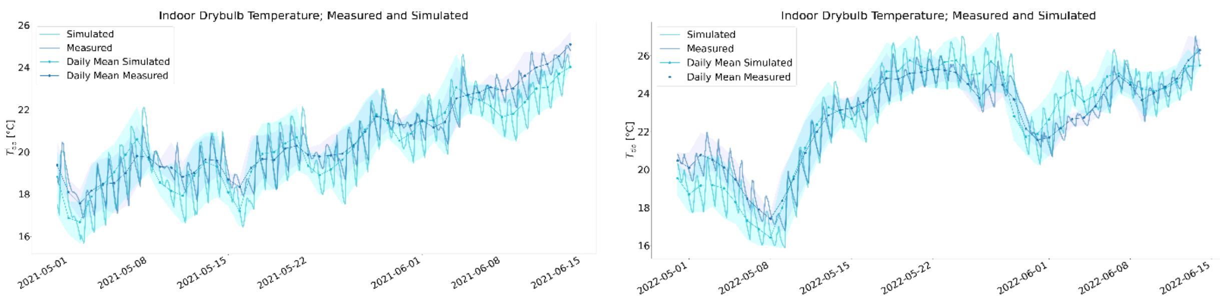

**Figure 68 Simulated and measured average temperatures' trends for demo case n.1 – municipality school ground floor in unoccupied period summer 2021 in (a) and 2022 in (b)**

The occupied period in May-June 2021 has been used to test standard modified conditions and set ventilation. Average ventilation with an always-on schedule was set to 2.5 ACH in the corridor and 1 ACH in the classrooms. Figures 69 and 70 show how the aligned trend of 2021 is also maintained in the same period of 2022. Moreover, Figures 71 and 72 detail classroom behaviour in the spring of 2021 and 2022: the trend is very well held in all classrooms for both years, and it is also similar in all classrooms, suggesting that people's behaviour is very similar over the floor.



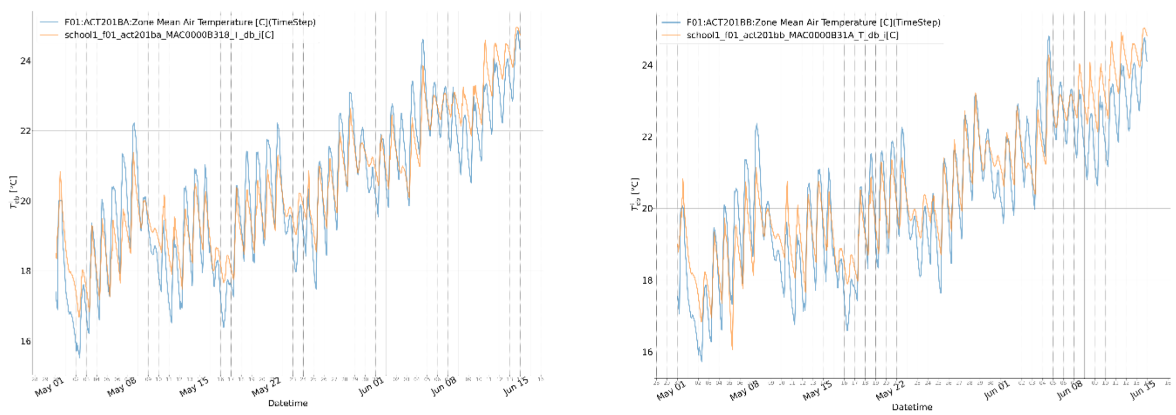

(a) (b)

**Figure 69 Calibration signatures for demo case n.1 – municipality school ground floor in occupied period May-June 2021 in (a) and 2022 in (b)**




*(a)* *(b)*

**Figure 70 Simulated and measured average temperature trends for demo case n.1 – municipality school ground floor in occupied period May-June 2021 in (a) and 2022 in (b)**



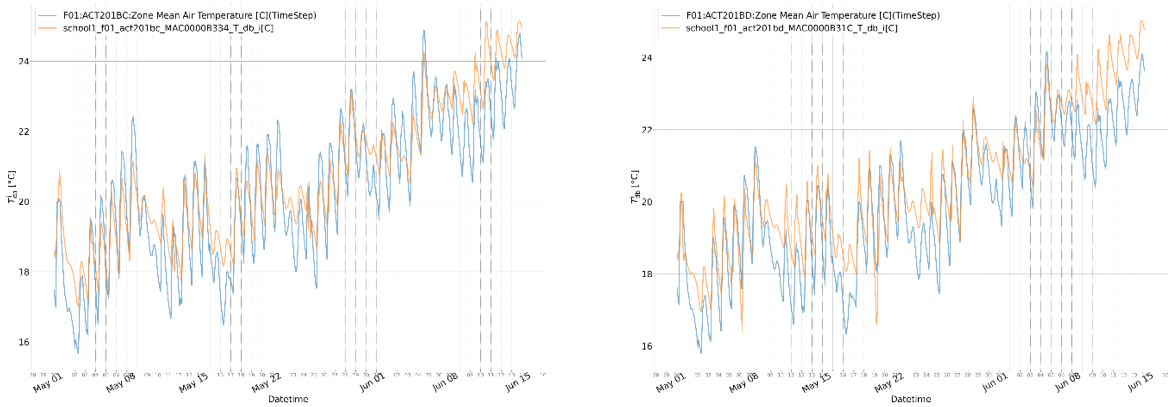



**Figure 71 Simulated and measured temperature trends with classrooms detail for demo case n.1 – municipality school ground floor in occupied period May-June 2021**

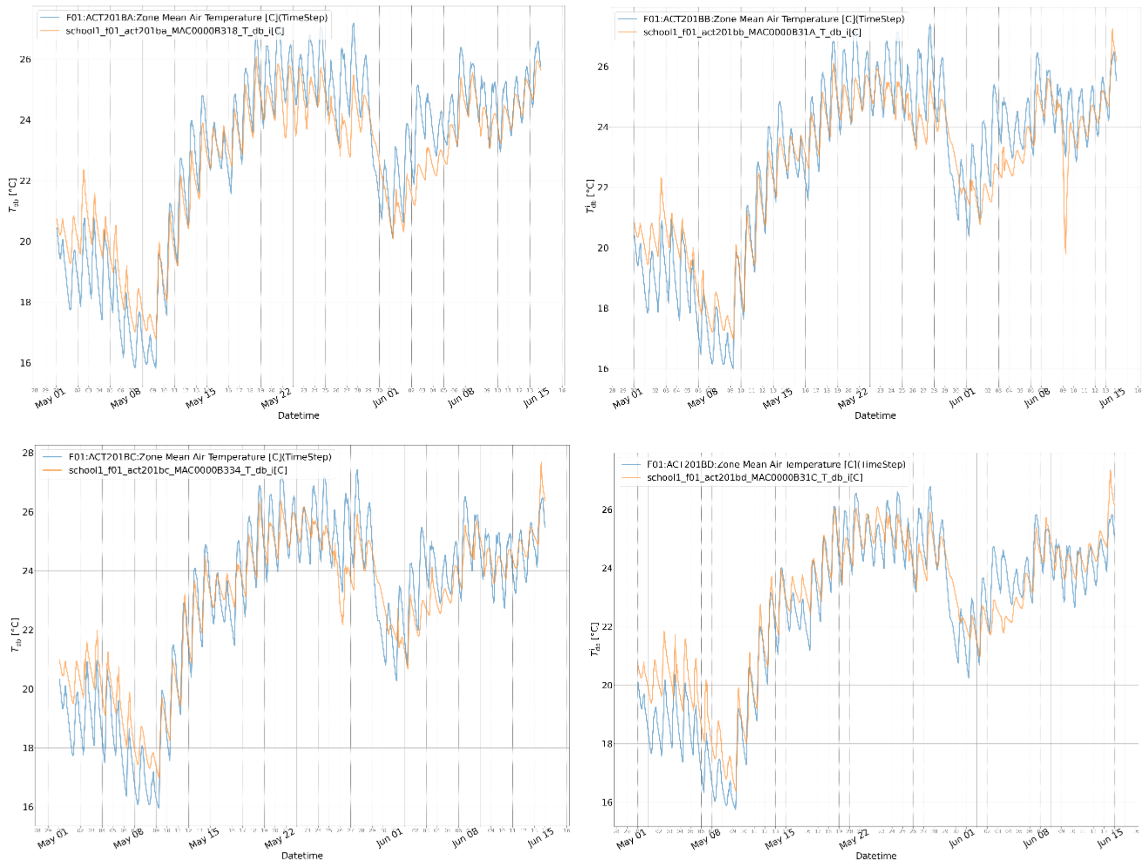
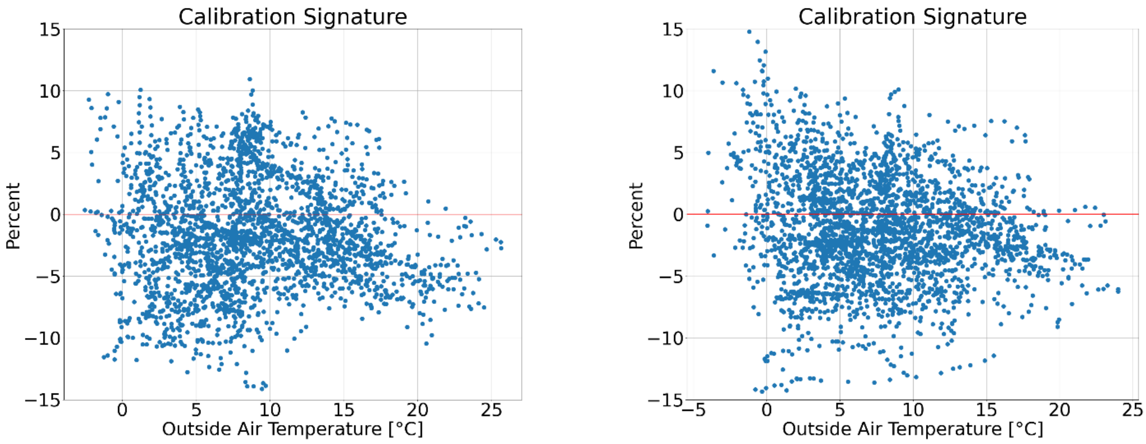


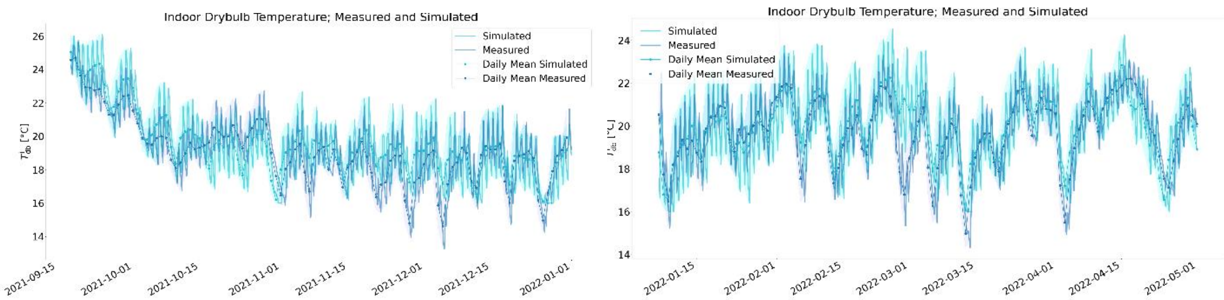

**Figure 72 Simulated and measured temperatures' trends with classrooms detail for demo case n.1 – municipality school ground floor in occupied period May-June 2022**

The heating setpoint and schedule have been verified to follow the winter temperatures trend. For all middle school floors (based on winter 2021), it was chosen to set a set point of 20°C, active on weekdays from 7:00 to 17:00, and a setback of 16°C. Also, the minimum outdoor temperature to allow natural ventilation was set to 13°C. Figures 73 and 74 show how these choices allow the simulations to follow the trend of heating seasons 2021 and 2022. It is possible to mention that simulations better follow the monitored temperature trends on this floor than in the kindergarten case. Nevertheless, in this building, winter behaviours may face considerable differences from simulations since simulations will forcedly follow chosen setpoints, despite any adopted ventilation strategies. Differently, room measured data are more subjected to oscillations since the actual setpoint is checked by the heating system in the specific point hosting the temperature probe (for middle school, this is positioned at the corner of one of the corridors). Nor rooms nor radiators have local control systems, so local thermal behaviours during the heating system do not combine radiator powers with internal gains and ventilation losses. In general, measured temperature behaviour (if simulated setpoints are correct) can be colder than the simulated one when high local ventilation rates are performed by continuously window opening. The ground floor heating system is linked, as previously described, to the heating circuit of the upper floors. Hence, the results of heating use of the three floors have to be considered together and compared with the measured consumption coming from the two circuits: the middle school one and the former secretary one. An approach similar to those described for kindergarten will be applied during the following months of data analysis.




