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Table of Contents

List of Figures

List of Tables

1 Executive Summary

This report details demonstration results focusing on evaluation of the proposed E-DYCE approach in demo buildings. It mainly pursues three correlated objectives.

Firstly, in Part A of this report, the proposed DEPC (Dynamic Energy Performance Certification) protocol described in Deliverable D2.4 is verified and evaluated in terms of functionalities and the meaning of the proposed KPIs (Key Performance Indicators). Adopted KPIs face energy, energy signature, indoor environmental quality (IEQ) and free-running issues. This point includes the test of the E-DYCE middleware (FusiX) and the dynamic simulation platform (PREDYCE), exploiting the hybridisation of calculated via simulations and measured data in detecting performance gaps. A comparison between standard and adapted simulations is also pursued to verify the impact of input adaptations of the conditions of use after inspection.

Secondly, in Part B of this report, the deliverable analyses the application of extended E-DYCE functionalities, including generating renovation roadmaps, forecasting behaviours and detailed measured and simulated data results. Hence, this point includes specific data analyses focussing on data results and verifying the E-DYCE potentialities related to extended analyses by exploiting the possibility of calibrated models, dynamic simulation approaches, and deep building monitoring plans. The focus on results allows verification and validation of the ability of the proposed approach, methods and platforms in supporting building performance evaluations. In addition, it is possible to mention extended IEQ analyses on indoor air quality and thermal comfort, district heating visions and free-running studies. Each national demonstrator is treated in this part individually, presenting the local-specific results focused on different functionalities, even if all demonstrators follow a general scheme to allow the cumulative verification of the other extended functionalities.

Thirdly, in Part C of this report, a scaling-up vision of the two above parts is discussed, supporting the E-DYCE post-project development by a short analysis of the E-DYCE platform and DEPC method ability in supporting policy and professional applications. This point includes lessons learnt recaps and some discussions about limitations and barriers.

Part A and C are suggested for policy makers, professionals involved in certification processes and owners and additional stakeholders interested in the E-DYCE dynamic certification protocol. Part B is mainly devoted for interested professionals and companies, such as ESCOs, researchers, supporting not only energy certification, but also energy management, refurbishment, focussed indoor environmental and energy in buildings analyses taking advantages of the extended E-DYCE methodology and platform functionalities.

For a detailed description of demonstration cases and the inputting modelling phase, please see deliverable D5.1 and the following D5.2-D5.5 reports focussing on national buildings.

2 Introduction

The E-DYCE project focuses on the development of a dynamic building protocol which supports real-time optimisation of energy needs and comfort, including renovation roadmaps. The approach combines smart technologies with low-tech solutions and valorises the free-running potential of buildings by proposing a DEPC (Dynamic Energy Performance Certification) methodology. The project also has a strong focus on end-user behaviour changes and personalisation of outcomes for different end-users to collect feedback and recommend adaptation and retrofitting actions. The E-DYCE methodology and protocol include the development and adoption of data-management platforms supporting building monitoring and simulations via the proposed middleware, based on the FusiX platform, and the developed dynamic energy simulation platform PREDYCE. The methodology may be applied to different solutions being technology neutral. In line with deliverable D5.1, E-DYCE methodologies and tools are based on a 3-dimensional approach by i.) proposing a simplified method to support building energy and comfort dynamic simulations, ii.) comparing monitored and simulated outcomes fastening the detection of performance gaps, and iii.) developing a middleware infrastructure connecting monitored and simulated dataflows including the application of the DEPC protocol and the integration of additional modules. The former E-DYCE tasks introduce the description of the E-DYCE DEPC protocol and correlated KPIs (Task 2.4), E-DYCE correlated simulation (Task 1.2, Task 3.1 and 3.2) and monitoring specifications (Task 5.1 - 5.5) together with an inspection protocol (Task 2.1) and the definition of the mentioned platforms (Task 4.1 and Task 3.1). A short summary of the E-DYCE logic is reported in Section 2.1, before detailing the contents of this specific D5.6 deliverable which aims at reporting and collecting the final key results of the E-DYCE demonstrators, including the check of the DEPC protocol and functionalities, and scaling up main lessons learnt.

This deliverable aims at reporting final demonstrator results supporting the description of main lessons learnt and the test of the E-DYCE DEPC protocol in demo cases. Additionally, this report also analyses scaling up approaches and topics supporting current and future E-DYCE potential developments.

2.1 Structure and objectives of D5.6

The main objective of the current Deliverable (D5.6) is the evaluation of the proposed protocol, including correlated KPIs, and the extended E-DYCE functionalities on the base of data analysis for the most significative E-DYCE demo cases. The deliverable includes demo case-building data results by also referring to previous deliverables' principal outcomes to discuss the E-DYCE proposed approach. In the deliverable, they are also analysed in detail the application of the E-DYCE extended functionalities within their main applicability domains, including renovation roadmaps, forecasting approaches, where applied, and direct comparisons of performance gaps (PG) between measurements and simulated standard and simulated adapted models. The capability of the E-DYCE dynamic platform and DEPC protocol is tested, and scaling-up suggestions are given by the Consortium, including the policy dimension.

The evaluation of the proposed approach is subdivided in this report into three main domains:

Part A of this report - The DEPC protocol with its KPIs and the calculation and visualisation platform is applied and evaluated; this part is devoted to testing of the E-DYCE protocol and the ability of the proposed KPIs in being passed to end users and focusing on the procedure evaluation.

Part B of this report - The evaluation of the E-DYCE extended functionalities, which differ among demo cases, focusing on the ability of the proposed methodologies and tools to support additional analyses and aspects; supports a deeper evaluation of data results, including, for example, detailed analyses and shortcoming in selected demos.

Part C of this report - The lessons learnt supporting future scaling-up activities and the policy dimension together with barriers and challenges detected.

3 PART A: E-DYCE protocol and main functionalities

3.1 Recap and Applications of the E-DYCE protocol

The E-DYCE DEPC protocol development is reported in detail in D2.4. The protocol utilizes existing assessment schemas (EN ISO 52000-1) and anchors the E-DYCE DEPC methodology to the current EPC rating. It serves as a supplement to the certification schema, aiming to identify performance gaps and support energy improvement without creating new labels. The E-DYCE methodology focuses on distributed energy demands and offers flexibility for different building types. It enhances certifiers' capabilities, generates valuable information, and is validated in pilot buildings. Accordingly, the E-DYCE certification will not generate a new type of label, but instead will be dedicated to detecting causes of the performance gap and to support potential improvement for PG elimination and the energy need reduction.

The protocol remains open for adjustments based on pilot outcomes. The choice between multi-zone and mono-zone models is being investigated and documented in D2.5 and D3.6. While the mono-zone solution is rather obvious and easy to address, by considering the whole simulation domain as one zone, the multi-zone approach can result in multiple geometrical solutions. The decision of zoning can also depend on the building typology, load distribution, or climate the building is located in, and it is crucial for the E-DYCE DEPC procedure.

E-DYCE DEPC process generates information to augment certifier capabilities to perform dynamic analyses on the energy behavior of buildings, to provide an incitement for the potential improvements of the building, to recommend renovations, or to suggest other behavior. The information generated through E-DYCE DEPC process will vary depending on the information that is fed in, but also depending on what information is valuable for the end-user. The scope and number of the Key Performance Indicators (KPIs) is adjusted according to the identified user groups:

a. *Tenants/users, operators, or owners of small buildings*
b. *Building energy professionals*

Examples of E-DYCE DEPC protocols for tenants and respectively experts are given in Table 1 and Table 2. The scope of identified potentially valuable results for tenants is proposed significantly smaller compared to experts.

Table 1 . E-DYCE DEPC protocol - KPIs for tenants

KPI	Symbol	Assessment schema				Evaluation period		Asset zoning		Operational zonning		Ref.
		EPC	DEPC-AS	DEPC-AA	DEPC-O	Min	Max	Mono	Multi	Mono	Multi	
Global energy performance index	Q_gl			✗	✗	month	year	✓	✗			ISO 52000-1:2017
Final energy need for heating	f_Q_h			✓	✓	week	year	✓	✓	✓	✓	For EPC: ISO 52000-1:2017 and for DEPC: EN ISO 52016-1:2017 and ISO 52017-1:2019
Final energy need for cooling	f_Q_c			✓	✓	week	year	✓	✓	✓	✓	
Final energy need for DHW	f_Q_dh			✗	✓	week	year	✓	✓	✓	✓	
Final energy need for heating for an average space in the building	f_Q_h_av			✓	✓	week	year	✗	✓	✗	✓	For EPC: ISO 52000-1:2017 and for DEPC: EN ISO 52016-1:2017 and ISO 52017-1:2020
Final energy need for cooling for an average space in the building	f_Q_c_av			✓	✓	week	year	✗	✓	✗	✓	
Operative temperature	t_op_i			✓	✓	week			✓		✓	
CO_2 concentration	CO2			✓	✓	week			✓		✓	

✓ – the KPI can potentially be calculated/measured
✗ – the KPI cannot potentially be calculated /measured

Table 2 E-DYCE DEPC protocol - KPIs for certification party

KPI	Symbol	Assessment schema				Evaluation period		Operational zonning		Asset zoning		Ref.
		EPC	DEPC-AS	DEPC-AA	DEPC-O	Min	Max	Mono	Multi	Mono	Multi	
Global energy performance index	Q_gl	✓	✗	✗	✗	month	year			✓	✗	For EPC: ISO 52000-1:2017 and for DEPC:
Primary energy need for heating	Q_h	✓	✓	✓	✓	week/month	year	✓	✓	✓	✓	EN ISO 52016-1:2017 and ISO 52017-
Primary energy need for cooling	Q_c	✓	✓	✓	✓	week/month	year	✓	✓	✓	✓	1:2019
Primary energy need for DHW	Q_dh	✓	✗	✗	✓	week/month	year	✓	✓	✓	✓	For EPC: ISO 52000-1:2017 and for DEPC-AS+AA: EN ISO 52016-
Primary electricity need for running technical installations	Q_tech	✓	✓✗	✓✗	✗	week/month	year	✓	✓	✓	✓	For EPC: ISO 52000-1:2017 and for DEPC:
Primary electricity need for lighting (if relevant)	Q_l	✓	✓	✓	✗	week/month	year	✓	✓	✗	✓	EN ISO 52016-1:2017 and ISO 52017-
Primary energy need for heating for an average space in the building	Q_h_av	✗	✓	✓	✓	week/month	year	✗	✓	✗	✓	For EPC: ISO 52000-1:2017 and for DEPC:
Primary energy need for cooling for an average space in the building	Q_c_av	✗	✓	✓	✓	week/month	year	✗	✓	✗	✓	EN ISO 52016-1:2017 and ISO 52017-
Primary energy need for heating for the critical zone	Q_h_cr	✗	✓	✓	✓	week/month	year	✗	✓	✓✗	✓	1:2019
Primary energy need for cooling for the critical zone	Q_c_cr	✗	✓	✓	✓	week/month	year	✗	✓	✓✗	✓	
Energy signature, global solar correlated	EN_SIG_2D		✓	✓	✓	month	year	✓	✓	✓	✓	EN 15603:2008, Acquaviva et al., 2015;
Energy signature, global solar correlated for the critical zone (heating)	EN_SIG_2D_h		✓	✓	✓	week/month	year	✗	✓	✓✗	✓	Eriksson et al., 2020; Hitchin and
Energy signature, global solar correlated for the critical zone (cooling)	EN_SIG_2D_c		✓	✓	✓	week/month	year	✗	✓	✓✗	✓	Knight,2016
Fictious Energy need for free-running mode (cooling)	FICT_COOL	✗	✓	✓		week/month	year	✓	✓	✓	✓	E-DYCE deliverable 1.2
Fictious Energy need for free-running mode (heating)	FICT_HEAT	✗	✓	✓		week/month	year	✓	✓	✓	✓	E-DYCE deliverable 1.2
Number of free-running hours (cooling season)	n_fr_c	✗	✓	✓	✓	week/month	year	✓	✓	✓	✓	E-DYCE deliverable 1.2
Number of free-running hours (heating season)	n_fr_h	✗	✓	✓	✓	week/month	year	✓	✓	✓	✓	
Number of free-running hours for critical room (cooling season)	n_fr_c_cr	✗	✓	✓	✓	week/month	year	✓	✓	✓✗	✓	
Number of free-running hours for critical room (heating seson)	n_fr_h_cr	✗	✓	✓	✓	week/month	year	✓	✓	✓✗	✓	
Number of hours when CO2 level is below category I, for heating season	n_co2_bI_h	✗	✓	✓	✓	week/month	year	✓	✓	✓	✓	adapted from EN 16798
Number of hours when CO2 level is below category I, for cooling season	n_co2_bI_c	✗	✓	✓	✓	week/month	year	✓	✓	✓	✓	
Number of hours when CO2 level is above category III, for heating season	n_co2_aIII_h											
Number of hours when CO2 level is above category III, for heating season	n_co2_aIII_c	✗	✓	✓	✓	week/month	year	✓	✓	✓	✓	
Number of hours when CO2 level is below category I for the zone with maximum heating/cooling demand	n_co2_bI_cr	✗	✓	✓	✓	week/month	year	✗	✓	✗	✓	
Number of hours when CO2 level is above category III for the zone with minimum heating/cooling demand	n_co2_aIII_cr	✗	✓	✓	✓	week/month	year	✗	✓	✗	✓	
Operative temperature in the critical zone for heating season	t_op_h_cr		✓	✓	✓	week	year	✗	✓	✓✗	✓	EN 16798-1 for adaptive comfort; EN ISO
Operative temperature in the critical zone for cooling season	t_op_c_cr		✓	✓	✓	week	year	✗	✓	✓✗	✓	7730 for Fanger model
Operative temperature in the critical zone in free-running for heating			✓	✓	✓	week	year	✗	✓	✓✗	✓	
Operative temperature in the critical zone in free-running for cooling			✓	✓	✓	week	year	✗	✓	✓✗	✓	
✓ - the KPI can potentially be calculated/measured												
✓✗ - determination of this KPI strongly depends on availability of data												
✗ - this KPI cannot be calculated												

3.1.1 Summary and definition of KPIs

The following section includes a short description of the key performance indicators that will be graphically represented in Section 3.3, for a more detailed description refer to the Deliverable D2.4. It should be noticed that not all indicators selected for the E-DYCE protocol will be included in the full integration and visualisation process. Some of them, which for different reasons (connected both to monitoring and simulation) were more complex to be included in the full process, will be however detailed in Part B of this report. The KPIs could be divided into four groups:

1. **Energy KPIs**:
   - ***f_Q_h***: <u>total final energy for heating on the selected period, expressed in kWh/m^2.</u>
     Note: It is possible for each demo provider to identify losses coefficients (due to generation, distribution, regulation, emission losses) to be applied to simulation result and/or to monitored data. The same KPI is provided also in a timeseries version, with an hourly sum, which in some cases (e.g., Italian Torre Pellice demo cases) is the lower time limit available for the transmitted monitored data. Despite primary energy is currently adopted in the certification procedure, it was highlighted how the final energy has a stronger meaning for the tenants to interpret the results. The user or the control authority may read this indicator on a counter or calculate it from the fuel consumption.
   - ***Q_h***: <u>total primary energy for heating on the selected period, expressed in kWh/m^2.</u>
     Note: Besides the losses' coefficients, each demo provider should identify the proper conversion factor to primary energy. The same KPI is provided also in a timeseries version, with an hourly sum. The same KPIs (final and primary energy) could be available also for the cooling system, for the domestic hot water, for electricity from lighting systems and from the technical installations. However, some of these variables are not monitored in most demo cases and some, e.g., the cooling system, are not even installed in most of the buildings except the Cyprus case study. Hence, the heating KPIs heating KPIs are the most relevant for the visualisation in Section 3.3, while other KPIs are addressed on the specific national demos' analyses in part B of this report.

2. **Energy Signature:**

   the energy signature is computed differently than all the other KPIs inside the integration process, since it requires to just once compute the points describing the straight line or the plane and then monitored points could be plotted on the graph without requiring any other simulation. Particularly, for the E-DYCE protocol it was chosen to provide two typologies of energy signatures: i. the standard energy signature, computed on a TMY for the selected location and on the standard version of the building model, and ii. the adapted energy signature, computed for each heating season (which is identified by a schedule provided by each demo provider) on the monitored weather and on the adapted version of the building model. The different energy signatures are provided once from the POLITO simulation platform to the EMTECH visualisation app and are then plotted together on the same graph to give an idea of how the current weekly consumption behave if compared to the previous years and to the expected standard behaviour. The proposed graph will be a one-dimensional signature with external mean temperature on the x-axis and heating/cooling final energy consumption expressed in Wh/m3 on the y-axis. A weekly time aggregation is used.

3. **Indoor Environmental Quality (IEQ) – Indoor air quality (IAQ) & thermal comfort KPIs**:
   - ***n_co2_bl_h***: total amount of occupied hours with an average CO_2 concentration value below the threshold of 600 ppm, during the heating/cooling season.

     Note: A low CO_2 value in occupied hours could be a symptom of over-ventilation with negative effects on heating/cooling consumption. So, this indicator could give a suggestion to close windows if open. The same KPI is also provided in the time series version, with Boolean values 1/0 indicating if a specific hour matches the condition or not.
   - ***n_co2_bl_c***: total amount of occupied hours with an average CO_2 concentration value below the threshold of 600 ppm, during the cooling (or the not heating) season.

     Note: Since most demo cases analysed in the E-DCYE project are not equipped with a cooling system, the “cooling season” KPIs, are also interpreted as computable during the free-running season where the heating system is not active. The same KPI is also provided in the time series version.
   - ***n_co2_alII_h***: the total amount of occupied hours during the heating season with an average CO_2 concentration value above the threshold of 1000 ppm.

     Note: The same KPI is provided also in the timeseries version.
   - ***timeseries_co2***: timeseries of hourly CO_2 average value

     Note: Since the threshold of 1000 ppm is commonly exceeded in buildings not equipped with mechanical ventilation systems, it was chosen to also provide the hourly CO_2 average value, which can give a better understanding of the current indoor air quality conditions and help in changing natural ventilation habits in the long term.

Note: differently by the E-DYCE initial protocol, for this analysis is provided a bar chart analysing the above-mentioned thresholds and a carpet plot distribution of the measured values following an approach compatible not only with mechanically ventilated buildings, but also with naturally ventilated one. The latter approach takes advantages form the French and Swiss approach by expanding the ICONE classification (confinement index). In this case, a starting threshold around 400-450 ppm is assumed (average outdoor concentration) is defined with two following acceptance thresholds set to 1000ppm (in line with E-DYCE mechanical ventilation one) and 1700ppm (suggested by the ICONE approach[2]) - the latter

[2] A recent change in the French regulation suggested a restrictive change in the thresholds (starting from 1st January 2023) passing respectively to 800 and 1500ppm. https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000046830005

may be substituted to adapt to changing local regulations and local conditions, such as the Swiss threshold suggestion (SIA 180 does not fixe a limit value but speaks of directive range 1000-2000 ppm for non-confined occupied spaces. Extreme critical thresholds are set to 3000ppm and 3500ppm considering for example the night behaviours in a residential bedroom.

- ***t_op_h_cr***: <u>average operative temperature during the heating season in the critical zone on the selected period expressed in Celsius degrees</u>.
  Note: KPIs computed in the critical zone should be used to identify the most critical zone in the building (with lowest temperatures in this case) as a reference to dimension the heating system and/or define the heating schedule. However, it was chosen to compute the operative temperature KPI on all the modelled zones which have an associated monitoring sensor, to identify in a second moment which is the critical zone for the building. It is also available as time series version, with average hourly values. Since the operative temperature is not measured in the demo cases, for the performance gap the simulated operative temperature is compared with the monitored dry bulb – see D4.3.
- ***t_op_c_cr***: <u>average operative temperature during the cooling/not-heating season on the selected period expressed in Celsius degrees</u>.
  Note: It could be used to identify the most critical zone in the building (with the highest temperatures in this case) as a reference to dimension the cooling system and/or define the cooling schedule. It is computed on all the monitored zones of the building model, and it is also available as time series version, with average hourly values.

4. **Free-Running KPIs:**
   - ***n_fr_h***: <u>total number of hours during the heating season (which is always identified by a schedule given by each demo provider) in which the hourly heating consumption in kWh is below the threshold of 0.01 kWh</u>.
     Note: The threshold was chosen to be very low, but not exactly 0 kWh, since in the simulation is very rare to retrieve as output a 0 value if the system is active according to a schedule. This KPI should give an indication of when heating the building is not needed and the building could also go free running without losing in thermal comfort, with respect to the setpoint. The same KPI is provided also in the time series version, with Boolean values 1/0 indicating if a specific hour matches the condition or not.
   - ***fict_cool*** and ***fict_heat***: <u>fictitious heating and cooling indicators</u>
     Note: These indicators are newly developed (inside the E-DYCE project) and very promising indicators, which should allow to address those buildings unequipped with a heating or cooling system making them comparable in terms of fictitious energy needs with those equipped with a mechanical system, additional details on the indicators are present in the Deliverable D3.2. However, they are quite complex indicators which need additional future studies to be finalised in a comprehensive vision. Hence, they are only addressed in Part B of this report exploiting a specific demo case as an example.

3.2 The E-DYCE platform

The application of the DEPC protocol includes the usage and test of the E-DYCE platform functionalities. The application bases on a complex dataflow between modules and functionalities - see Figure 1.

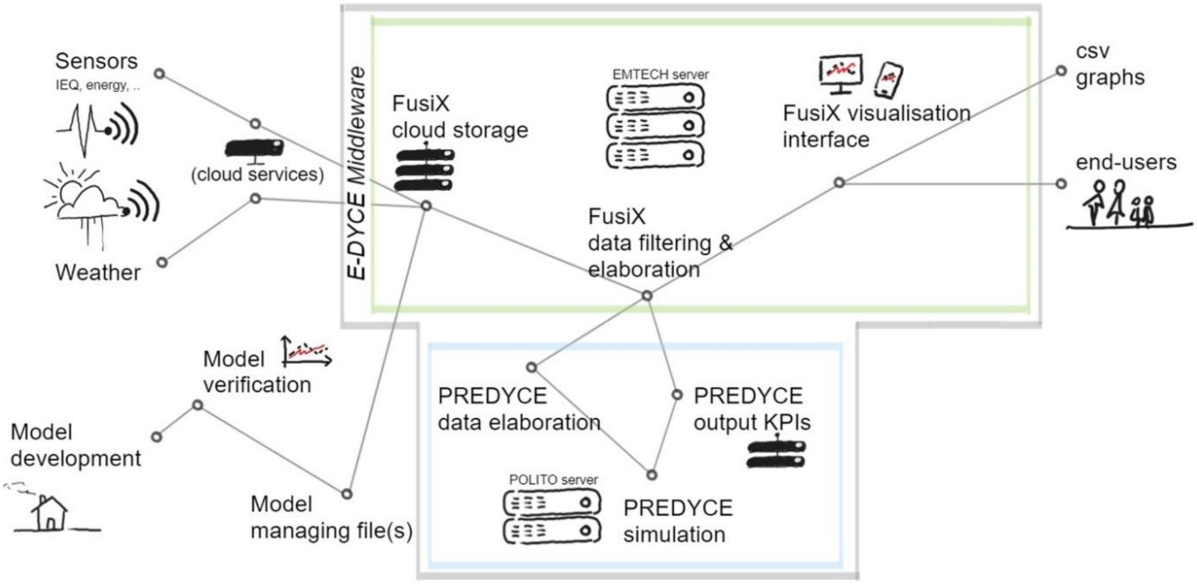


Figure 1 The general E-DYCE platform dataflow from sensors and models to end-users

On the base of this flow, upgrades have been performed for each demo case to consider the specific conditions, e.g. the local monitoring systems, the model spatial organisation, the confirmation of the KPI list. For example, EPWs have been directly produced via PREDYCE using the devoted Python module and exploiting the internal server database, for example, the Italian weather station was directly connected to the POLITO server. In sections 3.2.1 and 3.2.2 below can be found a more detailed elaboration of E-DYCE middleware (FusiX) and PREDYCE simulation platform that both constitute E-DYCE platform.

3.2.1 E-DYCE middleware (FusiX)

The project dataflow and data visualisation are managed via the FusiX middleware. The development of the E-DYCE platform is deeply described in project deliverables, although the specific middleware development is confidential. Nevertheless, Part A results are extracted by the E-DYCE middleware UI allowing to discuss FusiX correlated outcomes.

The FusiX platform is used to integrate monitoring data with smart functionality developed during the project and most notably the PREDYCE platform. The FusiX platform implementation is separated in the following elements:

- Data Bridges. Modules used to retrieve data via the necessary protocols from the monitoring platforms of the target buildings and the Technology Providers that provide the smart functionalities.
- APIs. Used to allow external entities to retrieve data stored in FusiX based on appropriate credentials and access.
- Data Management. Module that allows the processing of raw data as needed to support the technology providers.
- Data Storage. Module that handles database storage and retrieval for all raw and generated data according to the information.

The FusiX framework is supported by a Web and a Mobile User Interface to support the data visualization needs. These are connected to the APIs as external entities to enable data acquisition according to specific credentials and privileges. The following Figure 2 depicts the high-level architecture of the application.

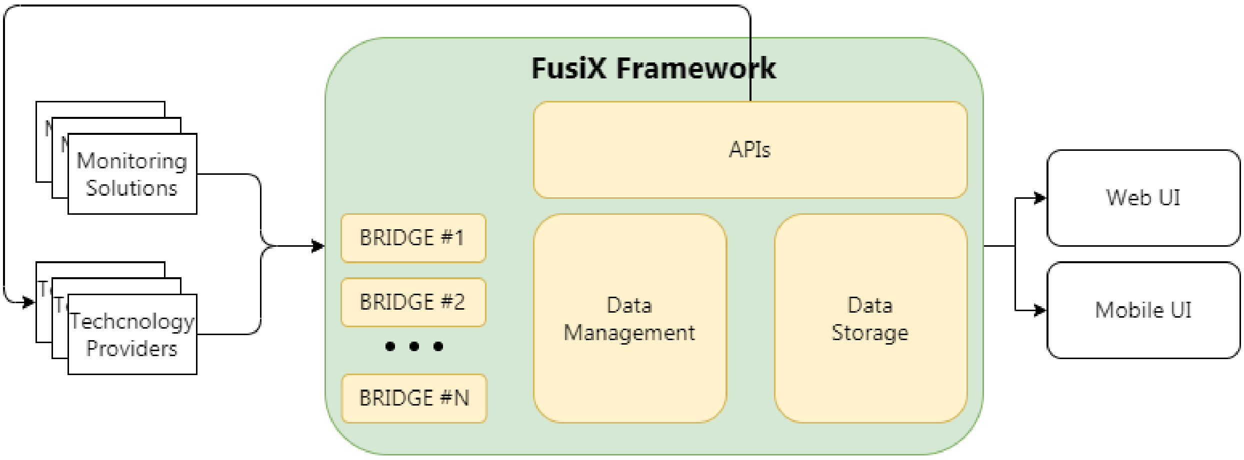


Figure 2 High-level architecture of the FusiX application

The major visualization element is the Web-UI. This user interface has been developed with expert users in mind and tries to accommodate a variety of graphs and allow maximum customization on the underlying visualization. The user interface is separated in the following sections:

- Dashboard. A page that displays high priority and important information to the user. The goal is to give a high-level overview of the general building condition.
- Building Knowledge. A page that allows expert users to upload and download specialized files to support simulations and renovation roadmaps.
- Simulation Platform. A page that allows users to examine the results of the PREDYCE platform. These are discussed and explained throughout this document.
- Annual Analysis. A page that allows historical analysis of building monitoring data on annual basis, using a variety of statistical tools.
- Administration. A page that allows users to perform general actions for user and building management.

Some example pages are depicted in the following Figure 3.

Figure 3 Sample pages of the Web-UI

3.2.2 E-DYCE dynamic simulation platform (PREDYCE)

The E-DYCE simulation approach takes advantage of the developed dynamic energy simulation platform PREDYCE based on the EnergyPlus engine. This platform can parametrically modify IDF input files according to required lists of input/output according to specific simulation scopes. PREDYCE also allows the calculation of the KPIs identified in the E-DYCE DEPC protocol. The developed simulation platform PREDYCE is tested in Danish and Italian demonstrators. The E-DYCE methodology developed to be technology-neutral, for the Swiss and Cypriot demonstrators, is applied by exploiting a stand-alone approach, including also simulations run in other energy dynamic tools such as DIAL$^+$. Concerning the PREDYCE applications, the Part A of this deliverable illustrates the use of the dynamic simulation platform as an automatically integrated module inside the middleware FusiX – see the above sub-section – to connect simulation runs with monitored results. By that, the full advantage of the proposed automatic dataflow to detect performance gaps and calculate specific KPIs via PREDYCE on both simulated and monitored results can be utilized. The description of the PREDYCE platform is available in the correlated deliverables D3.1 and D3.2, while its integration in the FusiX middleware is discussed in other project deliverables. A specific description of this integration is also reported in the following sub-section.

3.2.3 FusiX and PREDYCE Connection

Apart from the general overview above, the following notes can be made for the interconnection of PREDYCE with FusiX. During the project two approaches were used to generate simulation results and visualize them in the FusiX Web user interface.
The first concerns the fully automatic operation and is depicted in the following Figure 4. In this setup, FusiX independently collects the monitoring and stores them. Periodically, daily or weekly, the PREDYCE framework is called from FusiX with the necessary input to perform the simulation. The results are returned to FusiX and are in turn visualized in the user interface. This automatic process has FusiX as the master coordinator of the operation and is used for buildings that have consistent and complete monitoring datasets.

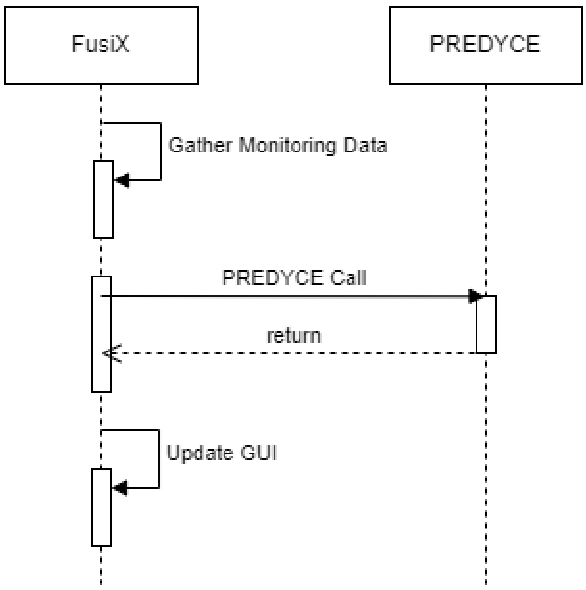


Figure 4 FusiX-PREDYCE connection: fully automatic operation setup

The second concerns the manual operation of PREDYCE and is depicted in the following Figure 5. In this setup, FusiX independently collects monitoring data. PREDYCE also works independently and on an ad-hoc fashion a) collects monitoring data from the FusiX APIs, b) performs the simulation, and c) provides the results back to FusiX either manually or via API calls. The results are finally displayed on the user interface.