(a) (b)

**Figure 73 Calibration signatures for demo case n.1 – municipality school ground floor in heating period autumn-winter 2021 in (a) and winter-spring 2022 in (b)**




*(a)* *(b)*

**Figure 74 Simulated and measured average temperature trends for demo case n.1 – municipality school ground floor in heating period autumn-winter 2021 in (a) and winter-spring 2022 in (b)**

Concerning $CO_2$ emissions, applied modifications for standard-modified settings allow for simulating a smooth peak over the occupied period, mainly due to the average ventilation rate applied all day to calibrate temperatures. The peak trend is also impacted by other ventilation rules, e.g., minimum outdoor temperature, especially in transitional periods between different seasons. Figure 75 shows how, even considering weeks in quite different periods, the average emissions trend is well maintained. However, actual behaviour is highly more variable than simulated one because of the variable manual windows opening schedule, which leads to more punctual higher peaks and rapid descents. Also, it has to be considered that students are not always present in the rooms because of physical education hours or multimedia lab visits, which are not predictable. Figure 76 shows how this average trend results from very different behaviours in the specific classrooms, which somehow compensate for maintaining a global balance. However, punctual classroom errors can be pretty high (e.g., with peaks of 2000 ppm). Figure 76 also shows with more detail the impact of the different ventilation strategies applied in the other rooms: each room is handled by different teachers according to individual perceptions, which lead to quite variable and unpredictable patterns during the year. This evidence is increased during the monitored period because of COVID-19 regulations suggesting opening the windows often. Some trials have been performed to define with more detail ventilation scheduling in the ground floor classroom equipped with mechanical ventilation unit obtaining good results in also following hourly peaks variations but repeating the same procedure for all rooms will result in a vast and not so meaningful effort (considering human variability in defining when to open the windows over time).

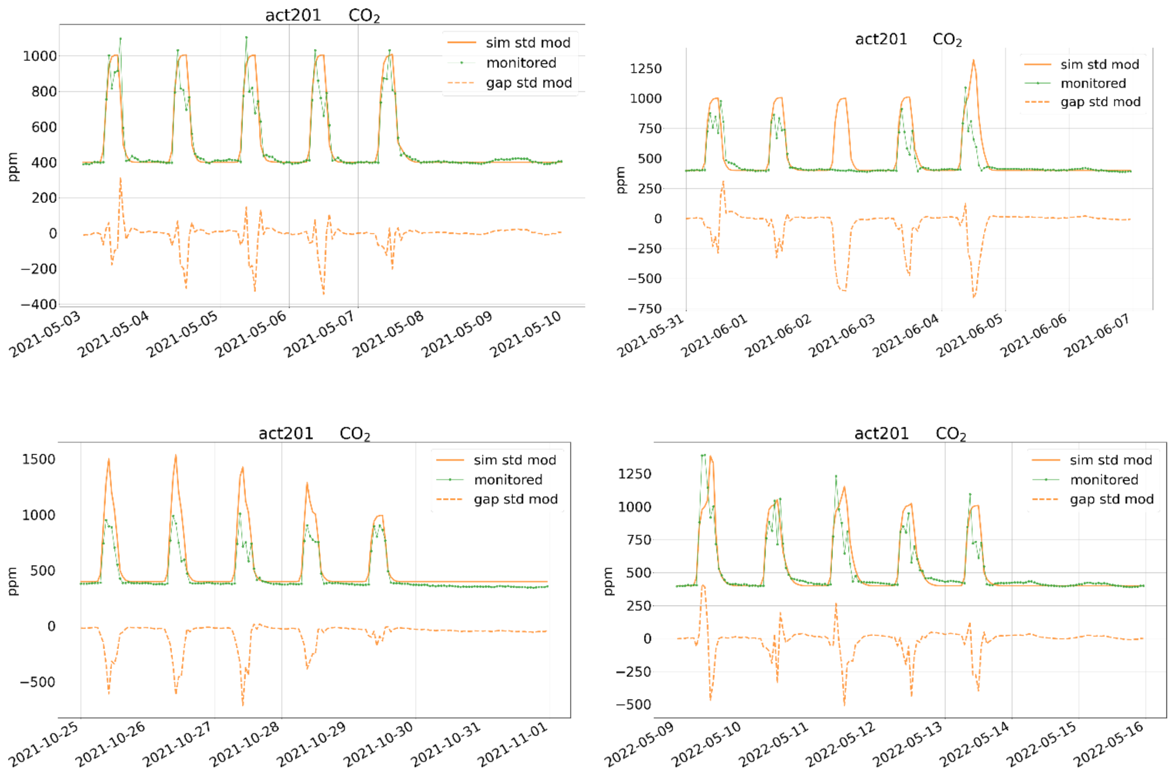



**Figure 75 CO2 emissions averaged on municipality school ground floor classrooms in different weeks of the year, in both 2021 and 2022 occupied periods**

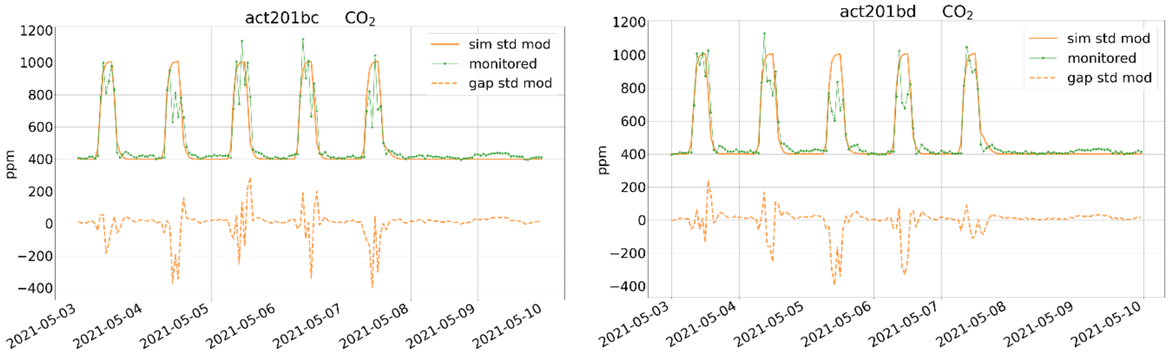
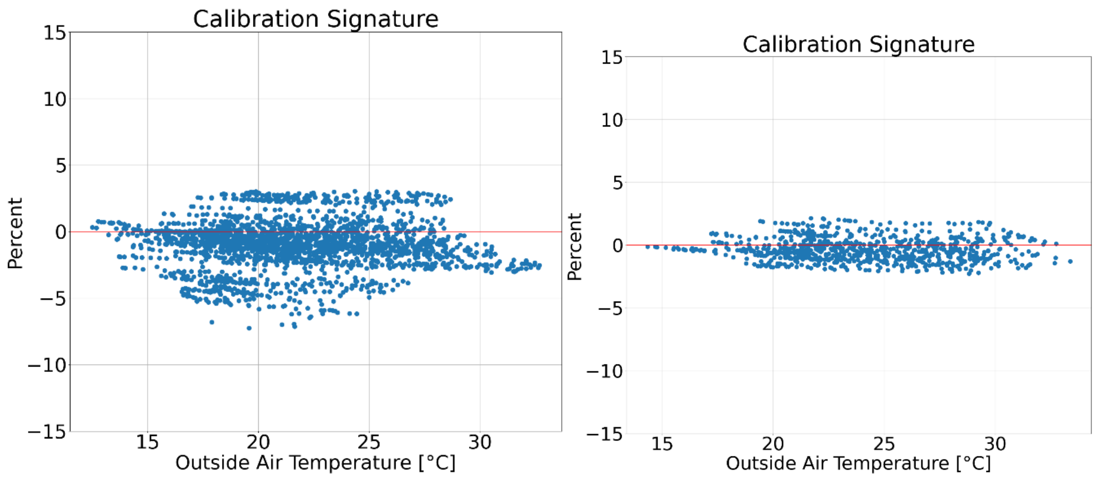



**Figure 76 CO2 emissions in all municipality school ground floor classrooms in a specific week of the year**

Proceeding with the other middle school floors, Figures 77 and 78 show how by applying the values obtained during the calibration period, i.e., from 15th of July to 15th of August 2021 (it was chosen to maintain the same period motivated for the previous two floors), the simulation trends maintain over summertime 2021 and 2022 a correct behaviour. Found values for calibration (U-factor and windows values are the same as on other floors) are:

- ACH infiltration = 0.7;
- Internal mass was set to 1800% for all classrooms, except for act201ce, for which it was set 1200%, the corridor instead was set to 800%.




***(a)*** ***(b)***

**Figure 77 CO2 emissions in all municipality school ground floor classrooms in a specific week of the year**

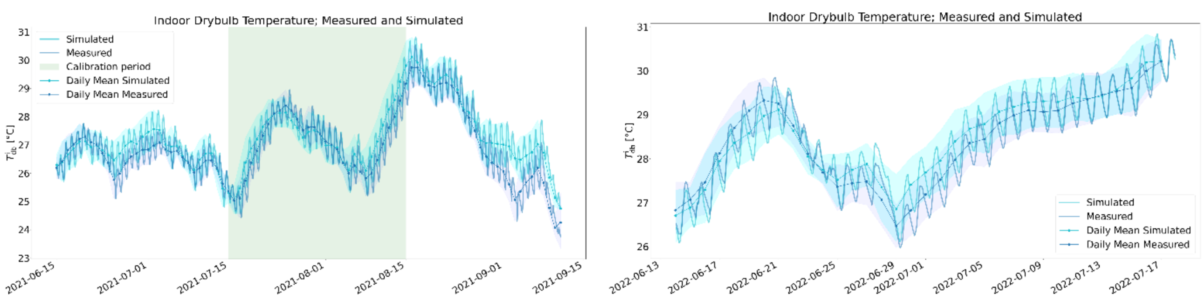
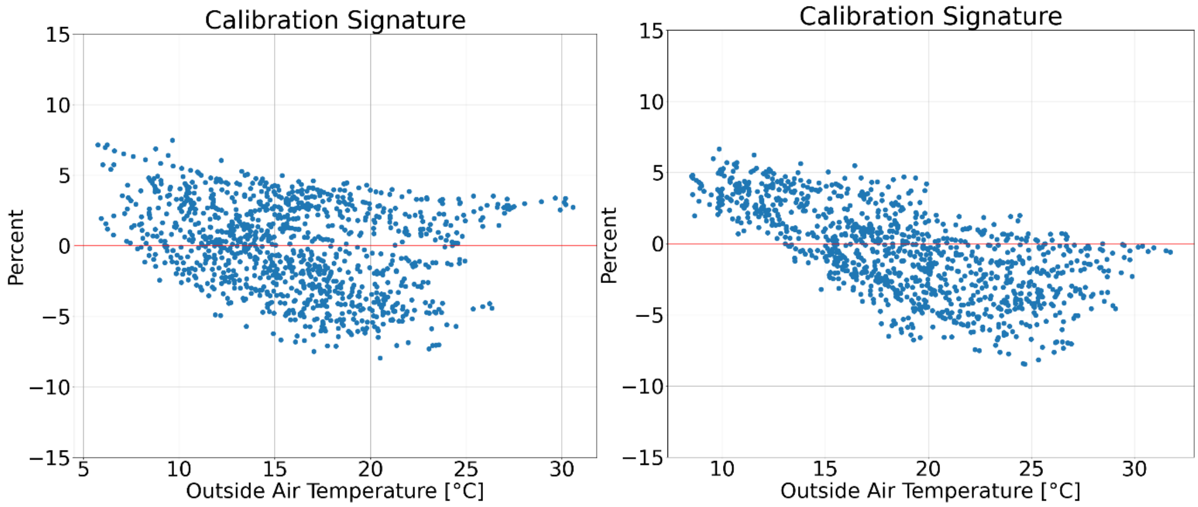



**Figure 78 Simulated and measured average temperature trends for demo case n.1 – municipality school first floor in unoccupied period summer 2021 in (a) and 2022 in (b)**

Instead of May-June, optimal values for standard modified schedules and ACH ventilation were the same for the ground floor (2.5 ACH for corridor and 1 for classrooms). However, as seen both from sparser calibration signatures in Figure 79 and from average trends in Figure 80, results are slightly worse than the ground floor ones. In particular, peaks amplitude in the occupied period is smaller in monitored data than in simulated ones. Nevertheless, peak amplitude re-aligns in summer 2022, as seen before. Moreover, as shown in the following, the problem is accentuated for the last floor (which is directly under the roof). However, the average trend is maintained correctly in the May-June period for both years. If this issue is underlined during winter 2022-23, a deeper verification of ventilation scheduling profiles may be considered.