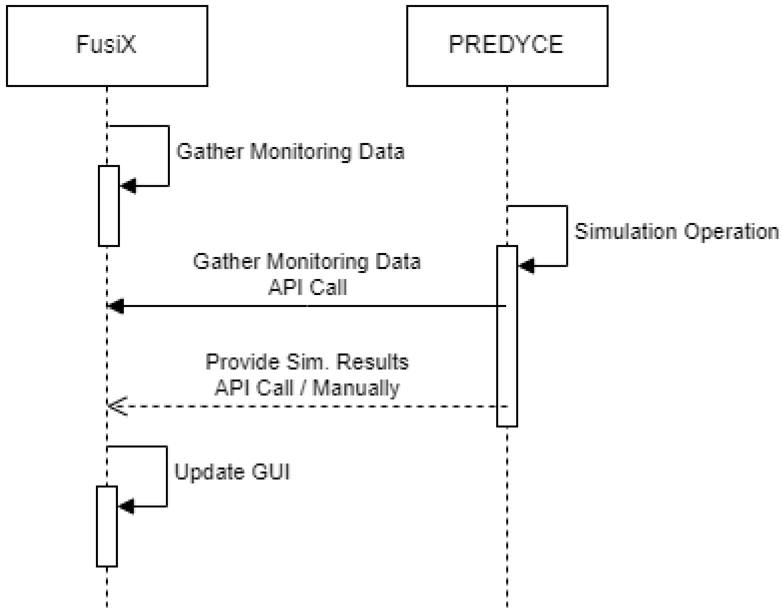


Figure 5 FusiX-PREDYCE connection: manual operation setup

3.3 E-DYCE protocol KPIs and demo applications

This section reports and discusses the results of the application of the DEPC's KPIs on demo cases. The graphs are obtained via the E-DYCE platform described above and illustrated in Figure 1. The whole process is supported for Danish and Italian buildings including the E-DYCE middleware management of simulations via the PREDYCE REST to automatically feed standard simulated and adapted simulated data and correlated performance gaps with respect to the measured ones.

3.3.1 Energy KPIs

Concerning energy KPIs, two graphs to address both user groups are reported via FusiX to describe the behaviours of E-DYCE connected buildings: one in Primary Energy (apply the coefficient of primary energy that is different in each county) and one in Final Energy. The plots are bar charts, with on the x-axis the week of the year (or the month of the year) and on the y-axis the energy use expressed in kWh/m^2. The weekly aggregation, used also in the energy signature, has been chosen as the most representative for feedback purposes, since less impacted by specific fluctuations but still frequent enough to early detect possible anomalies and take quick response actions. The graphs include three columns: two simulation outputs corresponding to standard and adapted model settings, both simulated under real weather conditions, and the monitored output. The energy KPIs are expressed in kWh/m^2 to be in line with the current certification standard.

3.3.1.1 Danish demos – primary energy for heating

Concerning the Danish demo case building "Haanbaek (building code number B1.4 given in E-DYCE project), results are presented for primary energy for heating (indicator Q_h). The selected results are presented as indicated in Table 3 and concern apartment level and weekly and/or monthly aggregated data. Data are illustrated in Figure 6.

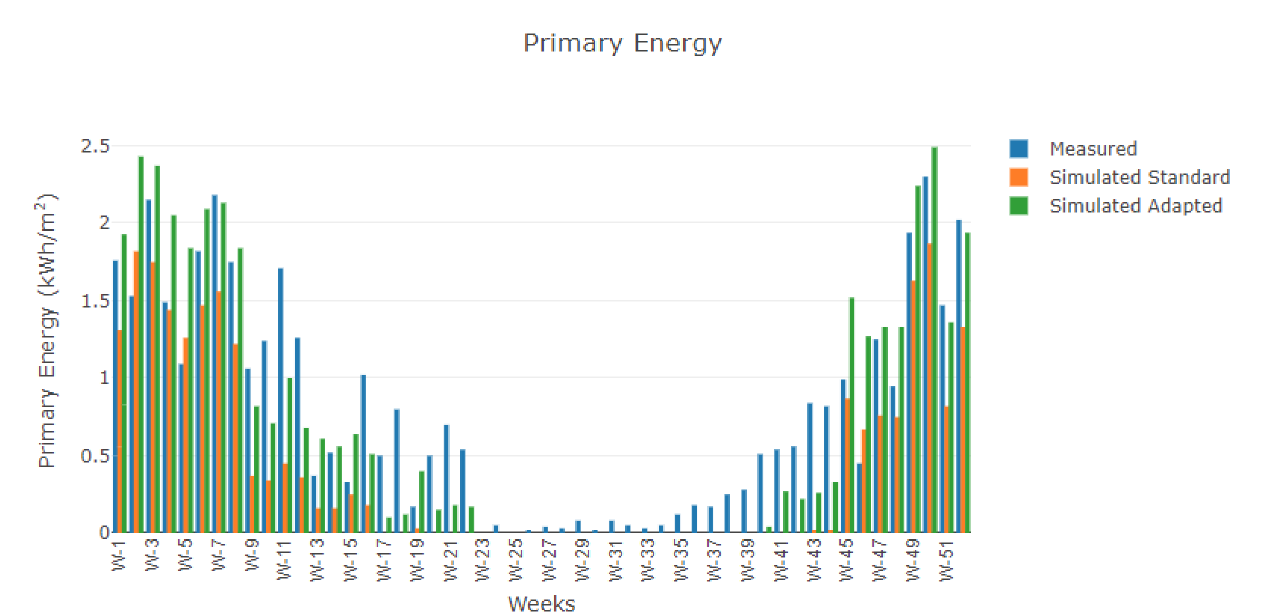
The advantage of the E-DYCE approach is visible for the selected apartment weekly aggregated data for 2021 and 2022 year. While simulated heat demand for standard and adapted conditions are to some extend different from each other they both indicate a good trajectory of expected space heating energy use. Adapted conditions contribute to a decreased performance gap. Still, measured space heating for week 48-50 in the year 2022 show a very significant discrepancy both from the simulated expected and from the previous year's operation in 2021. The expected energy use is up to about 2.5 kWh/m^2 while in

2022 year the heat demand goes as high as a bit above 15 kWh/m^2. The reason behind the elevated energy use is unknown but can be immediately captured and corrective measures can be sought. Moreover, it can be spotted that neither adapted nor standard simulation approaches can capture heat demand in weeks that are normally non-heating seasons (approximately weeks 17-34), while measurements show energy use. This again illustrates the robust E-DYCE approach to detect possible energy-saving potentials.

Table 3 Overview of selected results presented for the Danish case Haanbaek

	Year	Aggregation
Apartment level	2021 and 2022	weekly

Q_h B1.4 (Haanbaek) Apartment level 1tv– Y2021 weekly plot



Q_h B1.4(Haanbaek) Apartment level 1tv– Y2022 weekly plot

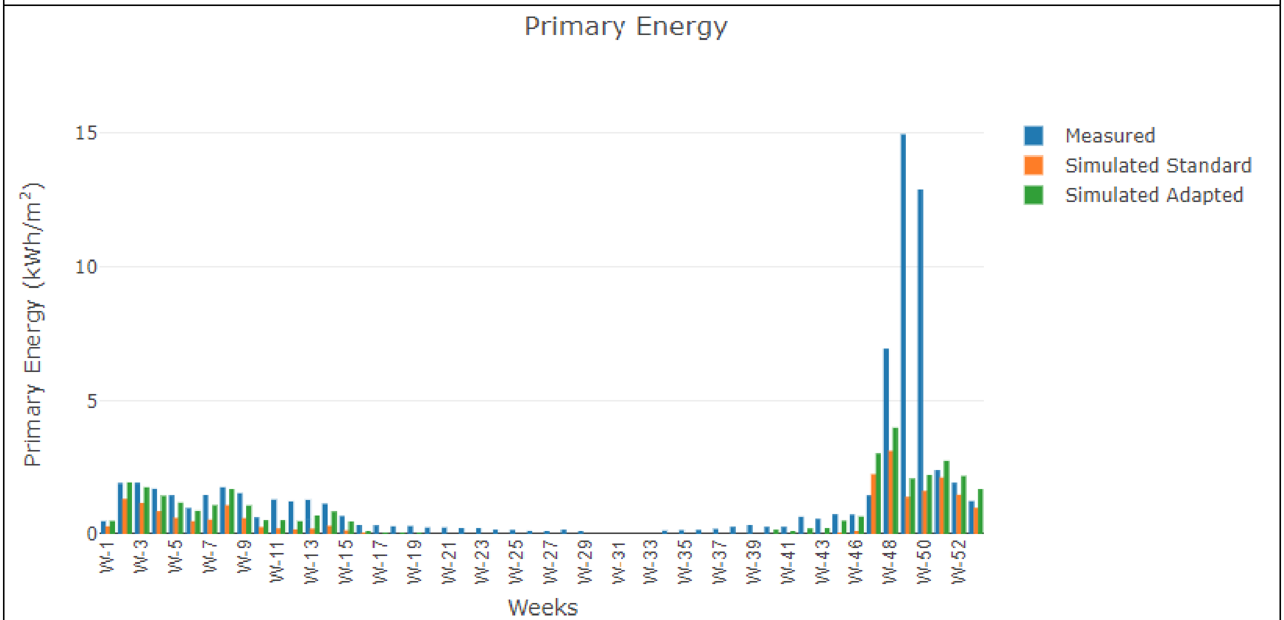


Figure 6 Primary space heat demand at apartment level for Haanbaek building case, weekly aggregated data for selected apartments for years 2021 and 2022

3.3.1.2 Italian demos – final energy for heating

Concerning Italian demo cases, Figure 7 shows the final energy indicator (f_Q_h) for B2.5, while Figure 8 for B2.1 on the kindergarten floor. In demo B2.5, the gap between monitored and simulated values is great both in the case of standard and adapted operational settings, even though the adapted one is smaller. In B2.1 instead, energy related KPIs are here visualised only for the kindergarten since it is controlled by a separate thermostat with respect to the other floors. The other floors are not shown since it was chosen to adopt four separate models for the four floors, hence requiring a post-analysis to merge the consumption results from the four simulations which is beyond the goals of the automatization process demonstrability. The use of computationally faster cut models has several advantages to be able to give more immediate feedbacks to users or building managers, but in terms of consumption analysis it presents several drawbacks. However, the analysis is still possible in principle by developing ad hoc algorithms. Results in this case show that adapted conditions allow to follow well the monitored trend, while standard settings highly overestimate the real consumption.

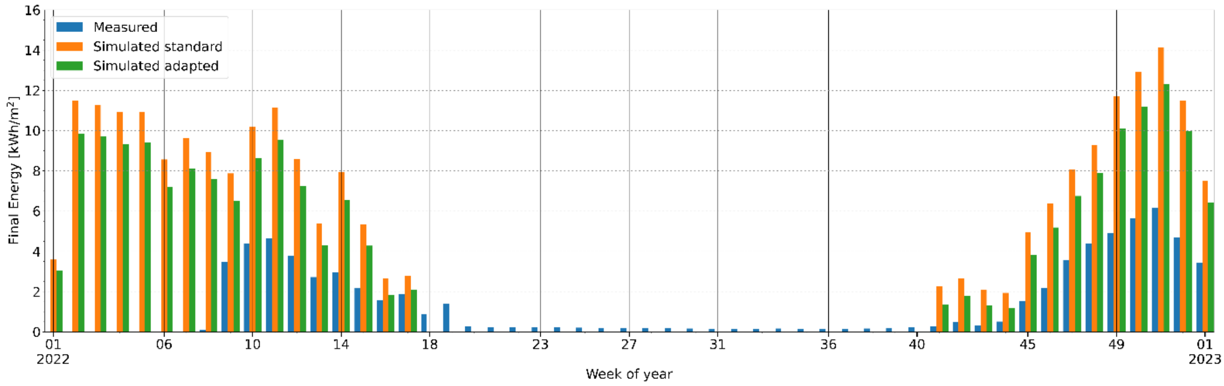


Figure 7 f_Q_h B2.5 Y2022 weekly plot

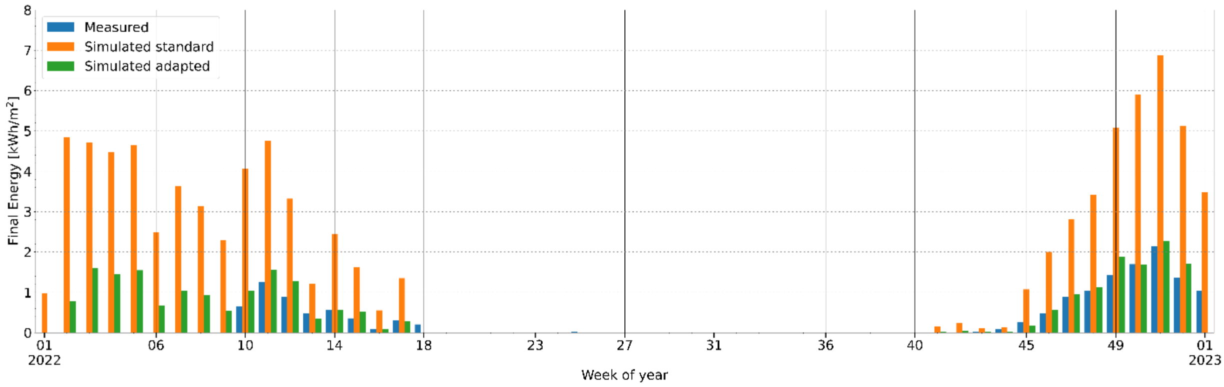


Figure 8 f_Q_h B2.1 Kindergarten Y2022 weekly plot

3.3.1.4 Italian demos – heat signature

Concerning Italian demo case B2.5, Figure 9 shows three first degree regression lines: the standard heating signature, the adapted heating signature for winter season 2021-22 and for winter season 2022-23. Monitored data points are available from March 2022, hence just the winter season 2022-23 is fully covered. The B2.5 demo case has not been calibrated with respect to heating consumption, since it uses a wooden stove on a regular basis – see Section 4.3.1. Hence, the simulated heating needs significantly over-estimate the real consumption for this demo case. This was common to all Italian residential demo cases, with the exclusion of demo B2.4. The plot shows also the monitored weekly aggregated data points, updating the graph once per week. Concerning B2.1 Kindergarten instead, adapted regression lines shown in Figure 10 can follow the monitored points and general trend, while it is evident how the standard signature greatly differs from the real behaviour.

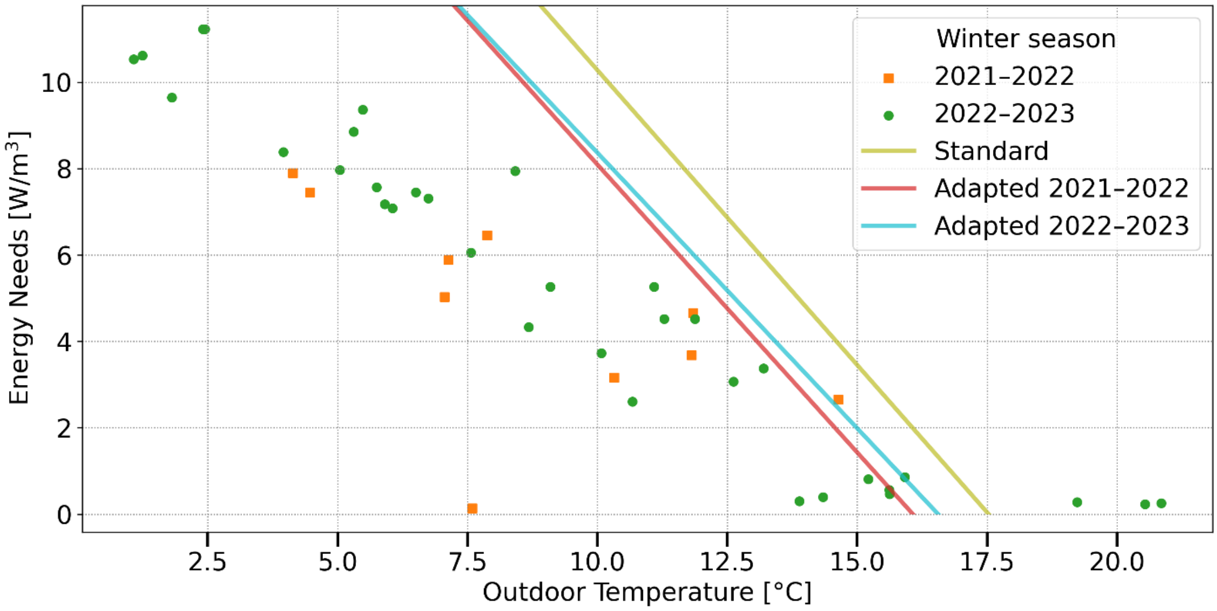


Figure 9 EN_SIG_1D B2.5

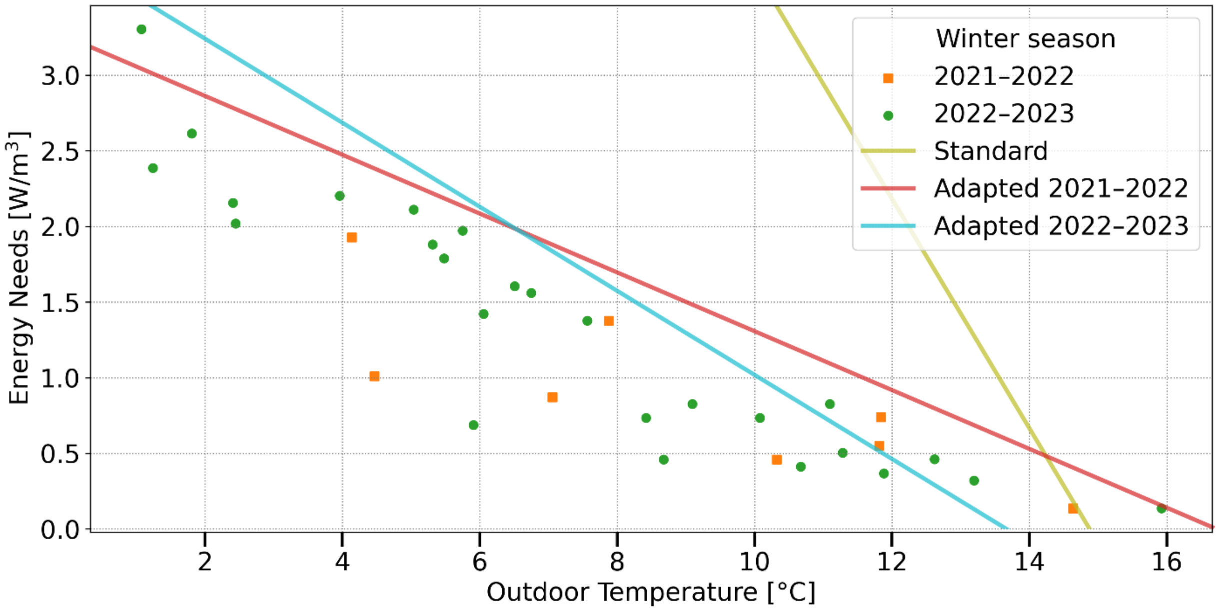


Figure 10 EN_SIG_1D B2.1 Kindergarten

3.3.2 Indoor Environmental Quality (IEQ) – Indoor air quality (IAQ) & thermal comfort

The available plots related to CO_2 simulation and monitoring results are:

- The monitored timeseries hourly CO_2 concentration value in ppm is shown in a carpet plot in which the colour legend is defined according to the following rule: all values below the threshold of 400 ppm, corresponding to an unoccupied zone, have the same colour (green); all values above the threshold of 3000 ppm have the same colour (red); the in between range 400-3000 ppm is shown with a colour range. The upper threshold of 3000 ppm has been chosen since it was seen during long term analyses that especially in the bedrooms during night it is possible to reach such high values in buildings unequipped with mechanical ventilation systems. Hence, it was considered useful to graphically allow to distinguish all possible reachable values since they present a different health risk, instead of stopping at 1000 ppm threshold.

- A bar chart showing the standard and adapted performance gaps of the n_co2_aIII KPI during the whole year. On the x-axis are the week numbers and on the y-axis the number of hours in which the condition is verified for that week.

The available plots related to thermal comfort are:

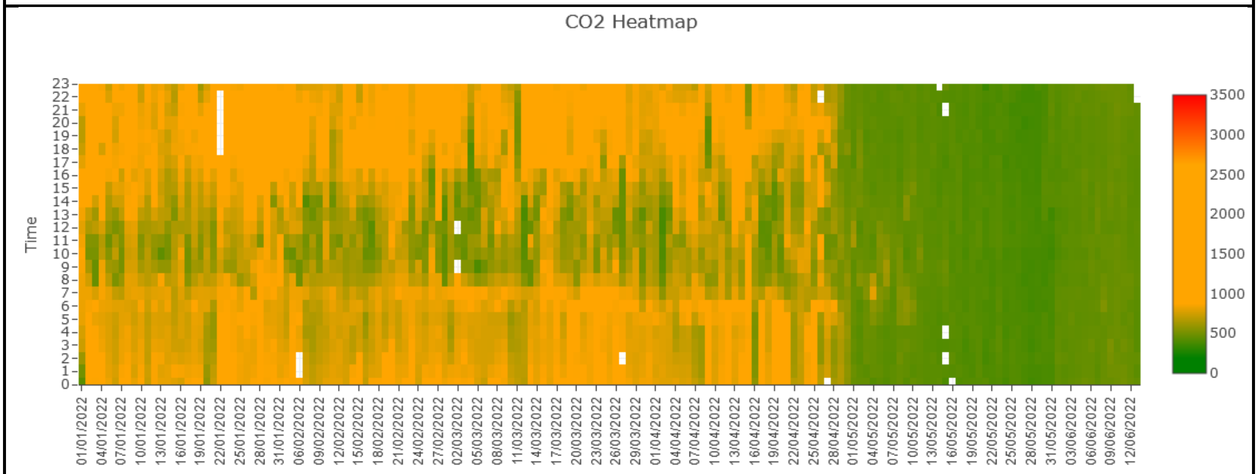
- The monitored timeseries of the hourly average indoor temperature value in Celsius is shown in a carpet plot in which the colour legend is defined according to the following rule: all values below the threshold of 18°C have the same colour (blue), while all values above the threshold of 30°C have the same colour (red). The in between range is expressed in a colour range from blue to red.

- A line chart showing timeseries indoor temperature hourly trend with five lines: two simulation outputs with standard and adapted model settings simulated under monitored weather conditions, monitored output from sensors and the two corresponding performance gaps showing difference between simulation and monitoring.

3.3.2.1 Danish demos – indoor air quality and thermal comfort

Concerning IAQ KPIs in the Danish demo case "Haanbaek (building code number B1.4 given in E-DYCE project), results are presented for CO_2 sensors located respectively in the sleeping area (bedroom) and daily living area (living room) for a selected apartment 2th that is considered as critical apartment due to the highest number of occupants. Results are presented for the year 2022. In Figure 11 and Figure 12 carpet plots and bar charts with a number of weekly aggregated hours above 1000 ppm are used to illustrate E-DYCE capabilities and added value for the end users to support them in understanding the situation of indoor environment quality in critical spaces and their occurrence in time. Results can support optimal and adapted ventilation strategies considering actual loads and individual needs.

Carpet Plot co2_2th_Livingroom_ (Haanbaek) B1.4 - Y2022



n_co2_aIII_h _2th_Livingroom_ (Haanbaek) B1.4 - Y2022

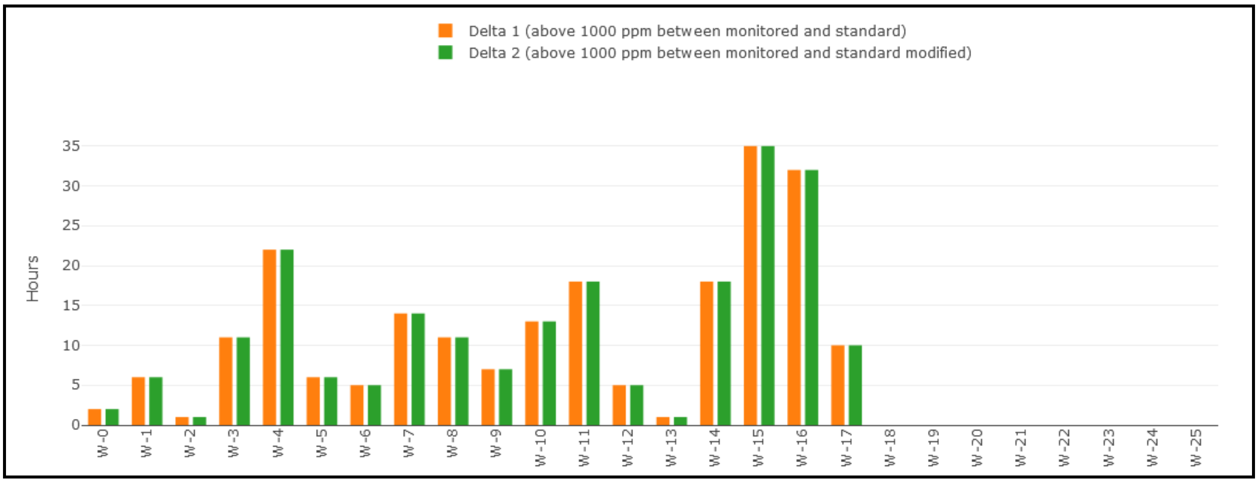


Figure 11 (Top) Carpet plot with CO2 in Livingroom, (Bottom) weekly aggregated hours when CO2 is higher than 1000 ppm for the year 2022.

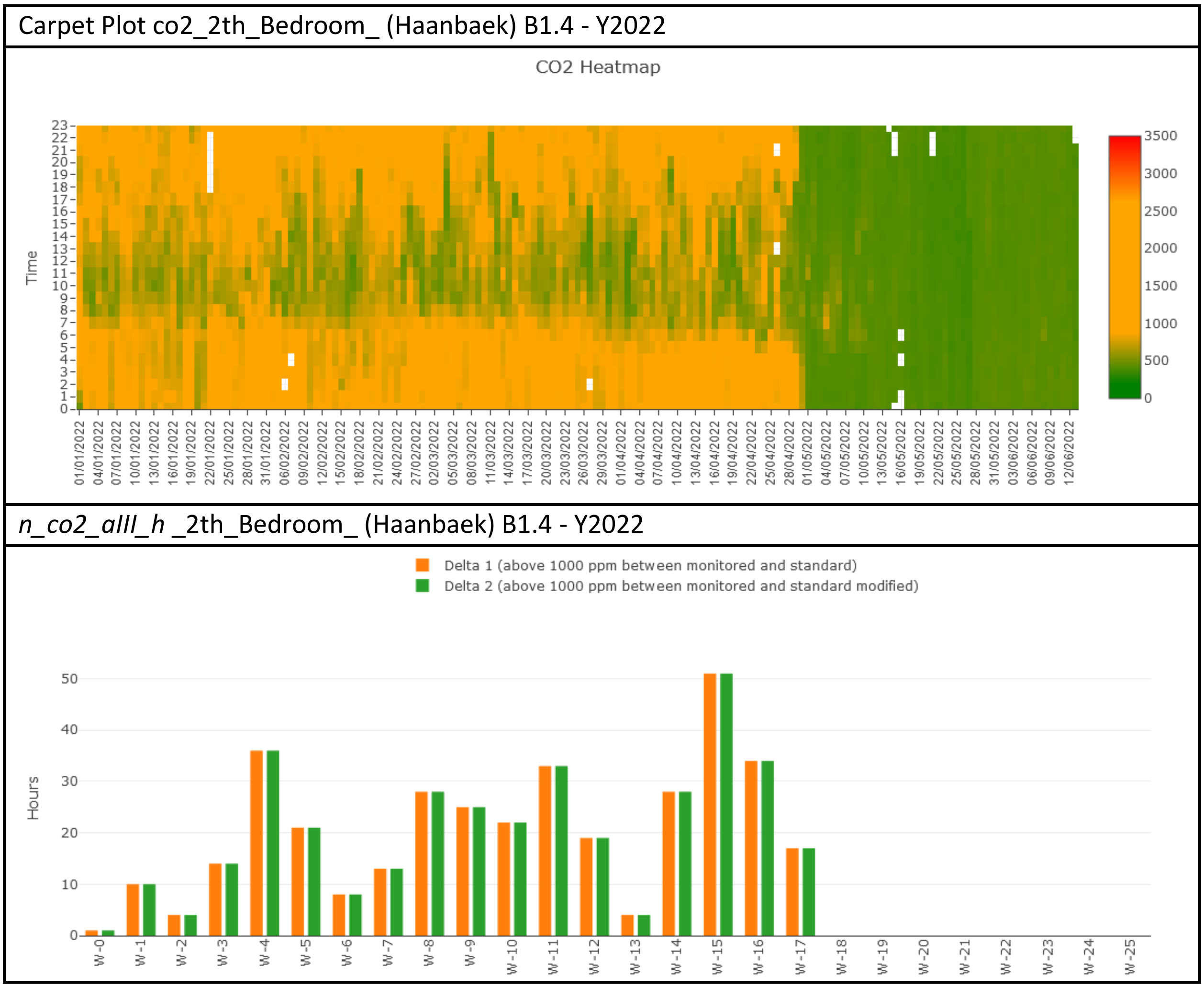
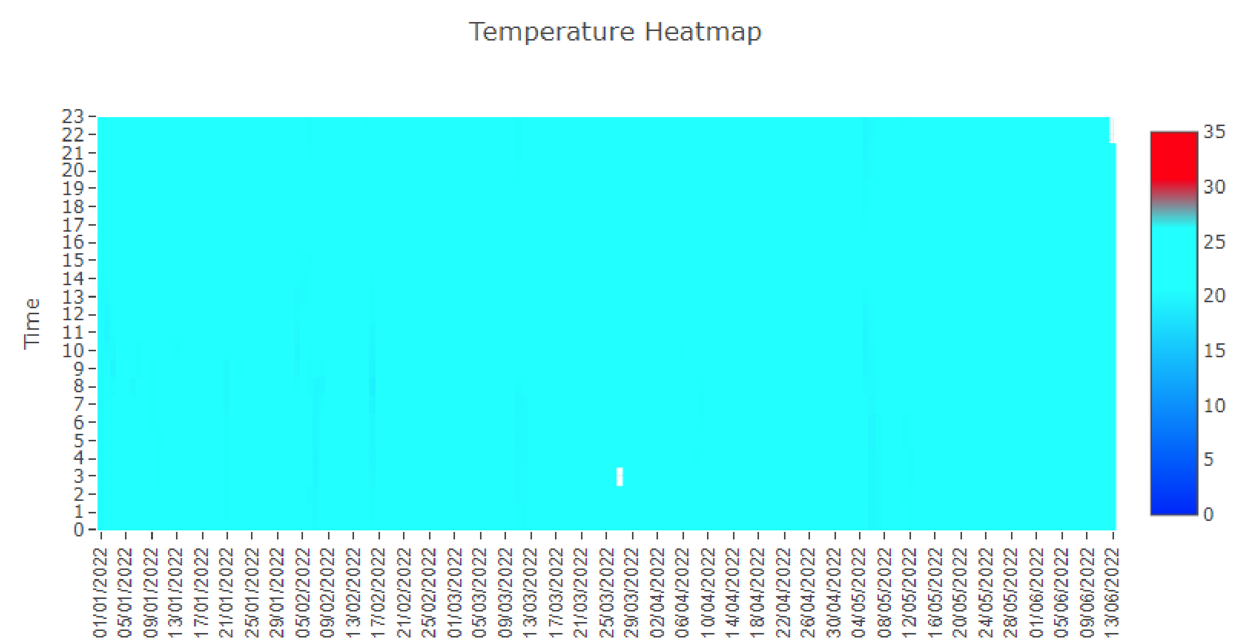


Figure 12 (Top) Carpet plot with CO2 in room, (Bottom) weekly aggregated hours when CO2 higher than 1000 ppm for year 2022.