***(a)*** ***(b)***

**Figure 79 Calibration signatures for demo case n.1 – municipality school first floor in occupied period May-June 2021 in (a) and 2022 in (b)**

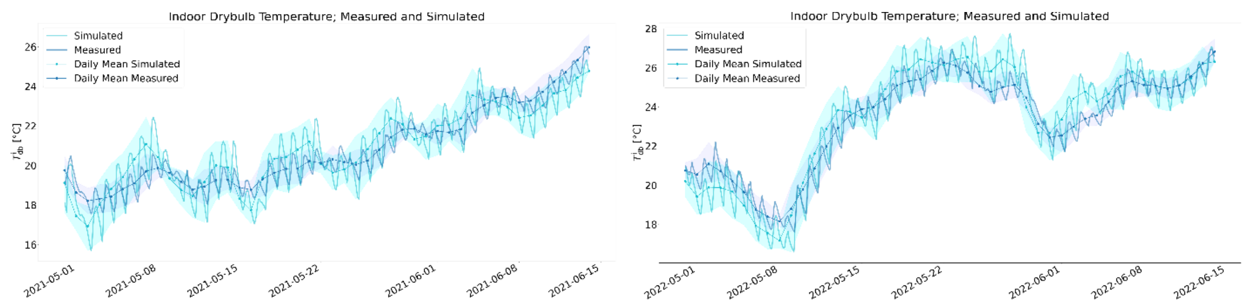



**Figure 80 Simulated and measured average temperature trends for demo case n.1 – municipality school first floor in occupied period May-June 2021 in (a) and 2022 in (b)**

Similarly to the ground floor, temperatures are maintained for the 2021 and 2022 winter seasons – see Figures 81 and 82 – applying the same heating setpoint and scheduling since the same thermostat also handles this floor.

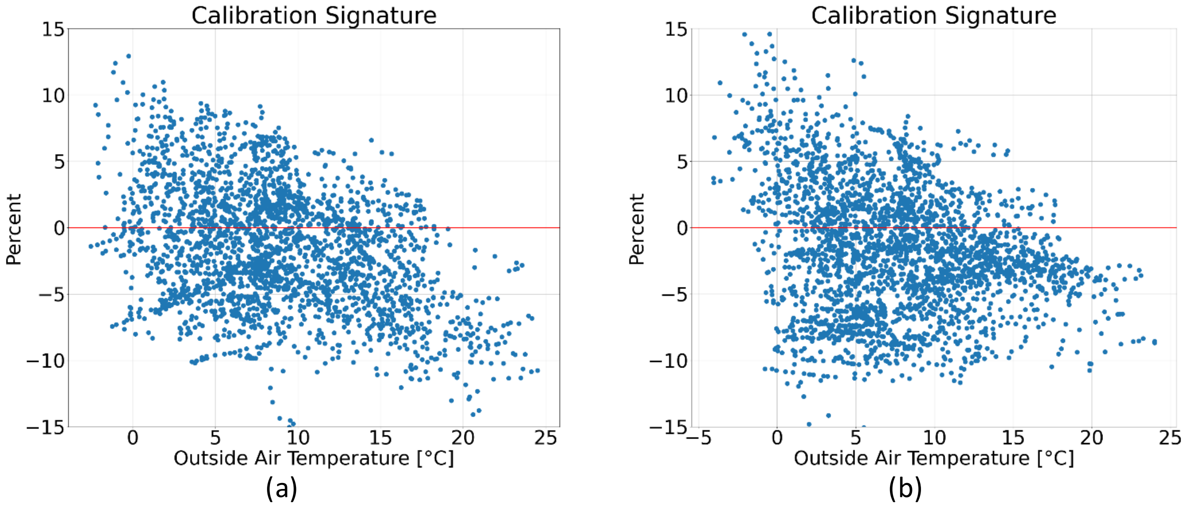



**Figure 81 Calibration signatures for demo case n.1 – municipality school first floor in heating period autumn-winter 2021 in (a) and winter-spring 2022 in (b)**

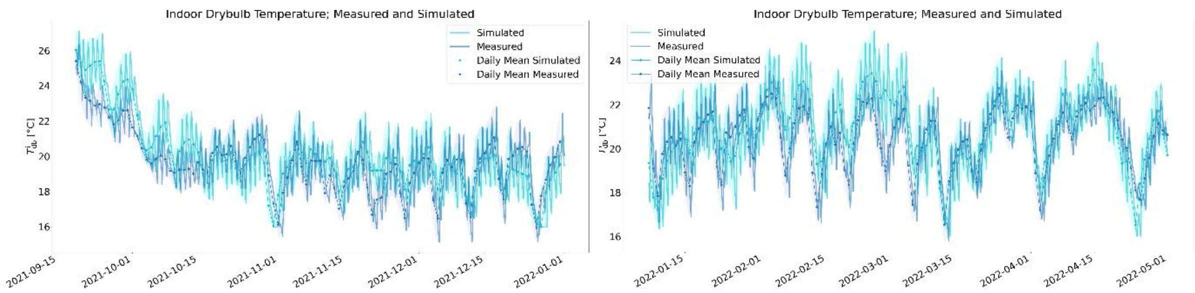
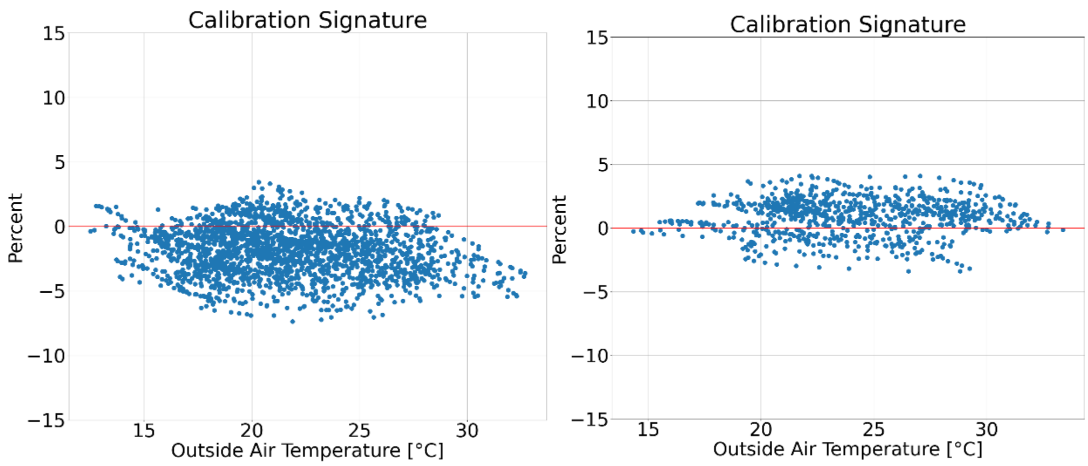


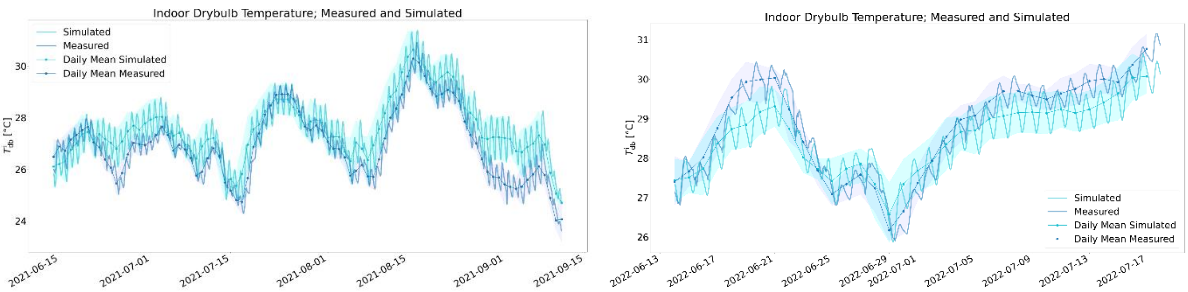

**Figure 82 Simulated and measured average temperature trends for demo case n.1 – municipality school first floor in heating period autumn-winter 2021 in (a) and winter-spring 2022 in (b)**

Some challenges were encountered in the model verification process of the last floor of the middle school, despite more extended calibration periods being considered (the whole 2021 summer). Figures 83 and 84 show the error range and how the trend is maintained in summertime 2021 and during the further verification in 2022. Despite most of the points being in the acceptable error range (even lower than 5% - see the calibration signature), Figure 85 showing room detail gives a clear insight into the problem. Good results are obtained in the average analysis thanks to a balance between an optimal corridor trend and wrong offices and classrooms results. Some classrooms show high monitored peaks, which are entirely lost in the simulations and potentially correlated to specific behaviours. The same situation occurs when looking at other periods, and significantly the condition worsens in occupied periods. Hence, further efforts will be spent optimising this model during the next project phase before ultimate municipality school calibration.



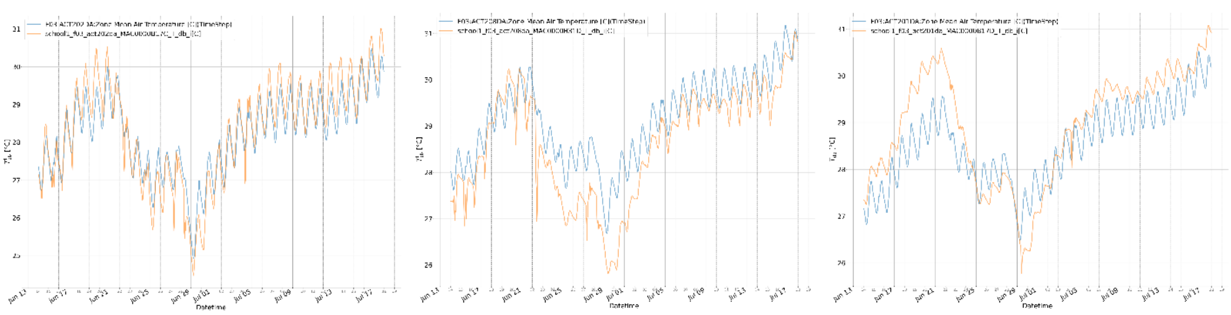

*(a)* *(b)*

**Figure 83 Calibration signatures for demo case n.1 – municipality school second floor in unoccupied summertime 2021 in (a) and 2022 in (b)**




*(a)* *(b)*

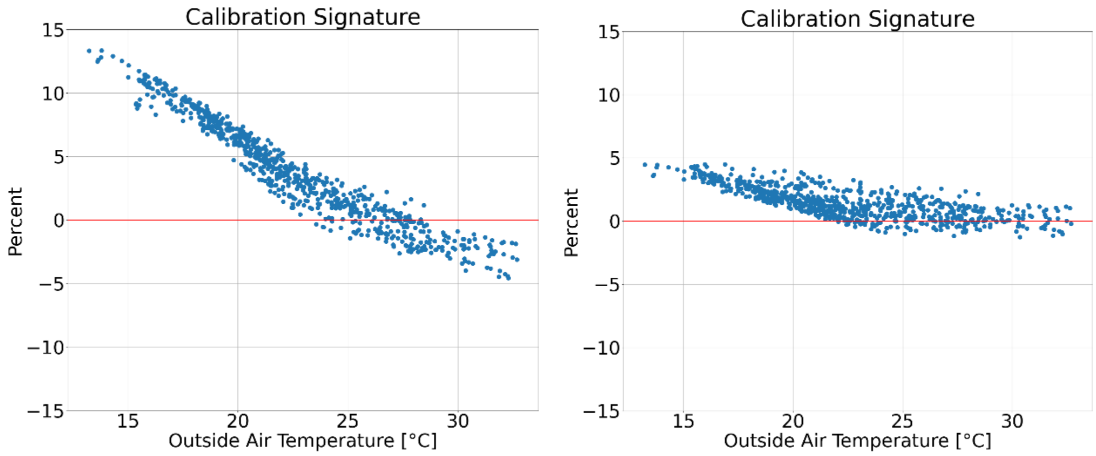
**Figure 84 Simulated and measured average temperature trends for demo case n.1 – municipality school second floor in unoccupied summertime 2021 in (a) and 2022 in (b)**