The adapted conditions in this example do not affect the CO_2 concentration resulting in the identical plot for standard and adapted conditions in the bar plot in Figure 12. In Figure 11, it can be observed that elevated CO_2 concentrations are present only until May 2022 indicating that the apartment is occupied. After that date, CO_2 concentration decreases until the end of the presented monitoring period. This is because tenants moved out for a longer period and the apartment was unoccupied. These results show that mechanical air flow rates could potentially be reduced to minimize heat demand when the apartment is not occupied. This information could be further used to set back temperatures and obtain further operational energy savings. Another potential utilization of the results is to optimize ventilation rates and account for actual loads in the apartment. This is possible with E-DYCE approach but would require tuning of plot scale to better capture concentrations close to maximum acceptable levels for mechanically ventilated buildings.

Regarding thermal comfort, the results are presented using the carpet plot from E-DYCE platform, see Figure 13 for the living room in two selected apartments. The selected scale and ranges that are used to plot temperature do not allow for analyzing temperature variation between 20 and 27 ^{o}C but on the other hand allow for immediate detection of overtemperature issues, see also Swiss case results in 3.3.2.3. In the Danish case, results indicate that overtemperature is not a problem, and temperature is maintained all the time at approximately between 20 and 27 ^{o}C. The same results are observed for all monitored rooms. The change in scale, which is also a possible option in E-DYCE platform, would allow for a better representation of the actual temperature situation, for example, the differences between heating and non-heating seasons and day and night operation.

Carpet Plot t_2th_Livingroom_(Haanbaek) B1.4 - Y2022



Carpet Plot t_3tv_Livingroom_(Haanbaek) B1.4 - Y2022

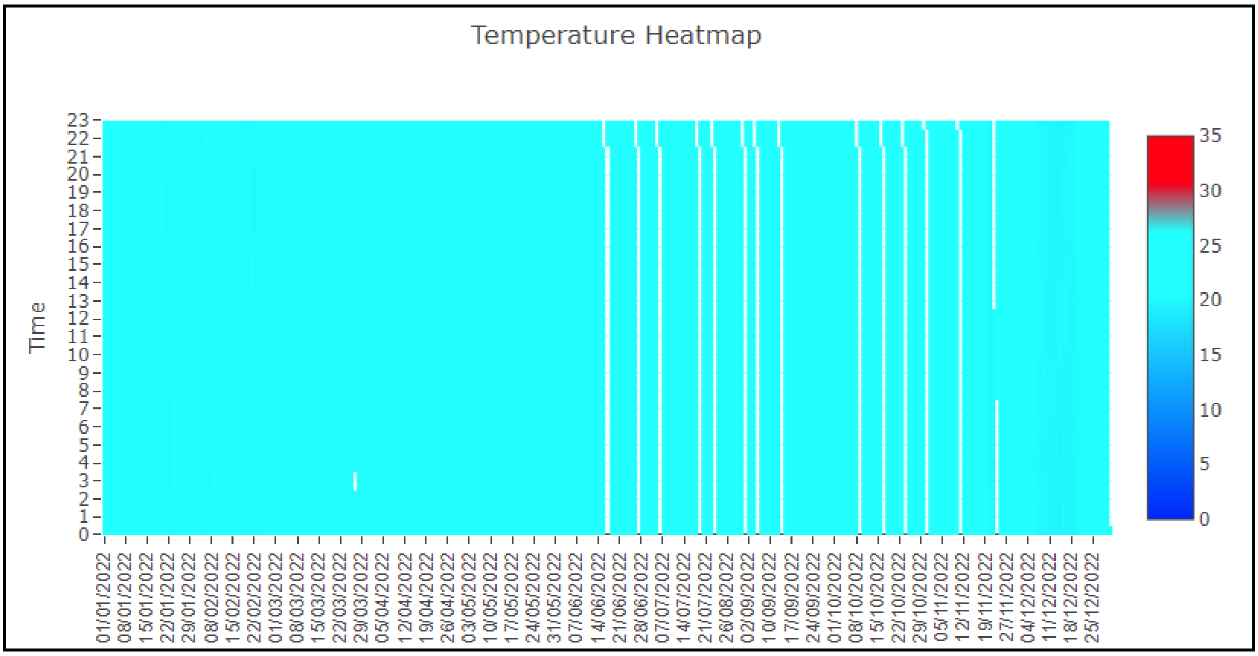


Figure 13 Carpet plot with temperature in two selected living rooms for year 2022

3.3.2.2 Italian demos - indoor air quality and thermal comfort

Concerning IAQ KPIs in Italian demo cases, B2.5 presents a single CO_2 sensor located in the most significant room (kitchen/living area). However, CO_2 concentration almost never reaches dangerous thresholds – see Figure 14. Only during wintertime, it could happen more often to see possible under-ventilated periods which could benefit from an optimized natural ventilation schedule. In this case, adapted and standard input have no significant impact on the results, also because it was not possible to define a proper adapted occupancy schedule use for the room because of its high variability.

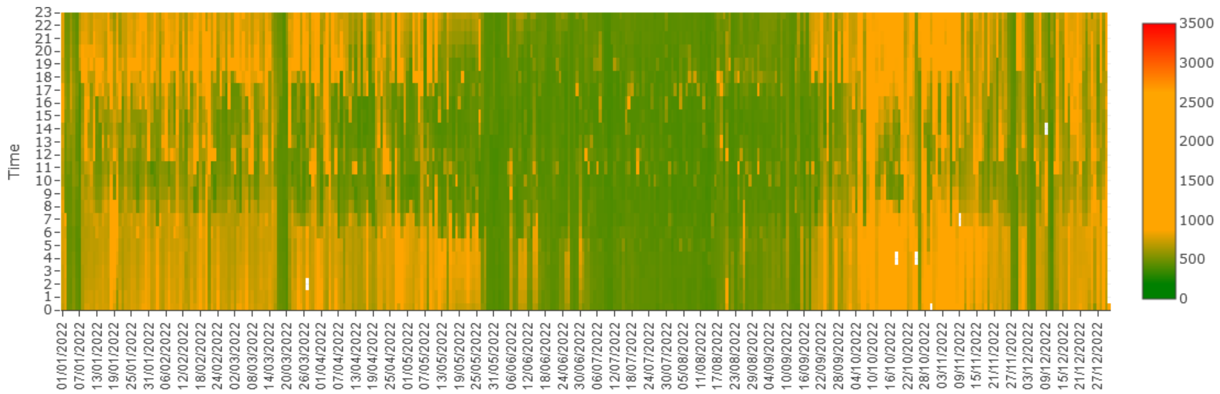


Figure 14 Carpet Plot co2_act104aa B2.5 Y2022

Focusing instead on the demo case B2.1 in Figure 15 and Figure 16, CO_2 sensors are present in most teaching areas over the four floors. Since main responsible for high CO_2 values is the manual natural ventilation adopted in the room, this visualization may help in defining and suggesting specific rules for that environment. It can be also noticed that the presence of high peaks in a certain zone could vary over time: in fact, natural ventilation habit could change significantly throughout the years if for example the teachers responsible for that classroom change or because of external dispositions, as it happened during these years because of the evolution of COVID-19 pandemic. Hence, looking directly at monitored data could provide an added value instead of focusing on standard and adapted performance gaps for CO_2 concentration, since both could better suit to a specific period but then become obsolete and need an update to adjust the fitting.

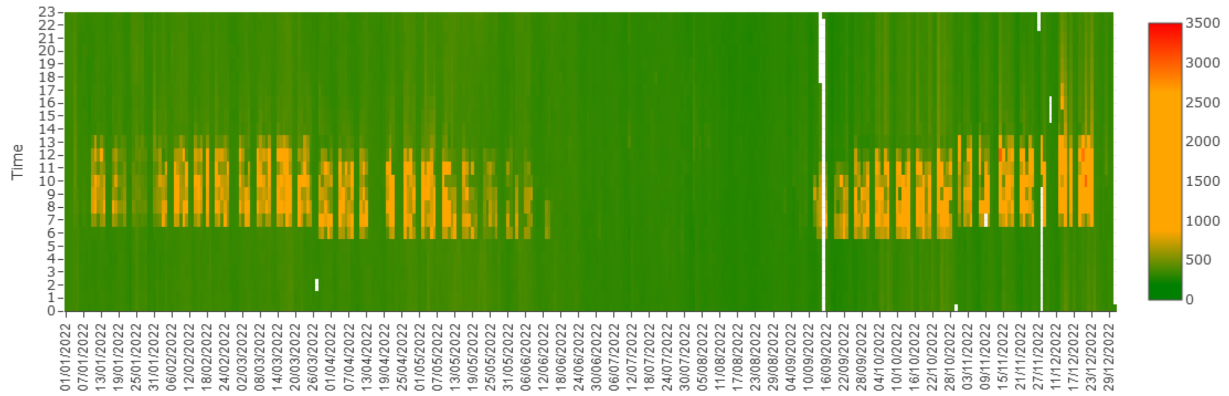


Figure 15 Carpet Plot co2_act201bb B2.1 Middle School Y2022

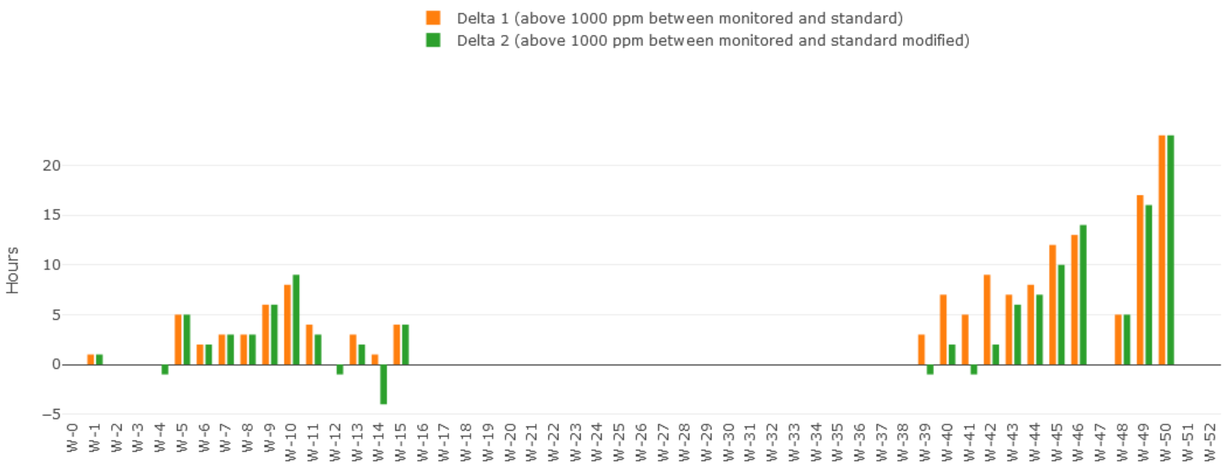


Figure 16 n_co2_alll_act201bb B2.1 Middle School Y2022

In both B2.1 and B2.5, temperature is monitored in all rooms. Monitored temperature carpet plots, especially if combined with CO_2 related information, could help in identifying possible over- or under-ventilation conditions which could lead to temporary low or high temperatures in the zone/classroom. Figure 19 shows that commonly temperatures are very low, especially in the kindergarten where, outdoor doors are kept open most of the time. During summer temperature could reach high values, but only during the months in which the school is closed (July-August). Figure 17 and Figure 18 instead focuses on two different zones of the residential B2.5 demo case: it is evident the difference in temperature of the zone in which the stove is located (Figure 17) and in the zone which is further from it (Figure 18) and hence less benefitting from the additional heating in winter. Also, in the case of the residential building, there are no significant over-heating risks neither during the summer months.