*(a)* *(b)* *(c)*

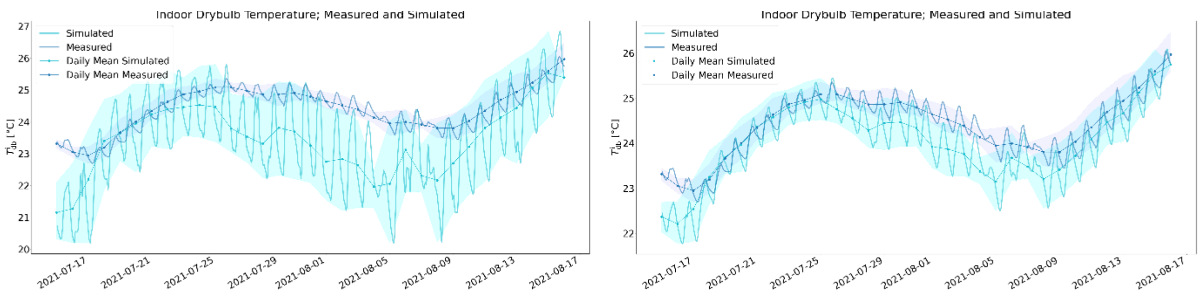
**Figure 85 Simulated and measured temperature trends with room detail for demo case n.1 – municipality school second floor in unoccupied summertime 2022 in corridor (a), in an office (b), and in one of the classrooms in (c)**

Concerning demo case B2.2 – the Liceo Valdese High school – as previously mentioned, some issues were encountered during the calibration process. Figures 86 and 87 show obtained results in terms of average temperature error range and trend over the considered calibration period in summer 2021 (from the 15th of July to the 15th of August). Significative improvements were obtained concerning the starting point, keeping the average error inside the 5% range (calibration signature), but this was due to unbalances between internal zones. Particularly for the high school, corner rooms behave quite well concerning monitored data, while central spaces misbehave. This could be due to model simplification choices, e.g., when defining the vertical airflow due to the stairs, and to problems during the automatic translation done by the CAD interface between the original 3D models and the EnergyPlus IDF. The latter may arrive when significant differences in wall thickness occur. For this reason, an alternative model will be elaborated during the following months to avoid geometrical challenges.




***(a)*** ***(b)***

**Figure 86 Calibration signatures for demo case n.2– Valdese high school in unoccupied summertime 2021 calibration period before calibrating in (a) and after the calibration process in (b)**




***(a)*** ***(b)***

**Figure 87 Simulated and measured average temperature trends for demo case n.2– Valdese high school in summertime 2021 calibration period before calibrating in (a) and after the calibration process in (b)**

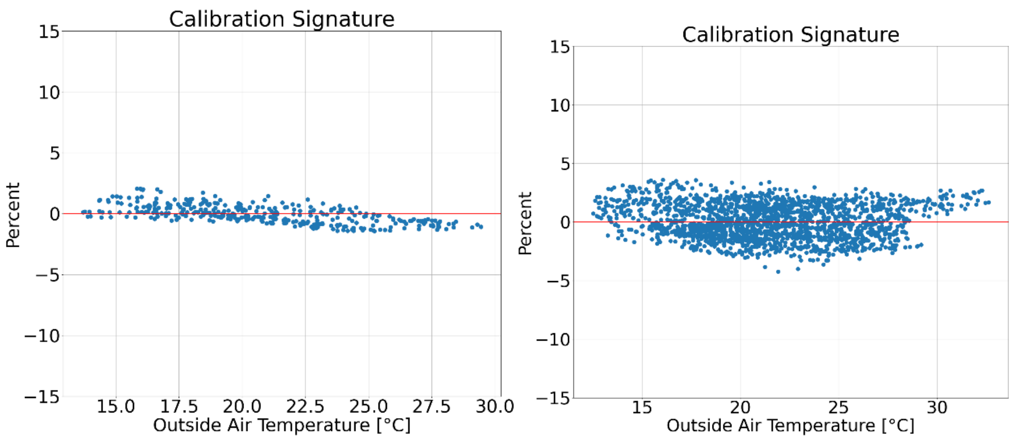
Concerning residential demo cases, for all of them, a first verification step was performed during known holiday periods (individuated through inspection) in summer 2021. Thanks to this choice, it can be possible to initially focus on limited variables since ventilation flow (off) and windows' shading positioning are known. The validity of the resulting calibration is verified in a second step considering long-term results by setting the models to standard modified conditions – see the values highlighted before. This long-term verification step helps define meaningful information that can impact building standard modified conditions when looking at simulation results.

Regarding demo case B2.3, it has been calibrated from the 17th of August to the 31st of August 2021, and obtained results are initially verified in the extended summer of 2021. Figure 88 shows the calibration signatures obtained at the end of the calibration process and over the extended analysis. Figure 89 shows the average temperature trend over time.

Founded values at the end of the calibration process are:

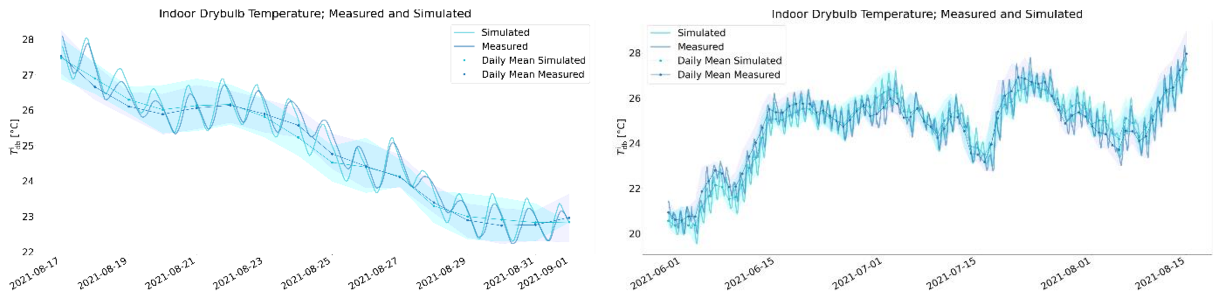
- Average ACH infiltration: 0.76
- U-factor of ground floor walls (except for living room): 0.58 W/($m^2$K)
- U-factor of upper floor wall: 1.44 W/($m^2$K)
- U-factor of living room wall: 1.12 W/($m^2$K)
- U-factor of internal floor: 0.64 W/($m^2$K)
- U-factor roof: 0.4 W/($m^2$K)
- Windows SHGC: 0.45
- Windows U-factor: 1.58 W/($m^2$K)
- Internal mass for kitchen and living room: 900%, other rooms 0% (unvaried).

Looking at room detail in Figure 90, it is underlined how upper-floor rooms and the home area devoted to the office follow very well the monitored trend. Although, the other ground floor rooms show a different monitored behaviour which is more difficult to be followed by simulations. Several tests were made to identify the best balance of internal mass, infiltration losses, and the other parameters to align these rooms without losing the excellent trend of the other ones. In this case, optimising an average value without looking at room details risks leading to wrong results, far from the actual building's technological and physical aspects. Figure 91 shows how outcomes are maintained over the extended summer of 2021, considering the room detail. During this phase (in which people were present in the house), shadings set during the holiday period were removed, and ventilation ACH was calibrated according to the occupancy schedule. The obtained values for ventilation ACH are 0 for the office and the ground floor bedroom, 1 for the upper floor, 2.5 for the suspended room (living area), 2 for the kitchen (entrance), and 1 for the other zones. These values are compatible with the information gathered during the inspections. Figure xx shows that the same rooms that showed a peculiar trend over the calibration period have a worse match. Moreover, the room individuated by nomenclature res1_z02_act107aa, which is the office, is more challenging to align during occupied periods, showing almost always a warmer trend than the simulated one.




***(a)*** ***(b)***

**Figure 88 Calibration signatures for demo case B2.3 at the end of the calibration process in (a) and considering the whole extended 2021 summer period in (b)**




*(a)* *(b)*

**Figure 89 Simulated and measured average indoor temperatures for demo case B2.3 at the end of the calibration process in (a) and considering the extended 2021 summer period in (b)**

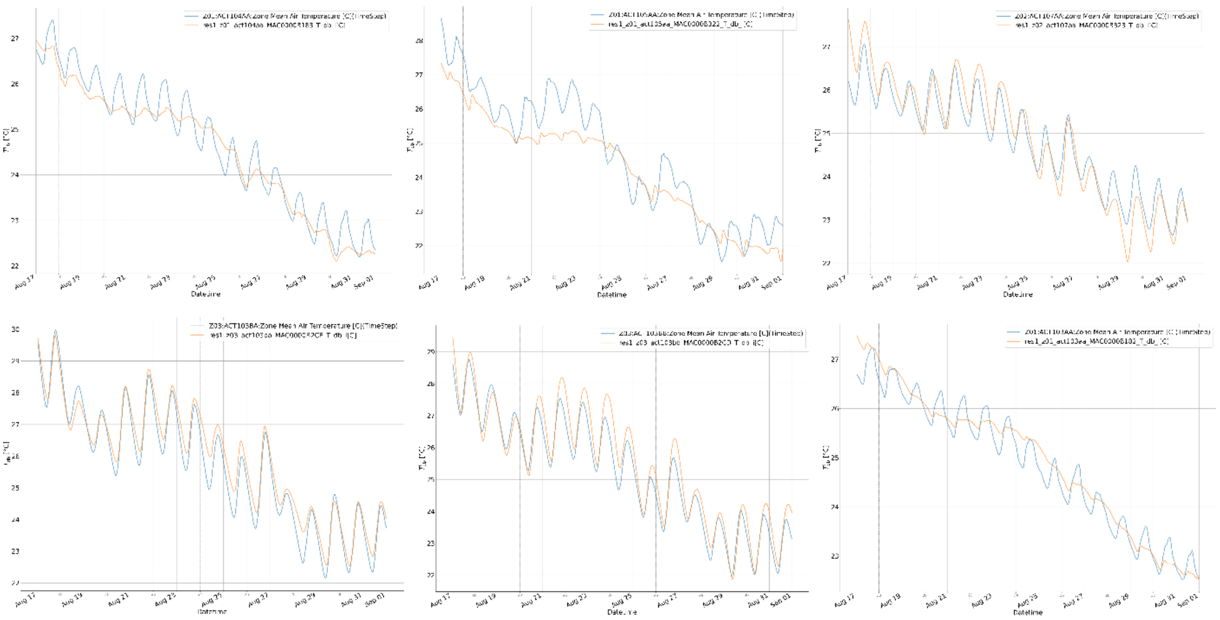
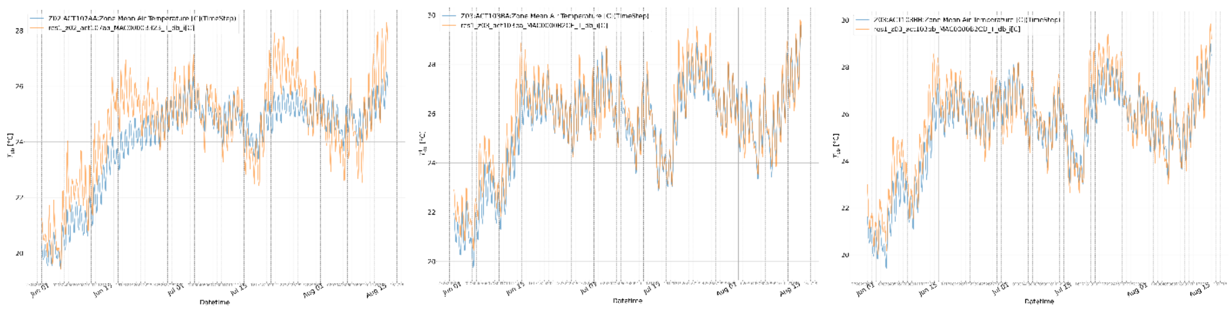


**Figure 90 Simulated and measured indoor temperatures in main rooms of demo case B2.3 considering the calibration period in summer 2021**



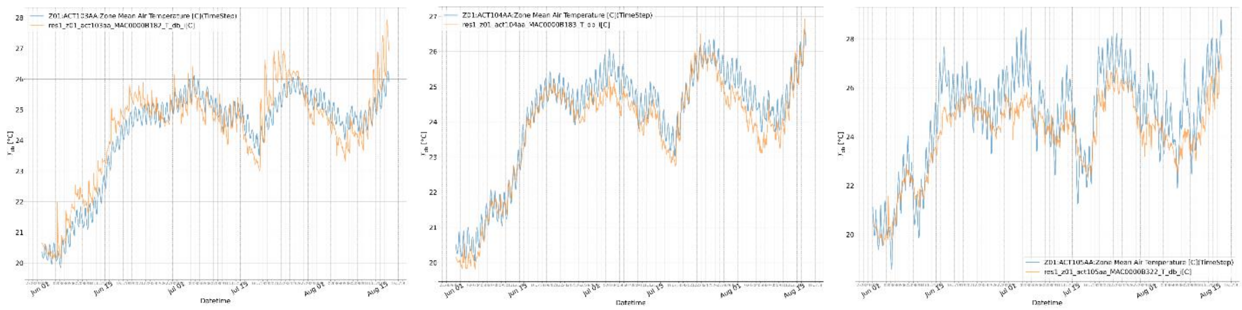


**Figure 91 Simulated and measured indoor temperatures in main rooms of demo case B2.3 considering the 2021 summer period**

Obtained results maintain for the average trend an optimal alignment also considering summer 2022, as shown in Figure 92. Considering single room details, the trend is also maintained, with slightly worse results in those rooms that were already more challenging in the previous year: the living area and the office. Initial analyses were made to try calibrating temperatures during the heating period, but two main issues were encountered. The house has two thermostats that seem to be used independently with different setpoints. Moreover, the monitored daily schedule is very variable, as if the thermostat were in "manual" mode most of the time instead of following fixed temperature thresholds and recurrent schemes. Consequently, this resulted in a very complex task that requires further analysis to determine possible average behavioural patterns.