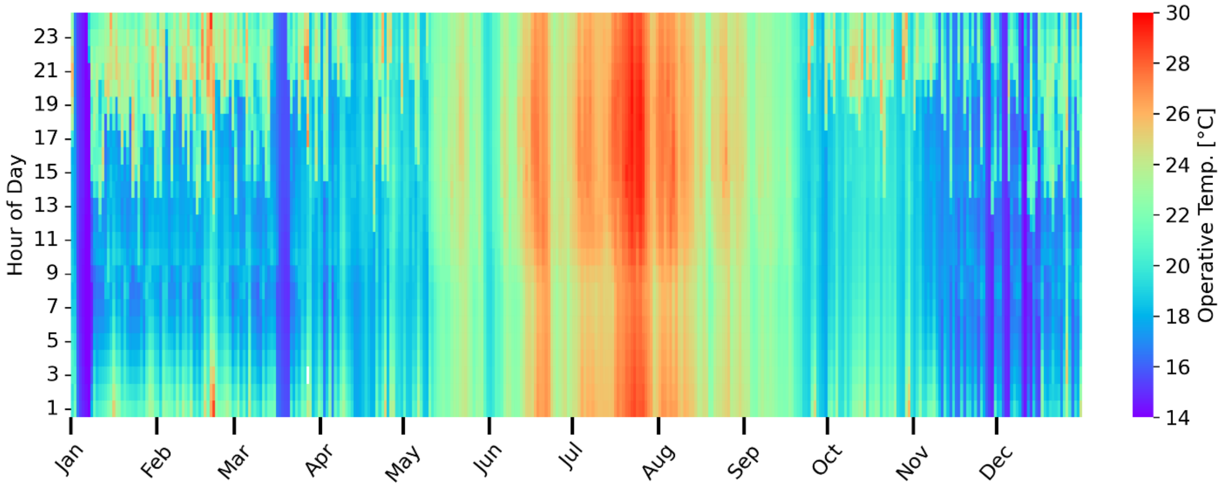


Figure 17 Carpet Plot t_db_act104aa B2.5 Y2022

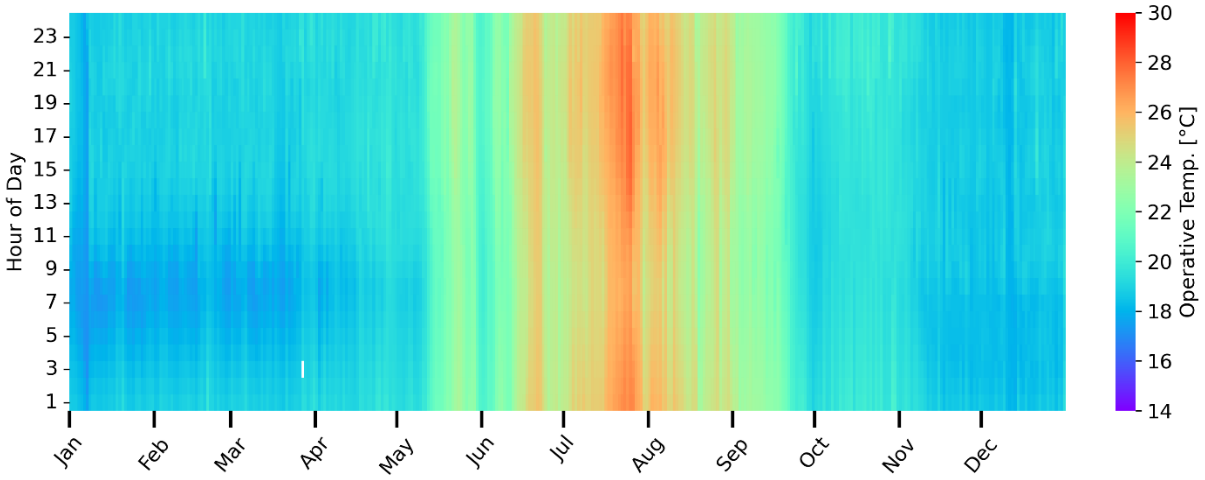


Figure 18 Carpet Plot t_db_act105aa B2.5 Y2022

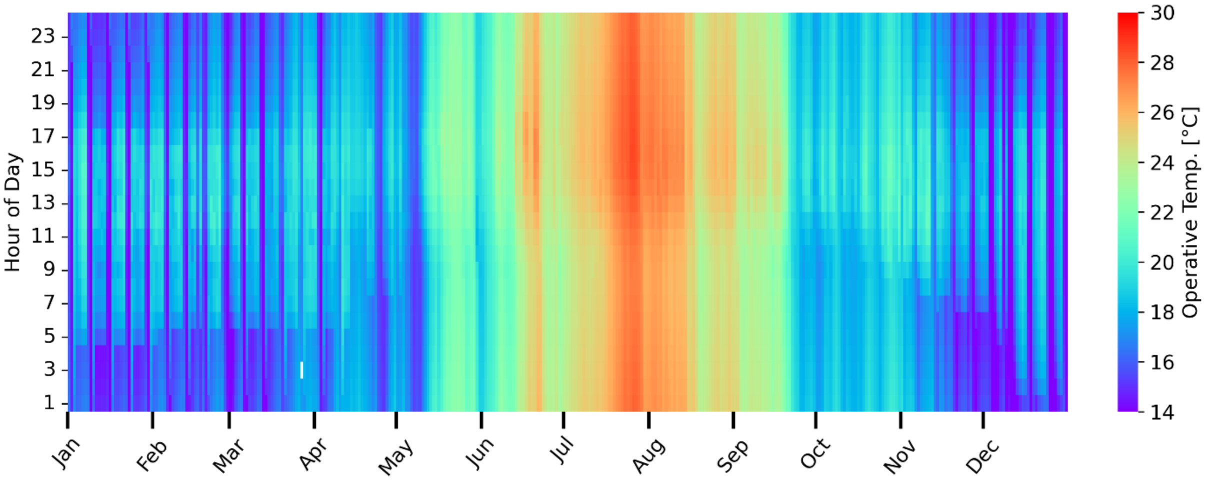


Figure 19 Carpet Plot t_db _act201aa B2.1 Kindergarten Y2022

Figure 20 and Figure 21 highlight instead simulations results and hence the detected performance gaps in temperatures with respect to the monitored data. Interesting results are visible on the residential case where it is visible the strong difference between the room with the stove (showing high punctual peaks also after the end of the heating season) and the further room from it which is following the setpoint.

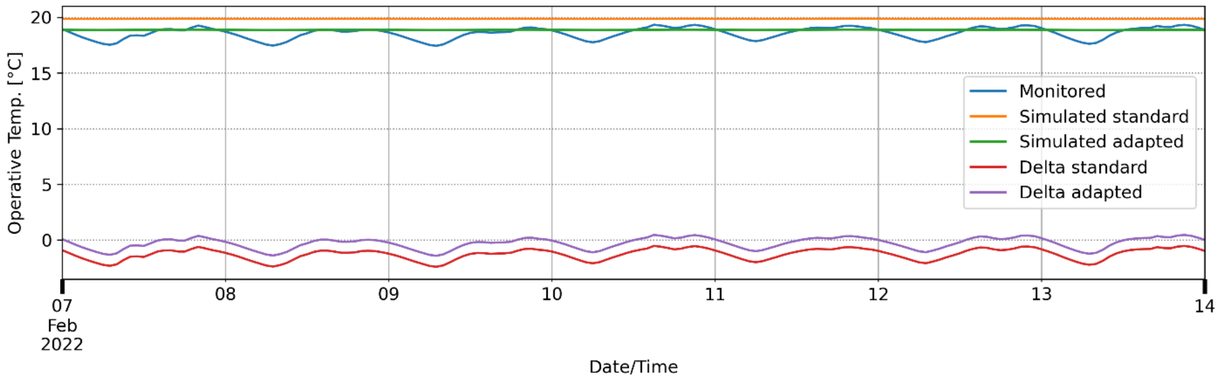


Figure 20 timeseries_t_op_act105aa B2.5 Y2022 W6

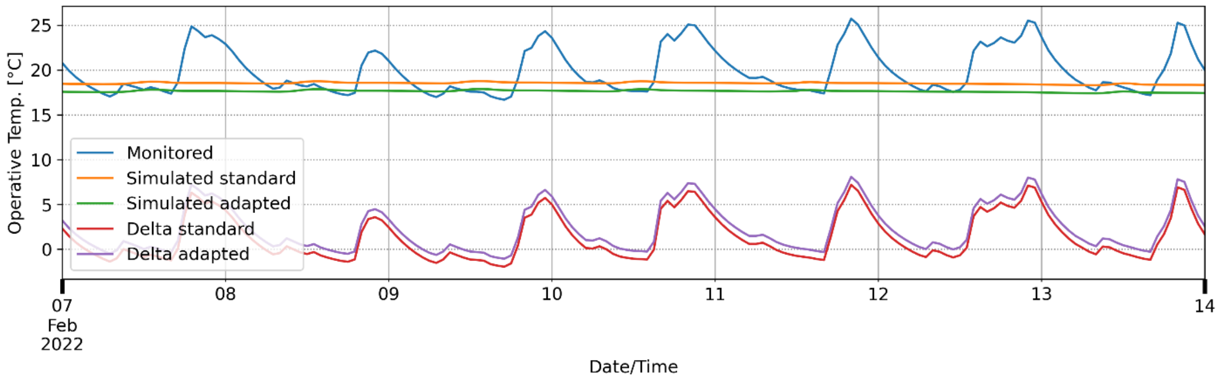


Figure 21 timeseries_t_op_act104aa B2.5 Y2022 W6

3.3.2.3 Swiss demos - indoor air quality and thermal comfort

The monitoring of the different Swiss case studies uses a different technology provider for each demo building (see D5.2). The availability of possible communication means with the middleware wasn't part of the criteria at the early stage of the project when they were chosen. Fortunately, both IEQ sensors and heat counters from Climkit, installed in Centurion building, allowed for an API connection. The building was therefore the one connected to FusiX to test the solution. The size of the building was a strong limiting factor for the simulation of the performance gap. Indeed, the computation time was too low for the developed algorithms. By the time the issue was identified, it was decided that the building would serve as a demo case for the monitoring data visualization, without the simulation and performance gap computation aspect.

Twelve of the 22 installed sensors are measuring CO_2 concentration. They were installed in different bedrooms of an alley of the building. Some communication struggles with the Lora antenna led to data losses at the early stage of the monitoring for one sensor. The visualization of the monitored data on FusiX can allow an expert user to identify general and extreme behaviours of specific spaces – See Figure 22. This further can allow us to consider a multi or mono-zone simulation as explained in D3.5.

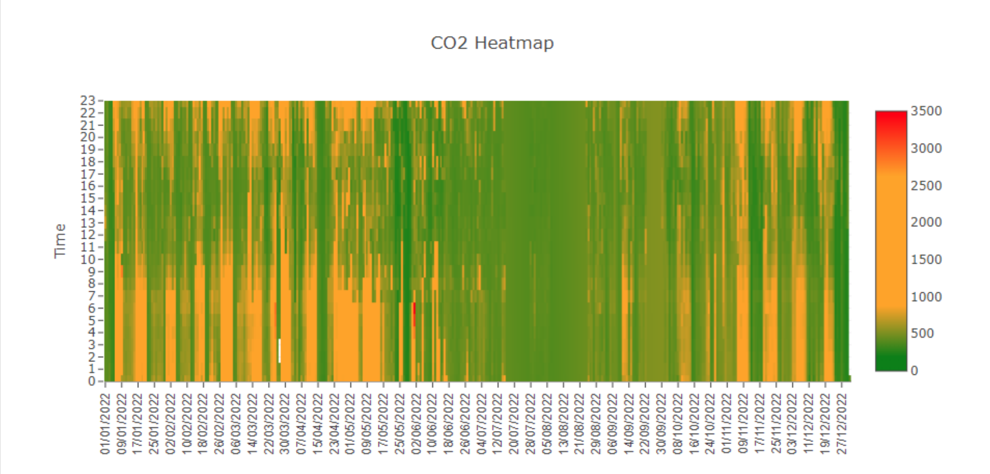


Figure 22 Carpet Plot co2_Sensor 12 Centurion Y2022

All the sensors from the building are measuring the indoor temperature. The carpet plot of the measured air temperature is also available on the FusiX platform – see Figure 23. The produced graphs allow us to see the different temperature measurements over time and identify systematic behaviours during the day as well as see the seasonal difference in the buildings' behaviour.

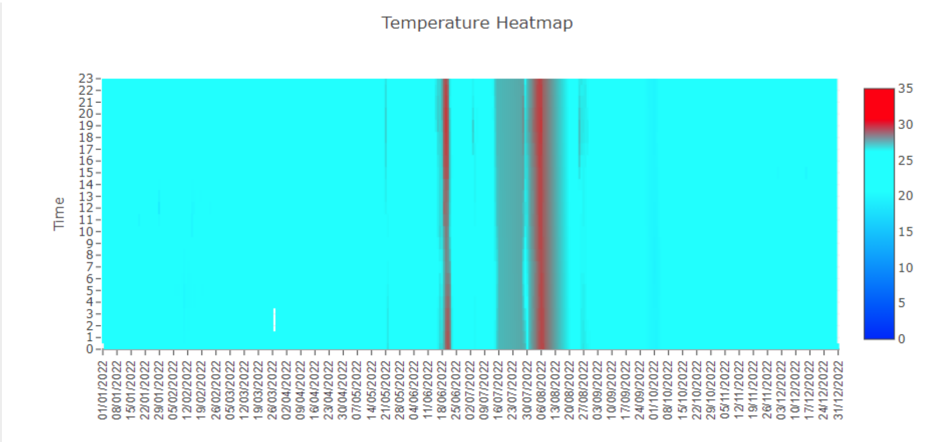


Figure 23 Carpet Plot t_db_act105aa B2.5 Y2022

The possibility to evaluate the IAQ KPI's for a building is essential and will be explored further in the Part B of the present report. The advantage of the FusiX middleware is the standardization of the KPI's graphs and its user-friendliness in data visualization.

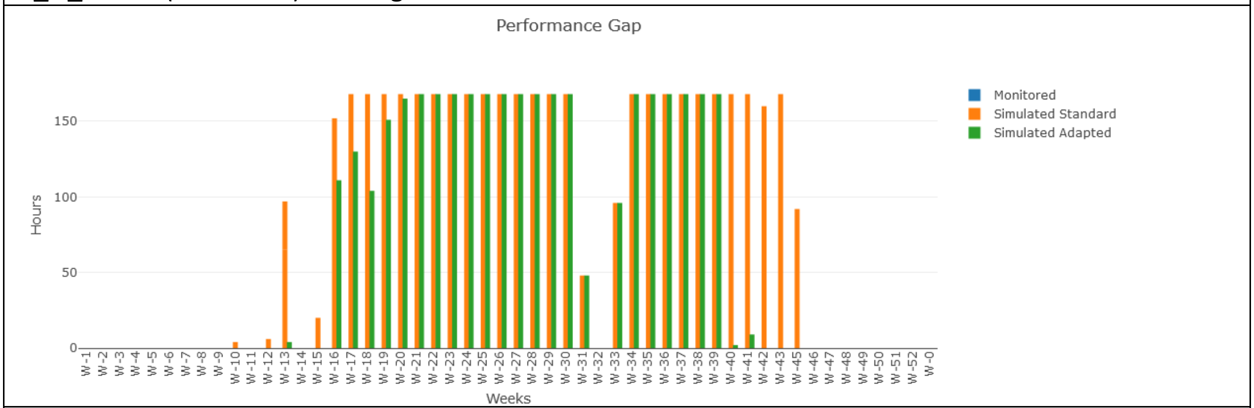
3.3.3 Free-running KPIs

The available plot representing the number of free running hours in the heating season is represented by a bar chart, with on the x-axis the weeks of the year and on the y-axis the total amount of hours in the week in which the heating system was inactive despite the schedule allowed it. The graph can be shown in two versions: one including three columns corresponding to the two simulation outputs and the monitored output, and the other including the two corresponding performance gaps.

3.3.2.1 Danish demos – free running

For the Danish case, selected results- reflect free running at the building level and one selected apartment level. In the Danish case, the free running considers only no demand for heat. Examining the monitored data for the Danish demonstrator in Figure 24, we can observe no monitored free running hours throughout the year. However, for the simulation standard and adapted, we can see a strong potential for deactivation of the heating system during the warmer weeks (e.g. weeks 17 – 45). This example showcases E-DYCE's capability to support building energy performance optimization by assessing heating system usage in the building and/or apartment. These results can aid building energy professionals in evaluating the optimization potential for heating system control and assisting occupants in developing better habits to reduce the insufficient use of the heating system. Although heat demand in the period is not very significant it is at the same time not necessary. Moreover, free running operation accumulated over several weeks can contribute to overall significant energy, CO2, and money savings. Generally, since the four analyzed apartments are similar the free-running potential is similar in each of them. Finally, free –running analysis can contribute to a better understanding of the performance gap. In the illustrated example, simulations indicate no need for heating while measurements show that heat is used. The discrepancy clearly illustrates the difference between anticipation and actual operation.

n_fr_h B1.4 (Haanbaek) Building level – Y2022



n_fr_h B1.4(Haanbaek) Apartment level 2th – Y2022

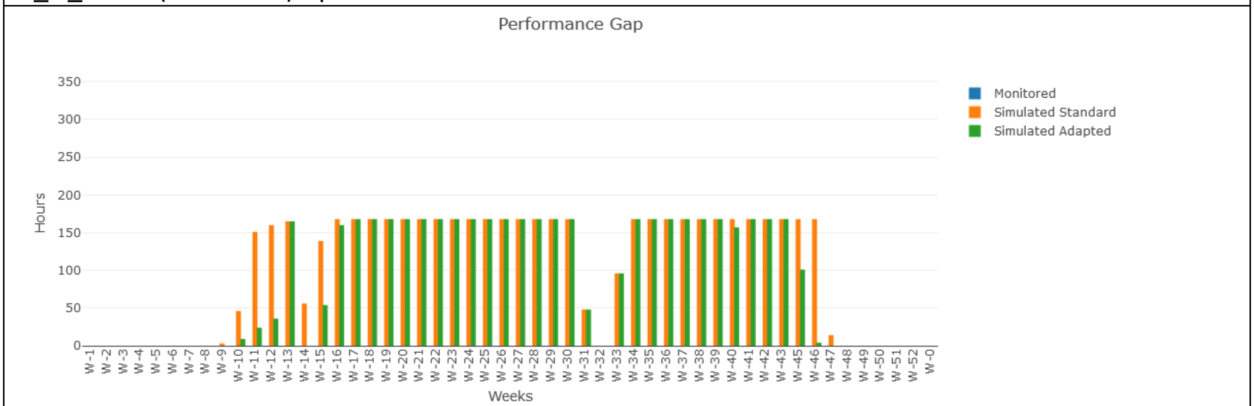


Figure 24 (top) Potential for free running hours at building level, (Bottom) potential for free running hours in selected apartment level for year 2022.

3.3.2.2 Italian demos – free running

Focusing on Italian demo case B2.5, in Figure 26 it is visible that both standard and adapted conditions are not able to identify potential free running periods during the heating season. This could be due to several reasons also underlined when looking at energy related KPIs in 3.3.1. In general, whenever the monitored heating consumption is 0 or below a given threshold (0.01 kWh in this case), it could simply be because of the occupant having turned down the system based on his presence or not in the building, which is very complex to be considered in the simulations for some residential cases with highly variable schedules. Maybe, also in case of an active heating system the concept of fictitious heating could help in identifying potential periods where the building could go free running without losing in thermal comfort. Focusing instead on B2.1 Kindergarten, Figure 25 shows that during the heating season the standard setpoint allows to better align to actual free running hours (that are filtered based on the standard or adapted occupancy schedules), but still the monitored behaviour shows a higher free-running potential than with simulations.