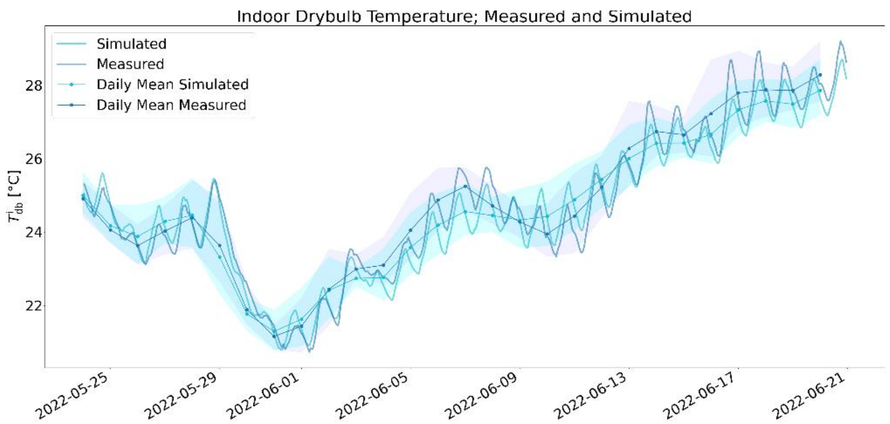



**Figure 92 Simulated and measured average indoor temperatures for demo case B2.3 in summer 2022**

Considering demo case B2.4, the calibration period was from the 9th of July to the 17th. Figures 93 and 94 show obtained results in this period considering the error range and the temperature trend. Looking at single room detail, it is immediately recognisable that a room (the kitchen) behaves hugely well, while the others (the living room and an average of the two bedrooms) behave worse. The main issues in this demo case focus on the alignment of the bedrooms because they are joined with a hole (internal stairs) that is always open. Considering the large living area, equipped with two temperature sensors, the sensor nearer to the kitchen was more aligned with the simulated trend than those closer to the bedrooms. However, the average behaviour was very good, so the following obtained values were considered:

- Average ACH infiltration: 1.23
- U-factor walls: 1.85 W/(m$^2$K)
- U-factor roof: 0.16 W/(m$^2$K)
- U-factor floors: 1.10 W/(m$^2$K)

- Windows SHGC: 0.4
- Windows U-Factor: 1.05 W/(m²K)
- Internal mass in the living area and bedrooms 1000%, other rooms 0% (unvaried).

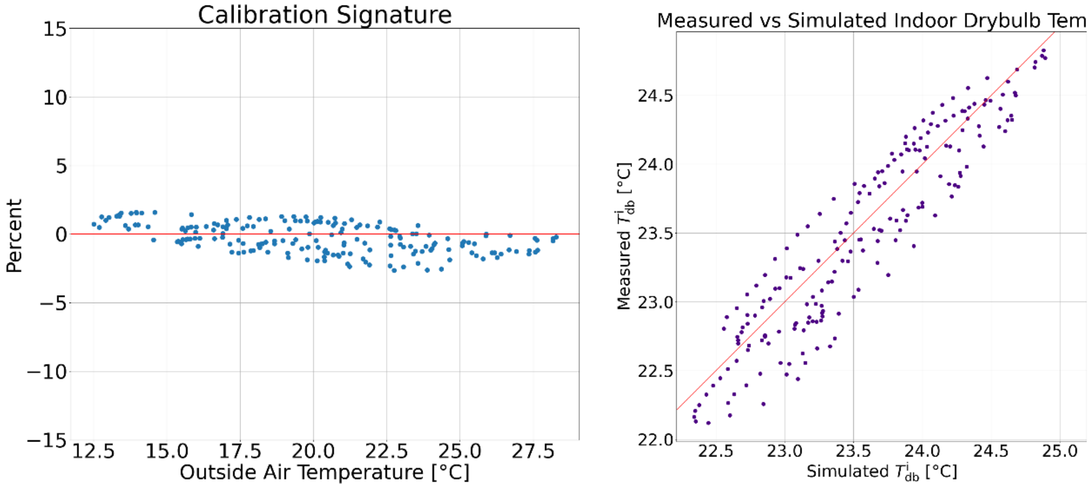



**Figure 93 Calibration signature for demo case B2.4 considering calibration period in (a) and simulated versus measured temperatures in the same period in (b**

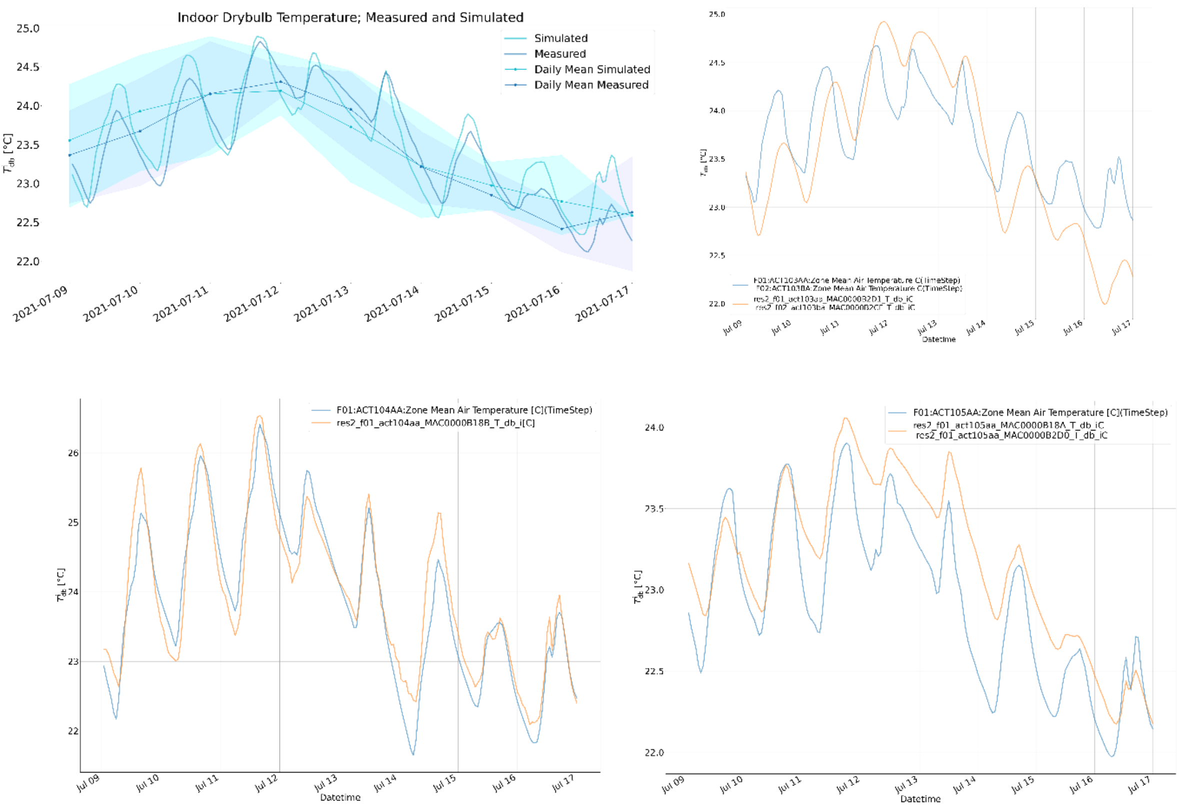



**Figure 94 Simulated and measured indoor temperatures averaged in the house and separately in main rooms of demo case B2.4 considering calibration period in summer 2021**

The resilience of obtained results was tested on warm 2021 and 2022 periods, adopting the standard modified conditions described in Section 6.1. Average ACH values were set to 1 in all zones during occupied hours. Figures 95 and 96 show results on average temperature, while Figures 97 and 98 enter in detail the different rooms. The kitchen continued behaving very well in both periods, while the other rooms showed the same issues underlined during the calibration process. In particular, most of the time, the monitored data result is colder than the simulated ones. Still, the problem was unsolvable by acting on ACH since it is correlated to random user behaviours.

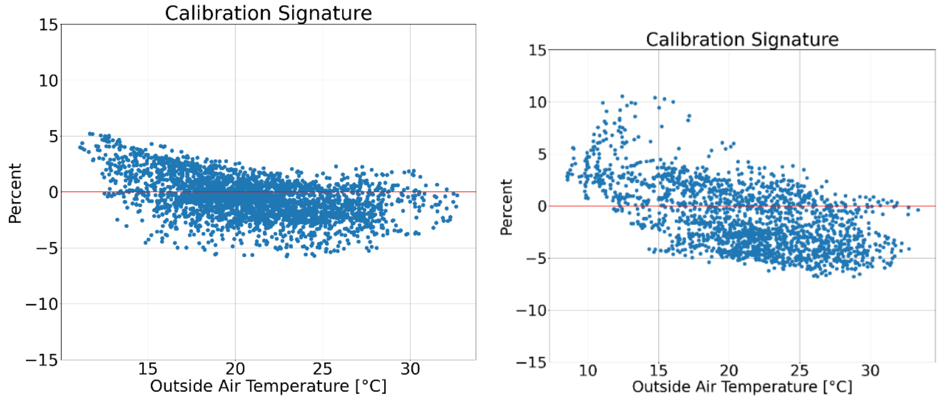



**Figure 95 Calibration signatures for demo case B2.4 considering the extended 2021 summer period in (a) and the extended 2022 summer period in (b)**

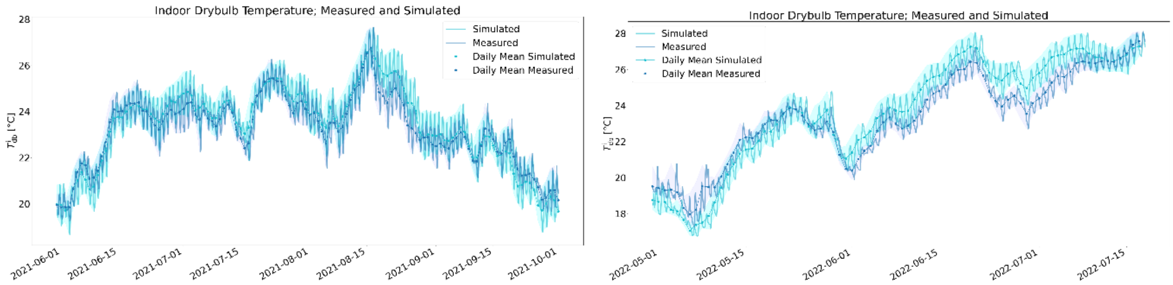



**Figure 96 Simulated and measured average indoor temperatures for demo case B2.4 considering the extended 2021 summer period in (a) and considering the 2022 summer period in (b)**

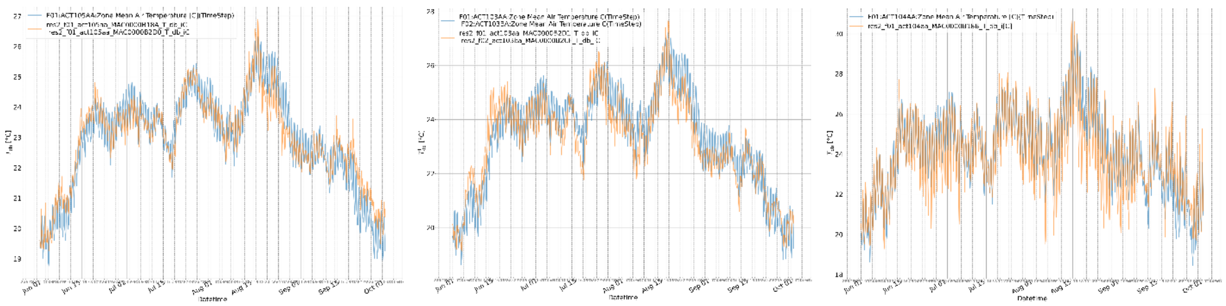


**Figure 97 Simulated and measured indoor temperatures in main rooms of demo case B2.4 considering the extended 2021 summer period**

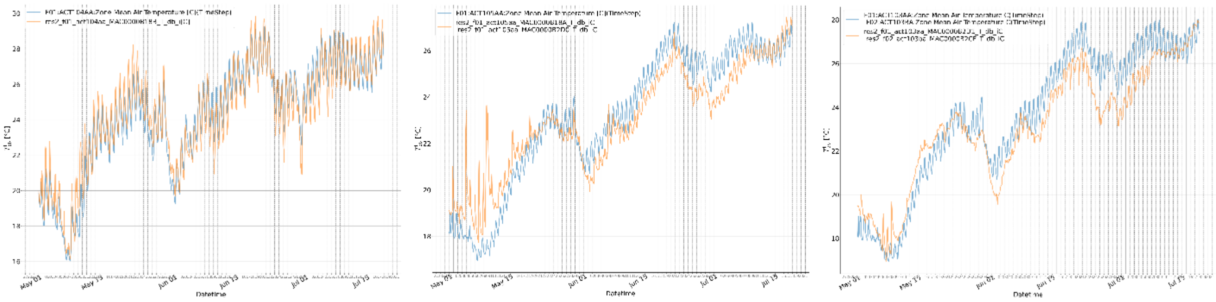



**Figure 98 Simulated and measured indoor temperatures in main rooms of demo case B2.4 considering the extended 2022 summer period**

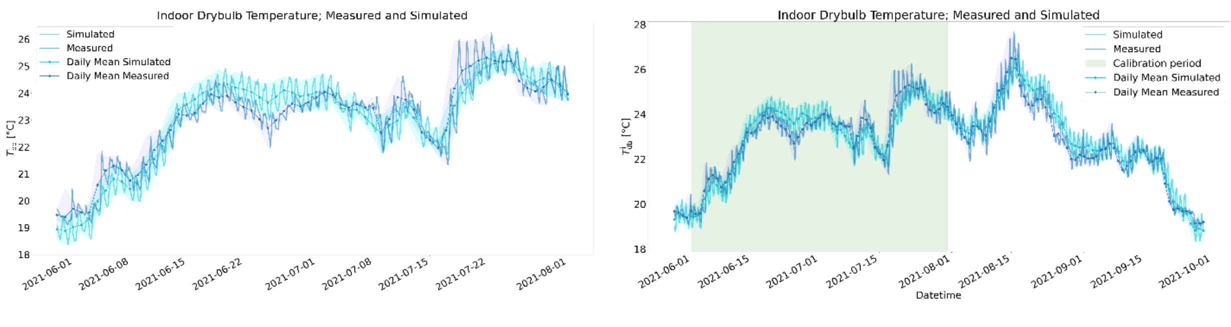
In this demo, an extra insulation layer was added in January 2022 on the outermost surface of the last floor slabs – see Section 7.1. Consequently, first trials on heating period temperatures were currently made considering autumn/winter 2021 considering the original building. Nevertheless, in the further months, a secondary calibration process is expected considering the hating users that will be measured in the following heating season. Figure 99 shows how the standard modified conditions defined for the heating setpoint and schedules in the previous section allow us to follow the actual daily cycle pretty well. This is especially underlined in the kitchen (*act104*), while the bedrooms measured high peaks are significantly lower than the simulated ones, while the living area is hotter. This could be due to two main factors: the use of the fireplace in the living room as heating integration or the thermostat location inside the house. The first factor was not so incident: the additional surface temperature probe on the fireplace later wall showed minimal usage. Considering the second, further studies may be needed to choose how to follow better-measured trends in manual operations, e.g., by creating fictitious setpoints as if different thermostats ruled each room or to define fictitious setpoints allowing for tracking the average building value. Moreover, the analysis for 2022 needs to be refined considering the additional under-roof insulation.


**Figure 99 Simulated and measured indoor average temperatures and in main rooms of demo case B2.4 considering December 2021**

Concerning demo case B2.5, it was first tried to calibrate indoor temperature in specific periods in which it was known that the house owner was on holiday. However, it was further inspected that other family members used the house during the same period, including people's irregular presence to keep car ing for pets. Hence, results over such short periods were not stable and did not allow to maintain good results over time. Consequently, it was decided to calibrate the model over a more extended period during the summer of 2021, from 1st June to 31st July, including occupation periods. Figure 100 (a) shows results obtained at the end of the calibration process, while Figure 100 (b) shows how results are maintained over more extended periods (the calibration period is highlighted in green). Also, Figure 101 shows the calibration signatures referring to these two cases, showing that error remains almost always inside the 5% range. The found optimal values during the calibration process are listed here below:

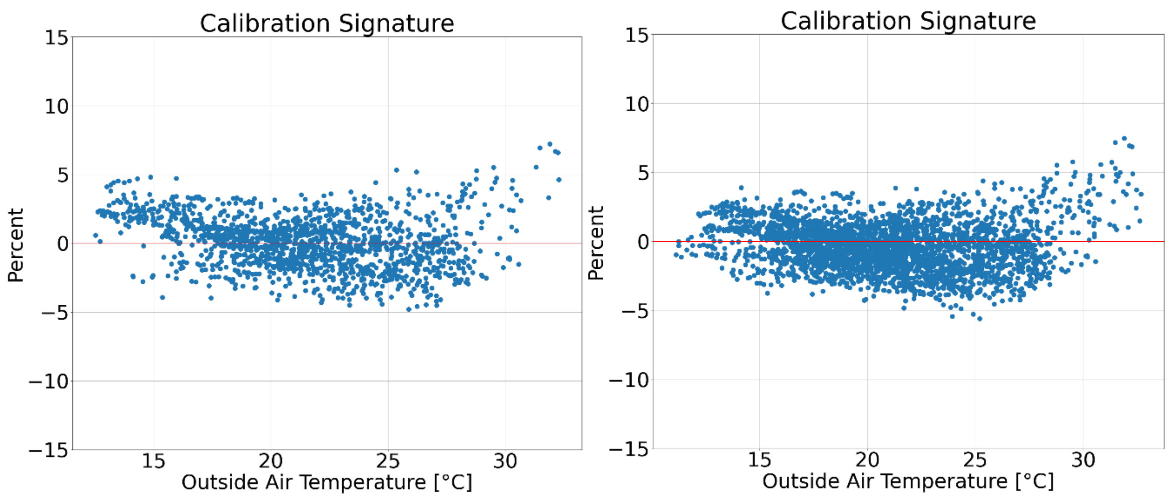
- Windows: U-factor = 2.031 W/(m$^2$K), SHGC = 0.4218;
- Older part of the building envelope: walls U-factor = 2.28 W/(m$^2$K) and 1.56 W/(m$^2$K), roof U-factor = 1.28 W/(m$^2$K)
- Newer part of the building envelope: floor U-factor = 0.8 W/(m$^2$K), walls U-factor = 0.18 W/(m$^2$K), roof U-factor = 0.16 W/(m$^2$K)
- ACH ventilation: scheduled always on and set to 0.05 ACH in the newer part and 0.4 ACH in the older part of the building, while ACH infiltration was assessed at 0.05 ACH for zones.
- Internal mass: 4000% of floor area for the newer part of the building, 150% for the two rooms of the older part of the building.

It is worth noticing that most values are coherent with the inspection plan, especially concerning U-values of the newly renovated part of the building, windows characteristics and ventilation habits (usually to keep open in the old part and close in the new one during summer months). However, founded values were not only defined by minimising the average error on temperature but also (once the error reached small movements) by looking at single rooms' behaviours. Moreover, to get good results for the newer part of the house, it was crucial to consider the soil reflectance of the front grass covered hill by considerably reducing it for all months. Moreover, all windows of this part of the house were simulated as always shaded to mimic the effect of surrounding trees (setting high conductivity values and solar and visible reflectance values). Instead, curtains are not present in any room of the house, and roller shutters are rarely used. Nevertheless, horizontal curtains are used in some periods on the southern balcony. Figure 102 shows how simulated temperatures behave in the four most essential rooms of the house concerning monitored data. Not all of them reach the same accuracy, but the overall trend is well followed.




*(a)* *(b)*

**Figure 100 Simulated and measured average indoor temperatures for demo case B2.5 at the end of the calibration process in (a) and considering the extended 2021 summer period in (b)**




*(a)* *(b)*

**Figure 101 Calibration signatures for demo case B2.5 at the end of the calibration process in (a) and considering the extended 2021 summer period in (b**

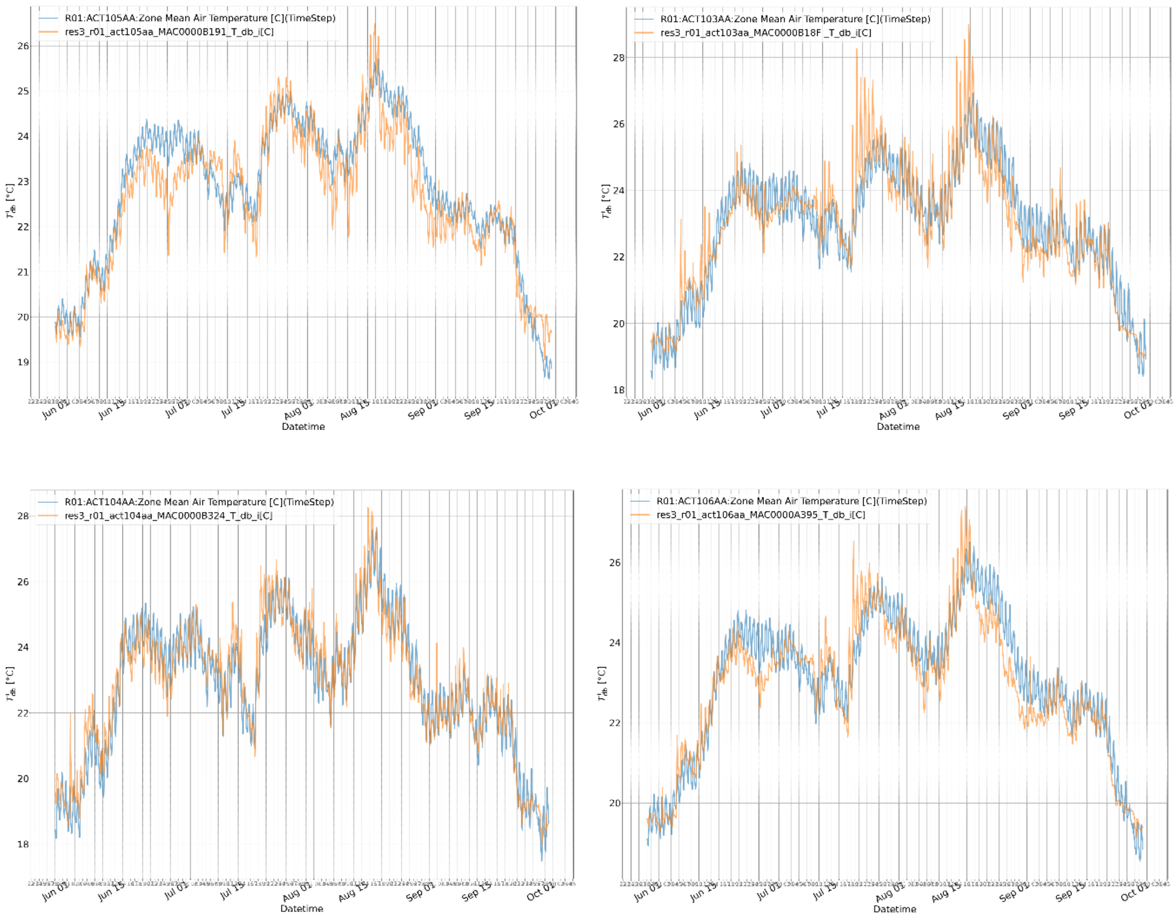
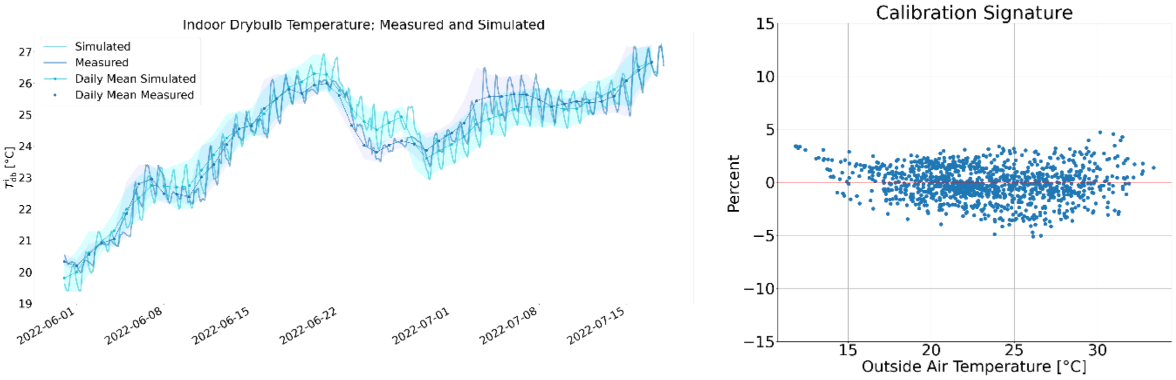



**Figure 102 Simulated and measured indoor temperature in main rooms of demo case B2.5 considering the extended 2021 summer period**

Figure 103 instead shows how obtained results maintain their accuracy in summer 2022 considering average values, while Figure 104 shows rooms detail over the same period.