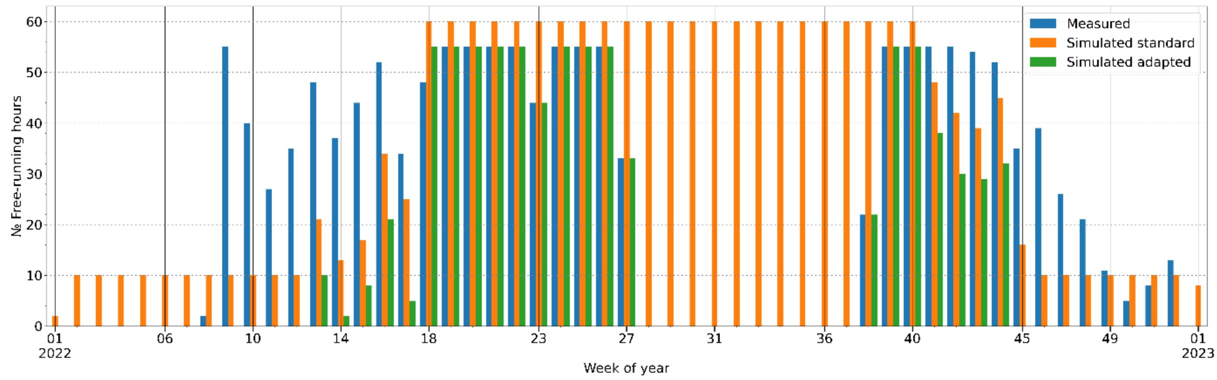


Figure 25 n_fr_h B2.1 Kindergarten Y2022

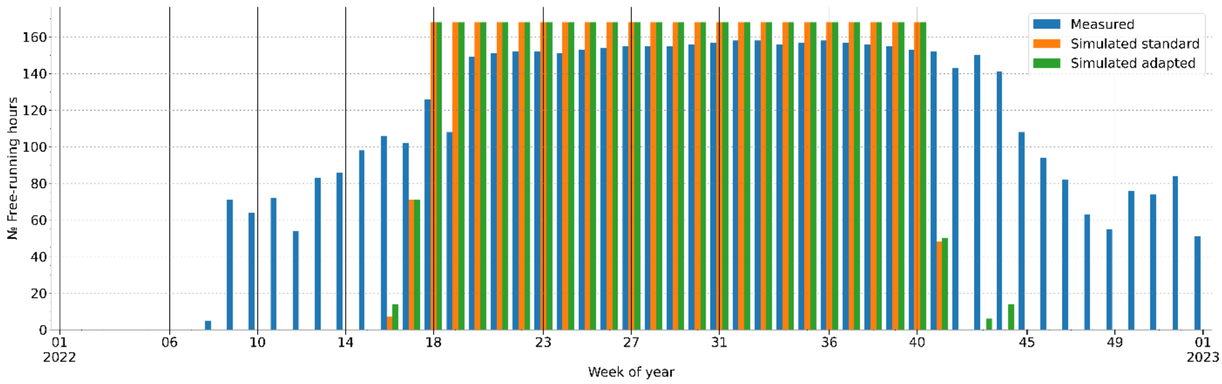


Figure 26 n_fr_h B2.5 Y2022

3.4 Main outcomes and discussions

The above-presented results allow us to evaluate and verify the E-DYCE DEPC approach positively. They illustrate its capability to detect the performance gaps in demonstration buildings encompassing both energy use and Indoor Environmental Quality. This underscores the effectiveness of the selected KPIs. Furthermore, the functionalities offered by E-DYCE, particularly through the visualization of KPIs, confirm the relevance and applicability of these selected KPIs for the performance optimization of buildings.
The comparison between measured (operational) and simulated (asset) performance is shown to benefit from the introduction of adapted conditions in simulations. It is illustrated that this approach can inform users about the nature and significance of performance gaps in specific cases, as it can support the differentiation between PGs caused by known factors in actual building operation, such as altered heating set-points or reduced internal loads, and those caused by unknown reasons like system faults or severe misbehavior. Thus, the results in part A confirm the interest in the future application of both standard and adapted conditions for simulations.
Lastly, the E-DYCE approach to disaggregate the global energy parameter (Q_gl), which is typically used in the current steady-state EPC, into a set of individual energy KPIs like heating energy use (Q_h), cooling (Q_c), domestic hot water (Q_dh), and more is exemplified in section 3.3.1, where the direct comparison between asset and operational heating energy is carried out, offering a more nuanced perspective of the building's energy use for heating and thereby validates the importance of disaggregation of the global energy use.

Summarising, the results reported in Part A demonstrate that the proposed E-DYCE DEPC protocol is:

i.) Based on a series of selected KPIs that can analyze the expected and actual building operation, including energy, IEQ, and performance gap detections,

ii.) Able to be formalized via automatic dataflows connecting measures with simulations and visualization of both to end-users,
iii.) Able to be applied to different demo cases, considering several levels of integration and automation,
iv.) Replicable in different contexts, including alternative solutions for building monitoring and building modeling approaches (each partner has developed its models),
v.) Able to integrate in the same evaluation scheme different families of KPIs, including environmental quality ones (e.g. IAQ, thermal comfort),
vi.) Applicable to aggregated (global parameter Q_gl) or disaggregated energy use including, for example, the heating, cooling, DHW, and other energy needs,
vii.) Compatible with several energy and IEQ evaluation typologies, including asset and operational ratings.

In addition to the verification of the DEPC protocol and correlated KPIs via the E-DYCE demo cases, the following section, namely part B, will propose and verify the extended functionalities of the proposed methodology. Additional comments regarding the impacts and the lessons learned are listed in Part C.

4 PART B: E-DYCE extended functionalities

The objective of part B is to demonstrate the added value of the DEPC approach which is also possible thanks to access to the measured data and dynamic modeling results. The added functionalities presented in the report can contribute to a better understanding of buildings and open for more free analysis that is not bounded by harmonized requirements for certification. For example, the reader can observe that in part B the visual presentation of results is diverse for building cases, and the scope of the presented analysis varies for countries and buildings. As presented in the report for different countries and buildings the extended functionalities can cover a wide range of analysis. The scope and depth of analysis are dictated by individual building case needs and data availability. The list of identified possible extended functionalities is presented and shortly elaborated in section 4.1.

4.1 E-DYCE extended functionalities

Considering the specific demo characteristics, its national context and reference background, and its related adapted objectives, the extended functionalities are detailed at the national level downscaling to the specific building and domain of the E-DYCE technologies. Here below, extended functionalities are generally recapped, mentioning related technical deliverables.

E-DYCE extended functionalities for the different demonstrations are presented in this chapter. The scope of the functionalities is dictated by the data availability reached during the project duration and the assessors' selection.

- **Renovation roadmap**

A two-part approach to improve the credibility and optimization of building renovations was proposed and developed. The outcome of the work is presented in D4.2 and published in paper [1]. The expert approach evaluates the building's existing condition and considers possible space and market solutions to identify the most probable actions. The expert approach is energy and cost oriented. It also considers model complexity, such as steady-state vs. dynamic and mono-zone vs. multi-zone, to address uncertainty related to modeling energy savings. The analytical approach uses sensitivity analysis to evaluate selected solutions, providing a deeper understanding of the indoor comfort consequences of renovation actions while disregarding market limitations. The analytical approach uses a dynamic simulation platform, described in [2]. The analytical platform is linked to environmental variables like indoor comfort models, temperature levels, and energy.

- **Forecast (climate data and energy)**

The objective of the work was to develop data-driven, location-specific prediction modules for E-DYCE demo buildings. Specifically, the Prediction Module consists of two sub-modules, namely the:

- Insolation and Temperature prediction models
- Energy Demand Prediction engine

designed to provide building-specific: temperature, insolation, and energy demand predictions for multiple forecasting horizons and time resolutions. The time resolutions are: Short–term: 24 hours ahead, Mid–term: 7 days ahead, and Long–term: 1 month ahead. For the weather models was consider the following target variables: Outside temperature, Global insolation (in W/m^2), Direct insolation (in W/m^2), and Diffuse insolation (in W/m^2 whereas the Energy Demand Prediction engine contains the prediction algorithms designed to provide forecasts for the energy (heating) consumption (kWh) of the building. The prediction module is integrated in FusiX middleware and a dashboard for visualization has been developed. The work is presented in D 3.4.

- **Performance gap (PG)**

The assessment of the performance gap (PG) has the potential to encompass all Key Performance Indicators, considering both standard and adapted conditions based on the availability of monitoring data and the geometry of the model. In its wide possible scope, the PG comprehensive evaluation serves to furnish users with insights into the building's measured performance against established building standards and anticipations. These insights extend to both energy use and comfort assessment. Such information expedites and refines building assessments by offering a nuanced perspective. It ultimately aids in pinpointing spaces with significant performance disparities and identifying potential causes for these gaps. These causes may manifest as under/over ventilation practices, significant deviations from expected set-point temperatures, system malfunctions, or instances of inefficient user practices.

- **Free-running and IEQ (extended)**

In several demo buildings detailed IEQ extended analyses have been performed on the base of the specific extended monitoring plans, including local-specific conditions and potential additional demo end-user requirements. Similarly, for some demos extended free-running studies have been performed, including in some cases the fictitious cooling vision or additional thermal comfort behaviors. These extended analyses are here reported showing the large amount of potential additional analyses that may be linked to the application of the E-DYCE methodology.

- **Heat signature: space heating and DHW**

The compliance tools (also used for EPC calculations) and building energy simulation tools are not capable of properly quantifying energy use for domestic hot water. Even if tapping profiles are known, which is very seldom, and in most cases based on questionable assumptions, tools typically do not have proper models to quantify energy balances in the domestic hot water system. Consequently, energy use for domestic hot water is often defined as a static value for specific building topology or a very simple correlation to some other parameters, such as a heated floor area and /or number of people. Moreover, the share of energy for DHW in total building energy use is increasing. It can be concluded that currently the best way, if not the only possible, to assess energy use for DHW is the operational one, which can be derived from the heat measurements. According to [4], since 2020, it has been obligatory in the European Union (EU) that newly installed district heating and cooling meters are remotely readable. From 2027 on, this rule will also apply to all meters installed before that date. This opens the possibility of detecting operational domestic hot water energy use if only total heat measured by the smart heat meters can be disaggregated to space heating and DHW. In the scope of the project, a new algorithm is developed and proposed that could serve the purpose of E-DYCE and deliver valuable results to the DEPC protocols. The proposed algorithm targets smart heat meters. The algorithms consider parameters that are available from these meters and their frequency rate. The method is proposed to estimate space heating and DHW share per household where the smart meter is installed. Otherwise, DHW and space heating can be derived from direct measurements if available. The work on method development was presented in D2.3. In this report, we present an example of the consequences if a heat signature is presented for total and disaggregated heat for DHW and space heating.

- **Model simplification – geometry**

The model's thermal zoning and geometry play a significant role in the modeling and computation time. The designers face difficulties creating the simulation model's geometry into dynamic simulation software. As stated in [5], modeling the geometry requires almost 50% of the total time spent on energy analysis. Moreover, the simulation model's geometry complexity significantly increases the computation time. For these reasons, in E-DYCE it was the objective to investigate the consequences of geometry simplification to facilitate the application of the E-DYCE approach. The key parameter included in simplifying the model's geometry is the separation of the thermal zones which is the critical parameter that influences the accuracy of the outputs. Therefore, the primary objectives were to explore and give recommendations regarding the model's zoning simplification procedure and its consequences on a number of KPIs. Two approaches were proposed to fill in the gap in the existing knowledge. The first approach focuses on simplifying the building energy simulation model, supporting the passage from a detailed multi-zone model to a single-zone model adopting specific techniques to include thermal mass effects in the results. The second approach describes a progressive simplification passing from a detailed multi-zone model to a single-zone model, including seven intermediary steps considering boundary rooms, room orientations, and vertical and horizontal aggregations. The objective was addressed in work presented in D3.5 and partly in D2.5.

- **Steady-state (current EPCs) vs. dynamic (DEPC approach)**

To make building energy simulation more accessible, various simplified methods have been developed, which allow for rapid and relatively straightforward predictions of building energy performance. These simplified methods aimed to strike a balance between accuracy and ease of use, making building energy simulation more accessible to a broader range of users while still providing reliable results. However, they were criticized for their accuracy in predicting energy demand, which led to large energy performance gaps in buildings. It is worth investigating to what degree a simplified static simulation model can provide reliable results for predicting the buildings' energy demand. Another research question and objective was to answer the question: How to set up a credible model for E-DYCE certification procedure that can address the effect of the dynamic services and technologies on cooling and heating demand in the building, that can reasonably well calculate comfort-related KPIs and at the same time have an acceptable level of complexity to ease the roll-out of E-DYCE DEPC concept? The identification of the credibility of the models is performed in two steps. In the first step, modeling results are compared across the models with different complexity levels and dynamic systems. In the second step, the results of simulations are compared against the monitoring data to identify which simplifications do not significantly interfere with the validity of the results. The hypothesis is that the same methodology can be applied to several buildings of the same building typology (dwellings), then the general conclusions about the acceptable level of model simplification in E-DYCE DEPC can be made, and the resulting model will be able to account for the effect of the dynamic services and technologies within the building, both in terms of energy and comfort. This work that answers the question was carried out and presented in D2.3 and partly in D3.5.

In the following sections, the application of all of part of the mentioned extended functionalities is discussed demo-per-demo.

4.2 Applications in Denmark demo sites (B1)

The Danish demonstrator consisted of 3 multi-family apartment blocks. Two of them (Magisterparken and Thulevej) were located in Aalborg and one (Haanbaek) in Frederikshavn. All three buildings are owned and managed by housing associations with space and water heating being supplied through district heating. These buildings were built in the period 1964-1972 and renovated in 2010-2012.
Sensing equipment was installed on the central heating installation as well as in a selection of apartments, which ended up the apartments for which user consent was obtained. This was carried out by Neogrid in collaboration with Aalborg University, which relied on its extensive experience of monitoring and also provided maintenance of the data collection in this challenging multi-family building context. More details on Danish demonstration case preparation are provided in D5.5.

In the following sections 4.2.1 - 4.2.8 are elaborated additional E-DYCE functionalities for Danish cases that are not explicitly captured in part A of this report which is about E-DYCE protocol and main E-DYCE functionalities. The extended analysis of Danish case buildings is presented in the following order using the exemplary results:

- Extended analysis of building operation using monitored data – an example
- Model simplification with a focus on geometry simplification
- Extended analysis of summer comfort assessment – an example
- Adapted conditions toward closing the performance gap
- Heat signature (space heating and DHW)
- Renovation roadmap
- Weather and energy forecast

4.2.1 Extended analysis of building operation using monitored data

In this section, we would like to highlight the power and potential of the basic data analysis that could be utilized to pinpoint inefficient operation of buildings once monitoring infrastructure is placed in the building. The authors also wish to highlight the benefit of firstly utilizing the data and monitoring infrastructure that might already be installed in the building and then using further effort and resources to additionally equip the building with monitoring hardware for deeper operational assessment of buildings.