***(a)*** ***(b)***

**Figure 103 Summer 2022 results for demo case B2.5 considering average temperatures (a) and calibration signature (b)**


**Figure 104 Simulated and measured indoor temperatures in main rooms of demo case B2.5 considering the 2022 summer period**

Considering winter behaviour, in this residential demo case, the use of the stove located in the kitchen is almost wholly substituting radiators in that part of the building during main occupation periods. Hence, calibrating heating consumption is quite complex and finding setpoints and schedules allows for following temperatures correctly. Moreover, the stove is also used outside the heating period. Hence even during May and September could be more challenging to track the temperature in the kitchen. Figure 105, for example, shows how temperature is better followed in the living/office area (far from the stove) than in the kitchen, where punctually differences in temperature of 5°C are present. Potentially, it can be interesting to analyse during subsequent phases stove activation periods and performance gap detections.

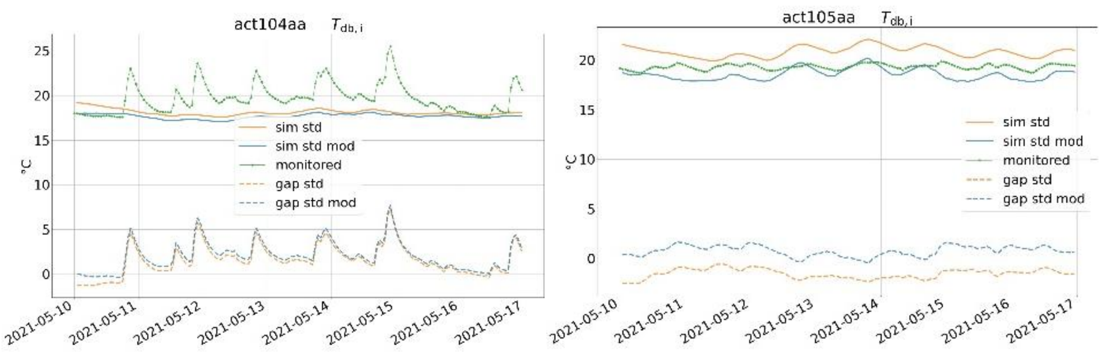



**Figure 105 Performance gap on air temperature values in residential case B2.5 – unit kitchen (left) and living area (right).**

## *6.3 PREDYCE connection and transfer to FUSIX*

All five Italian demo buildings have a monitoring system that is expected to be connected to FusiX (and the POLITO server) – see WP4. Additionally, all Italian demos have one or more EnergyPlus models, as mentioned above. These models are organised and developed to be runnable via the PREDYCE tool to support simulations and output analyses considering different usage scenarios – see D3.2.

Building models, weather data, and other input files (containing standard and standard modified definitions, together with lists of KPIs to be retrieved) for performance gap runs have to be stored on the FusiX platform by EMTECH (and on the POLITO server for Italian demos). The script intended for performance gap runs as part of the PREDYCE tool, and it is exposed on the Internet from POLITO servers via a REST API. These two elements create two-way communication between the data stored on FusiX and/or on the PoliTO server and the executing programs stored on the POLITO side. The performance gap launches are available on-demand; therefore, the simulations are scheduled via the FusiX platform, which also is in charge of getting back and storing the results.

Results of data analyses from both monitored and simulated databases will be shown in D5.6. Nevertheless, some samples visualising potential random outcomes are reported below to suggest expected elaborations – see the following Figures 106, 107, 108.

Some initial results discussing the use of PREDYCE to support performance gap analyses in two Italian demo buildings have also been introduced in an open access book chapter, which is under publication [17].

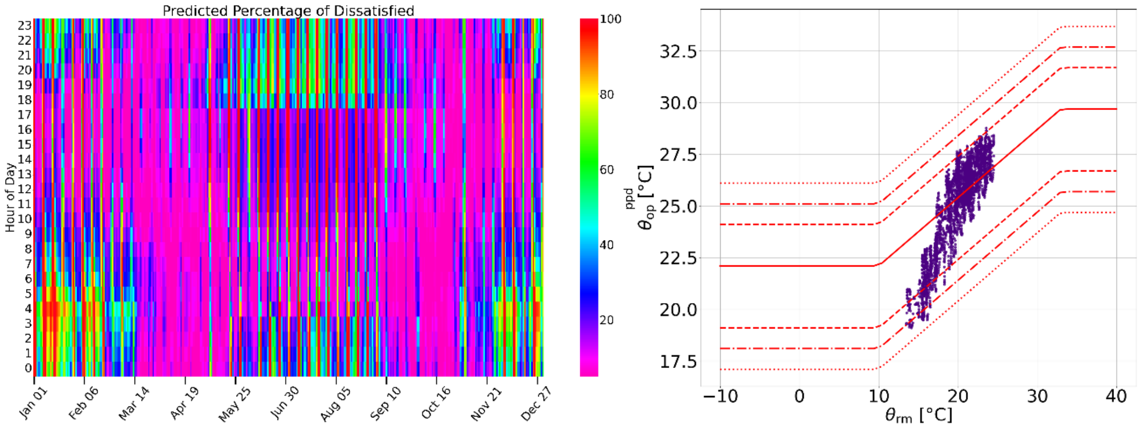



**Figure 106 (a – left) A carpet plot showing the PPD index (Fanger model) and (b – right) the distribution of hourly data points considering the EN 16798-1 adaptive thermal comfort model**

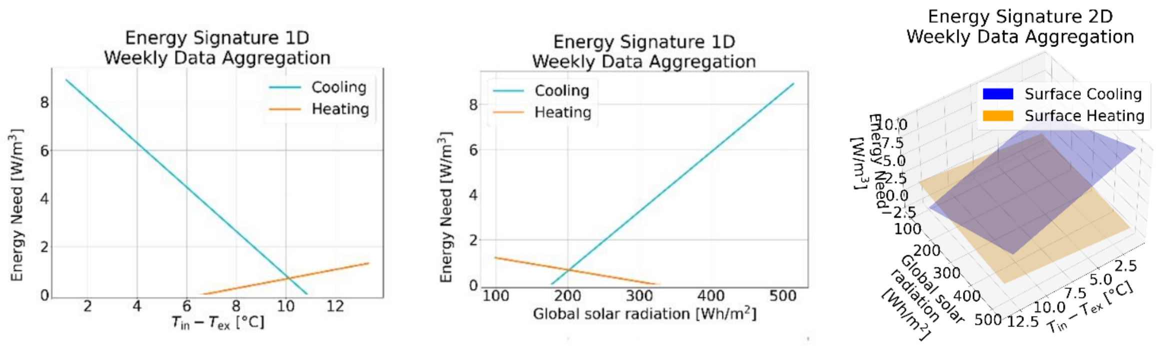



**Figure 107 The results of 1-D and 2-D energy signatures (weakly aggregated data) based on building simulation.**

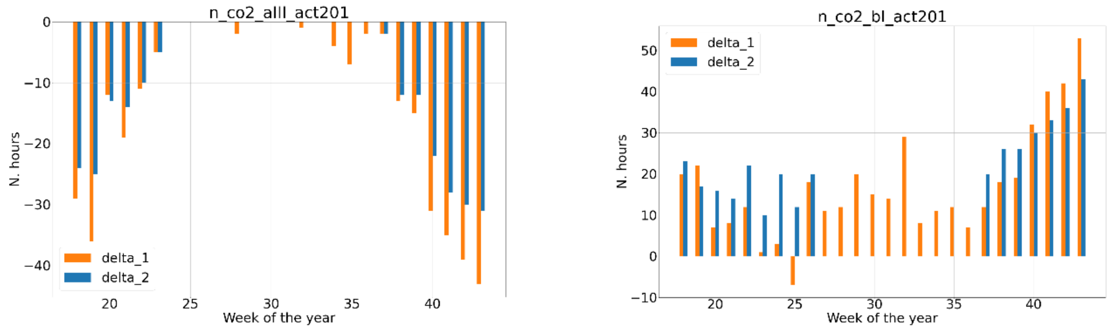



**Figure 108 CO2 KPIs aggregate results in all kindergarten teaching areas. The graphs show the performance gap between the monitored number of hours and simulated ones for standard (delta_1) and standard modified (delta_2) profiles for hours (a – left) above 16798-1 cat. III and (b – right) below the cat. I**

# 7 Actions to end-users and educational activities (user involvement)

## *7.1 Continuous check with users*

Starting from initial inspections, a continuous exchange of information with users has been implemented. This specific approach allows for collecting feedbacks, identifying criticalities, and supporting the project phases of data analysis. Thanks to this exchange, some of the residential users have supported self-renovation actions to improve the energy efficiency of their own houses. The project does not fund these actions. Still, they may be mentioned as a secondary consequence of the increase in user attention to energy topics and in the interest to E-DYCE correlated issues in supporting local renovation. For example, during the summer of 2022, the heating system of B2.3 was renewed, including a new heater with higher efficiency and a secondary heating source composed of an intelligent fireplace insertion connected to the radiator system moving part of the energy needs to renewable sources (biomass). Additionally, an increase in envelope insulation has been planned by self-adding a layer of insulation in the intrados of the basement, reducing the losses between the not-heated semi-buried spaces and the living floor. Also, in another residential building (B2.4), E-DYCE correlated discussions supported a secondary self-driven action to increase the building efficiency. Indeed, the users self-installed in January 2022 two layers of glass wool of 7 cm each to reduce the heating dispersions between the not-insulated under-roof spaces and the inhabited spaces of the last floor.

Other positive aspects of this continuous check with end-users include a preliminary application test showing monitored data – see the following section 7.2 – and the possibility to discuss their expectations and doubts with users and collect valuable feedback. For example, in school 1, also due to the pandemic situation, the usage of some classrooms changed between the two monitoring years to re-organise lectures in larger classes. Similarly, we had a clear vision that windows are left continuously opened during more critical Covid periods to support ventilation in line with national suggested rules. This last issue is strongly impacting results, being the CO2 levels considerably lower than the expected typical ones for spaces with a high occupancy profile and random ventilation. The installation of the three detached mechanical ventilation units is another exciting aspect of the project since this specific test is critical due to the recent interest in schools about the inclusion of these systems. Local interest is envisaged to participate in future specific funding opportunities (e.g., regional development) to install similar machines in all classrooms.

## *7.2 Students' mobile app development for initial user involvement*

During the A.Y. 2021-22, a group of students[3] at PoliTO (Master Degree ICT4SS) has been involved in a collateral E-DYCE education action. This action, part of their Interdisciplinary Project course, supported the development of an android-based application named SBV (smart building visualisator) with a high standard of user protection showing monitored data in Italian demos. The application is not substituting the official E-DYCE one under development but aims to interact with end-users since an initial phase to collect feedback and increase users' involvement. Additionally, the group developed a coding interface

[3] The student group is composed of BEng. Balan, Finocchiaro, S.Ten. Mastrodicasa, Roldo, Vigliotti under the supervision of prof. Chiesa and Eng. Fasano and Grasso. Prof. Dovis is thankfully acknowledged. Interdisciplinary Project – Master Degree in ICT for Smart Society (Telecommunication Engineering) – Politecnico di Torino.

on the PoliTO research unit server to download automatically and continuously data from Capetti and Netsens clouds. The educational activity also includes the development of data filtering, data analysis and a simple temperature ANN forecasting model (only partially trained but coded to repeat the training phase each month while the database is increasing).

From the dissemination and educational point of view, this action focussed on the following aims: i.) diffuse the E-DYCE monitoring logic among future local engineers working in the ICT field; ii.) increase the local curiosity about intelligent and smart buildings; iii.) increase end-user involvement; iv.) collect end-user feedbacks; v.) demonstrate specific replicability of E-DYCE correlated issues.

During this activity, a survey on intelligent buildings was also defined, collecting more than 200 answers (adult people, reached casually via socials) between October 2021 and January 2022, plus about 70 responses by TPM local pupils. Focussing on adult answers, 84,6% of the interviewed people define as ‘crucial’ or ‘high importance’ to have potential access to real-time monitored data from their residential buildings. In comparison, 85.5% ‘strongly agree’ or ‘agree’ that the technology acceptance of intelligent solutions is now reached. 49.6% of the interviewed people prefer to use a mobile application. In comparison, 40.9% of them appreciate an on-wall screen. On the visualisation mode, the majority of involved person aims to see current values, while a quarter would like colours or smileys, and about 18.2% an entire chart interaction. The latter is very appreciated by the pupil population and those who have tested the developed android app. This basic information supports the educational activity's further development by defining a mobile app showing different visualisation modes: simple icons, average current data and room-by-room current data, and interactive charts with current and limited historical data, including thermal comfort and $CO_2$ KPIs.

The tool development is based on a microservice architecture, supporting full scalability and modularity and helping easily debug and upgrade it under request. The structure includes the development of a simple Middleware acting as both Service and Device Catalog. The application is developed using Android Studio as IDE and Kotlin as a programming language. Four types of users are considered for defining the graphical interface: classic (accessing data at room level); superuser (like a classic user, but able to grant access to new users and change sensor names for the specific building to which they have superuser access); technicians (similar to classic users, but they can add new sensors to the systems following specific recognition procedures); student (simple view and potential limited access to data).

The following Figure 109 shows the general software structure; each number in a ballot includes extra functionalities and structure parts that are not here reported. The software consists of seven blocks:

1. Data retrieval and storage
2. Data analysis, filling and smoothing (row data real-time analysis to remove potential noise based on an LSS regression and up-sampling smoothing technique)
3. Queries (InfluxBD clients for row and smoothed data)
4. Processing servers (used for the mobile application)
5. Mobile application
6. Neural network service
7. Historical data retriever

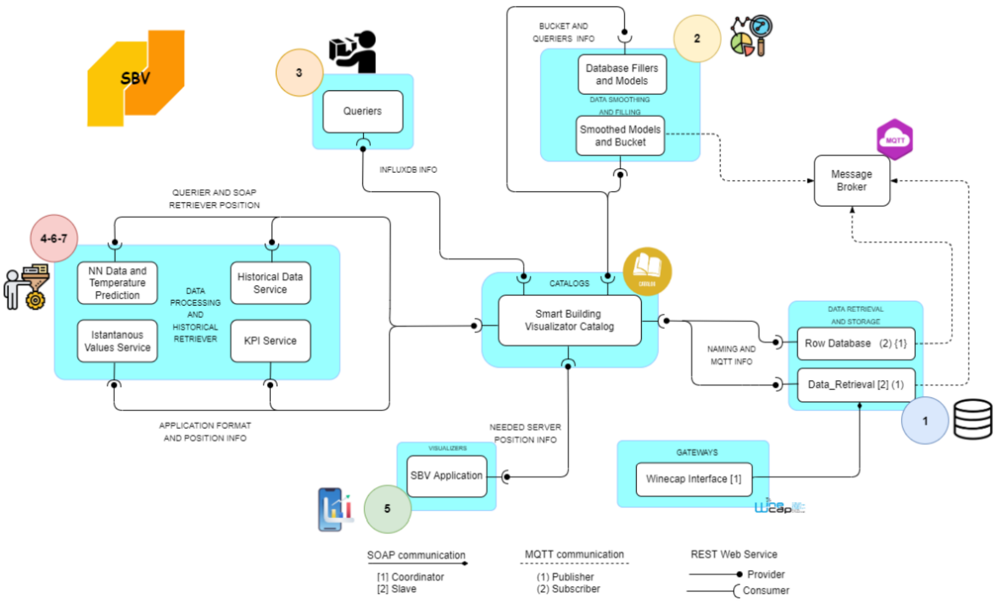



**Figure 109 the SBV general software structure developed by the students**

The SBV app developed during this educational activity has been tested in residential buildings (giving the independent user access to the proper demo building) and shortly shown to some students for initial feed-backs – see also the following Figures 110 and 111. All users collected very positive answers, suggesting some new ideas, like including meteorological data visualisation, maintaining the user logged-in to limit the need to insert user and pass at all accesses, and specific notes on visualisation and specific sensor accesses or naming. The positive outcomes suggest that the future implementation of the E-DYCE application will be very appreciated and that all users are interested in having access to this type of data. Additionally, the educational activity was enjoyed by involved university students and their colleagues in course discussion moments, defining this experience as win-to-win work. The work is derived from an educational activity. It is open to potential errors, communication problems during a continuous operation, and other issues in line with original objectives that are not the development of a professional, thoroughly tested and high feasible product.

**Figure 110 a testing moment in an E-DYCE demo building using a RaspberryPi device with a touching monitor programmed to act similarly to an on-wall screen**

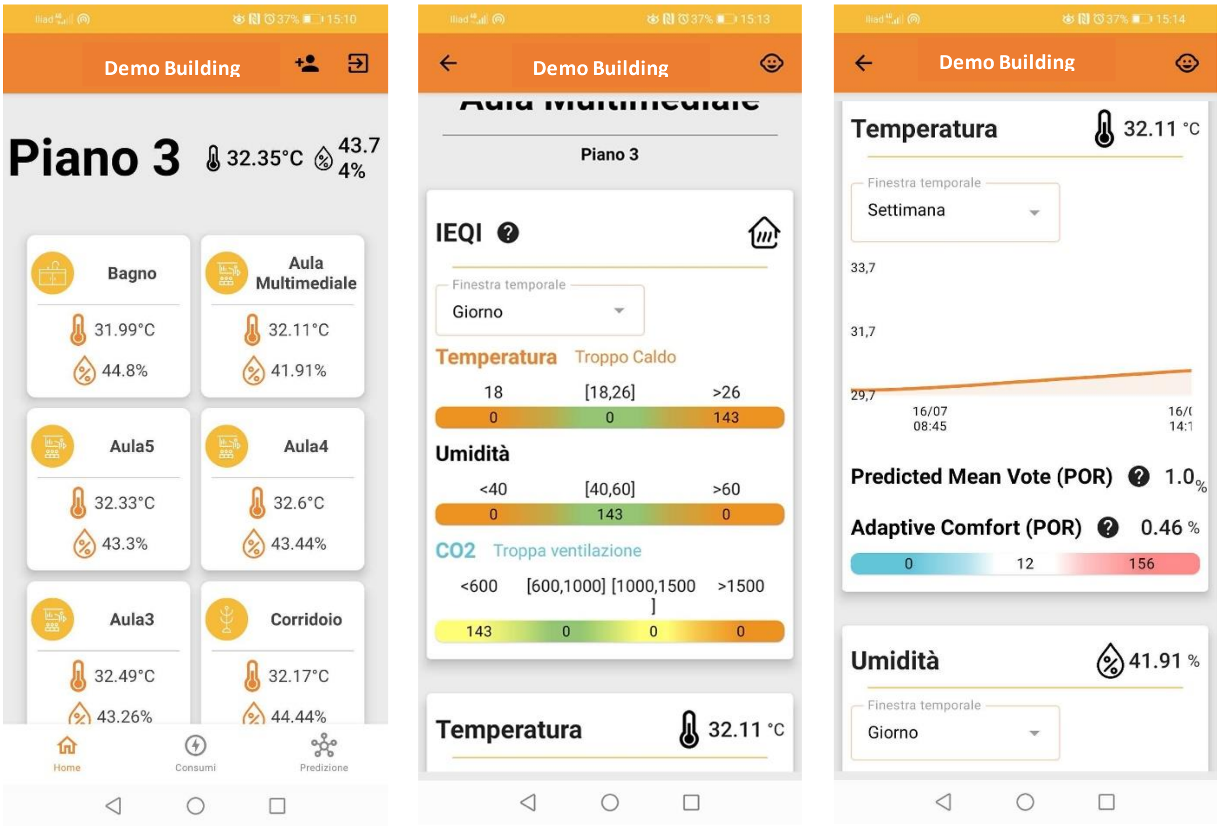



**Figure 111 casual app screenshots taken by a mobile phone during operational tests.**

## 7.3 *Educational activities for schools*[4]

E-Dyce provides that at the I.C. Rodari and at the Liceo Valdese of Torre Pellice are developed educational laboratories and activities, about Environmental education and Sustainability, with 10 classes for each school year, for a total of 200 total frontal hours in the period.

To achieve this goal, in December 2021 TPM published a call for tender for the implementation of educational laboratories. The contract has been assigned to Cooperativa La Tarta Volante in January 2022, which implemented the educational activities from April 2022.

Before the start of educational activities, in April 2022, TPM, through the action of the contractor Cooperativa La Tarta Volante, presented the project to the classes of the I.C. Rodari of Torre Pellice, and students attending school buildings directly involved in E-DYCE as case study.

In the period between M1 and M24, at the I.C. Rodari, the first meetings were held, and involved 6 classes for 6 hours each, for a total of 36 hours of activities.

The detailed design of the activities involved the creation of N. 1 initial table of co-design of the educational activities, with the presence of Cooperativa La Tarta Volante, responsible for the Municipality of Torre Pellice and the Principals of the schools involved. Various subsequent meetings were then held, for the design and operational programming of the paths, also with the involvement of the Polytechnic of Turin.

[4] Section 7.3 is developed by TPM.

The educational activities, according to E-Dyce project, are focused on the themes of energies and energy consumption, connected to climate changes and mitigation and adaptation policies, to be developed on the territory.
The articulation of the activities is inspired by the European project Life PREPAIR (Po Regions Engaged to Policies of Air) - Action E5, and includes:

a) Introduction to the topic and analytical discovery of the concept of energy to produce a first clarification on the subject. The students also explore daily energy consumption using recreational activities, like role-playing games.
b) Role play on energy consumption; In-depth study of the topic; Comparison on the different forms of energy and the alternative energies and their functioning.
c) Elaboration of ideas and actions to address the critical issues encountered with regard to energy and communication of the results to the territory (other students, families, population, etc.). In this phase the results of activities will be processed in graphic / multimedia form in order to make them more usable.

The methodology is characterized by a series of quality elements related to the System of Quality Indicators of the Piedmont Region:

1. student leadership;
2. direct involvement of participants (students, citizens) in dealing with problems affecting their lives (in this case energy problems);
3. joint decision with the students of the problems and objects of work;
4. strong integration with the territory;
5. caring for relationships (learning to listen, educating in coexistence and dialogue, cultivating a sense of community);
6. promotion of systemic thinking;
7. emergence/clarification, enhancement and dialogue of different points of view;
8. working methods that combine knowledge and action, giving importance to the experience;
9. activation of meta-cognitive and meta-reflexive processes;
10. education to imagine and think about the future;
11. highlighting the links between local and global situations.

# 8 Conclusion

This deliverable reports the current state of development of the Italian demonstrator. Five buildings have been identified: two schools and three residential houses. They all represent typical Italian building typologies showing high replicability values. This report gives information about the E-DYCE rationale for step 1 (inspection) for the five buildings, including methodological aspects. Additionally, an intelligent monitoring system in all buildings has been positioned for project purposes. Chosen probes are here described together with the selected monitoring plan and methodology. In addition, different aspects of the E-DYCE rationale step 2 are also described, including the development of EnergyPlus models for all of the Italian demos. Models have been verified on initial monitored data to support the following project steps. The models are adjusted to be usable by the E-DYCE dynamic simulation platform (PREDYCE) and managed via the E-DYCE project middleware (FusiX). Additionally, the model organisation allows connecting thermal zones with related monitoring data points to support performance gap analyses further and help the model verification phase. Additional information about Italian demo buildings is also provided in D5.1.

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