As an example, can be given a quick and fast analysis of space heating data from smart heat meters. The smart heat meters are mandatory for the district heating-connected buildings. The example of the analysis is given for the Haanbaek building in which each apartment was equipped with its smart heat meter for billing purposes. The data extraction and proper visualization in the form of heat signature, as presented in Figure 27 allow for quick apartments' assessment. Figure 27 presents daily aggregated space heating [kWh] as a function of the daily average outdoor temperature. From Figure 27 it can be observed that apartment 1tv (heat meter ID 1792) reflects significantly higher energy use compared to its 3 neighbors. The energy use is higher, especially for low outdoor temperatures which could indicate that either tenants prefer high indoor temperatures and/or the tenants over ventilated apartment even during cold days. More IEQ monitoring would be required to be able to conduct further diagnosis and analysis but with only a smart heat meter a detection can be carried out and tenants can be made aware of their energy use.

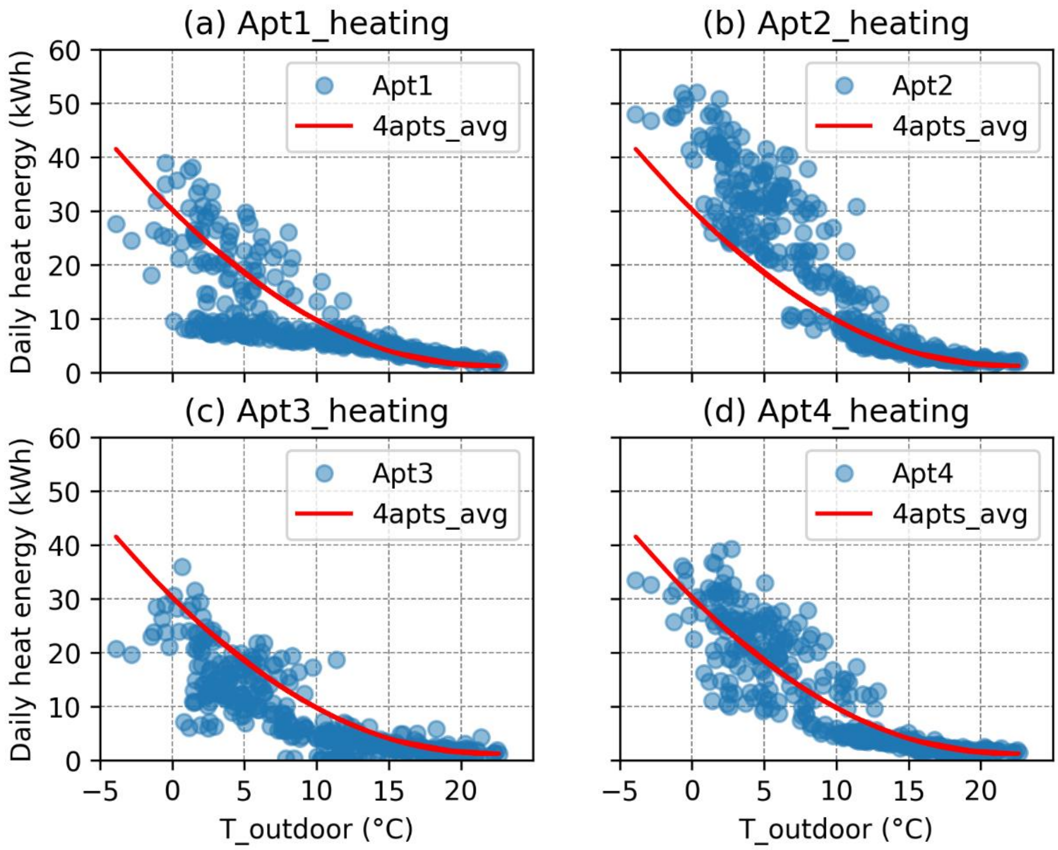


Figure 27 Heat signatures of 4 apartments monitored in Haanbaek case building and an average of four apartments – daily aggregated space heating. The regression equation of the 4apts_avg is $y=30-2.66x+0.06x^2$, $R^2=0.82$

To continue with this example the hourly space heating demand, radiator performance (supply, return, average radiator surface), indoor temperature and CO2 were monitored. Also, window operation, opened or closed, was monitored but data were inconclusive therefore is not presented. Data analysis was carried out to better understand the reason behind energy use for the space heating in the apartment 1tv. The data are depicted using carpet plots or as data series. In the carpet plot, the x-axis presents days (1-year data) and the y-axis depicts hours during the day, 0-24h.

Figure 28 presents a carpet plot of the heat demand for the entire apartment 1tv. It can be observed that the control system in the building which is central weather compensation provided by Neogrid lowers the heat demand during night hours in the heating season. The peak demand is visible in the early morning hours (red color). Heat demand remains high during day hours until late evening hours during the heating season when the night setback is activated again.

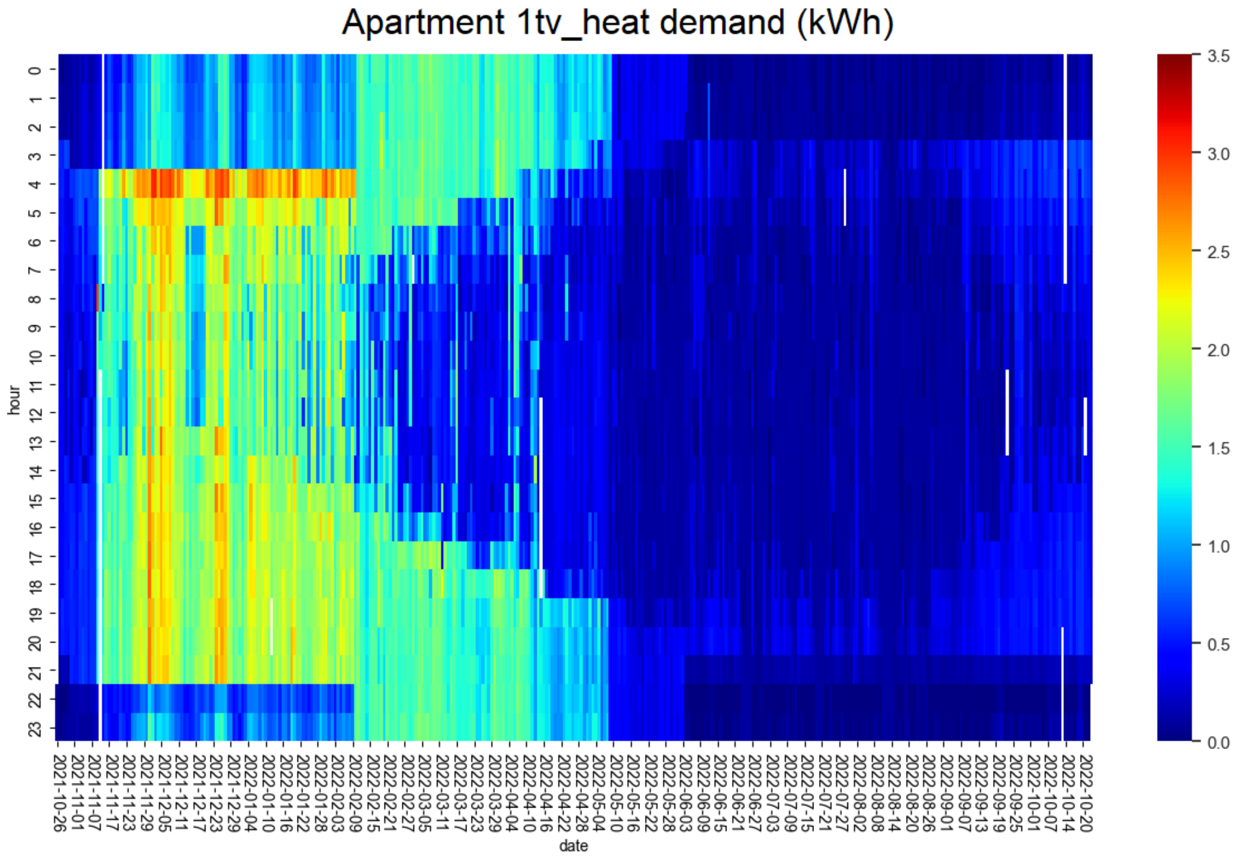


Figure 28 Carpet plot illustrating the yearly profile of heat demand in apartment 1tv

Figure 29 presents the performance of the radiator located in the living room. The temperature drop on the radiator is very low in the range of approximately 10 ^{o}C due to high flow through the radiator. This indicates very poor utilization of district heating and can contribute to monetary penalties. These results can also indicate that other radiators are switched off and the apartment is heated by a few instead of all radiators.

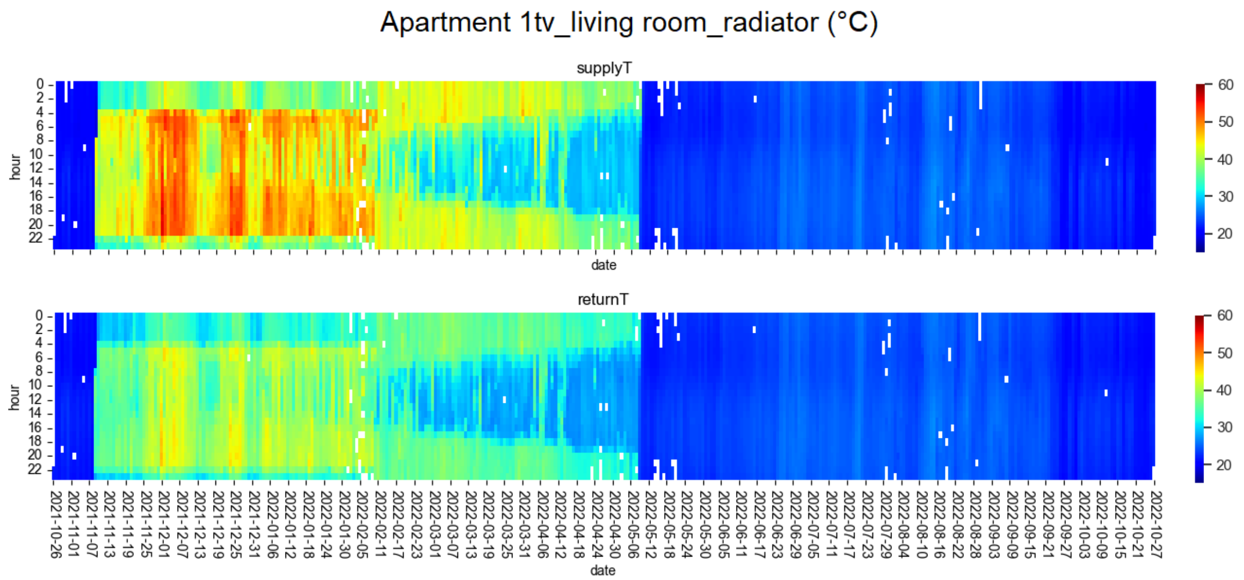


Figure 29 Radiator performance in the living room, supply water temperature, surface emitter temperature, and return temperature from the radiator.

While Figure 27, Figure 28, Figure 29 indicate high energy use for space heating, Figure 30 provides the answer behind this. In Figure 30 one can see low CO_2 concentration during the heating season which indicates possible unnecessary high ventilation airflow that results in high ventilation heat losses. Moreover, temperatures in the entire apartment are maintained relatively high in all spaces and are in the range between 22 to 24^{o}C.

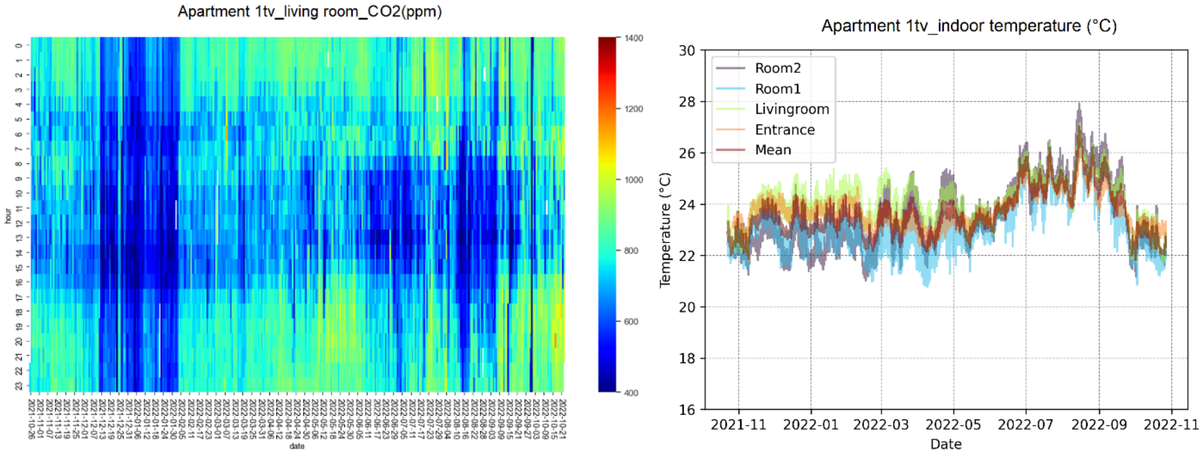


Figure 30 (Left) Carpet plot of CO2 concentration in the living room and (Right) Indoor temperature time series for spaces in the apartment 1tv .

Finally, the short survey of the tenants and further analysis of radiators indicated that some radiators are never switched on, however, because the internal doors of all rooms are always kept open the room temperatures are similar. Also, in May 2022 the old tenant moved out and the apartment was occupied by new tenants. This is also visible in the new data illustrating the beginning of the new heating season 2022/2023 which indicates to be different from the previous one.

4.2.2 Model simplification with a focus on geometry simplification

The model simplification study was conducted within Task 3.5 and its outcome for Danish demonstration cases was documented in D3.6. Model simplification investigation was conducted for two demonstration cases Haanbaek and Magisterparken. Since the outcome of the study was similar for both buildings in this chapter presents only results for Haanbaek case building, see Figure 31.

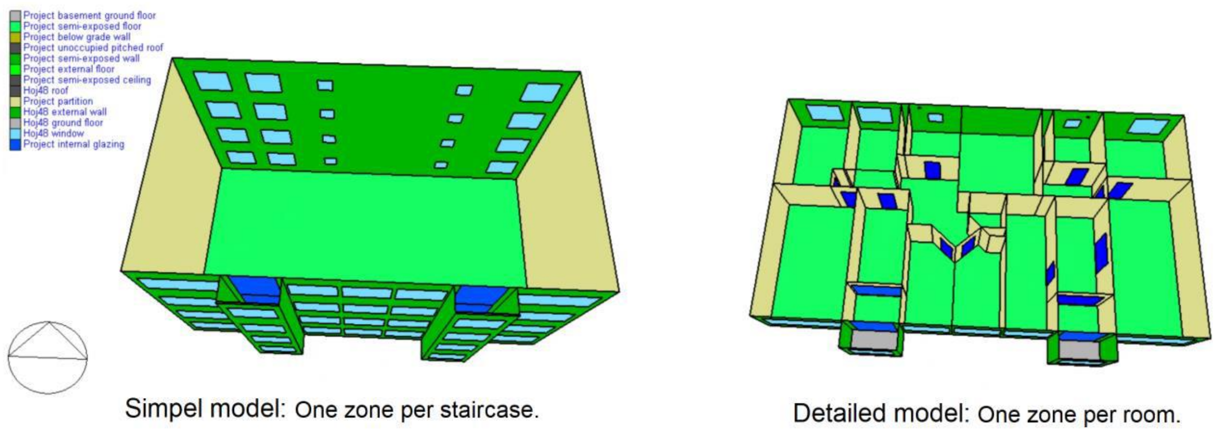


Figure 31 (Left) Simple model and (right) detailed model of Haanbaek building.

The models of Haanbaek, see Figure 31, were simulated with standard conditions for internal loads and schedules, but measured room temperature setpoints and measured outdoor weather conditions. The measured room temperature setpoints were the hourly values of the average room temperature of 16 rooms in total. The thermal mass for not-drawn internal partition walls was included in the simple model, see Figure 31 (left). Modeling results of space heating energy use and operative indoor temperature were compared for simple vs. detailed model as presented in Figure 32.

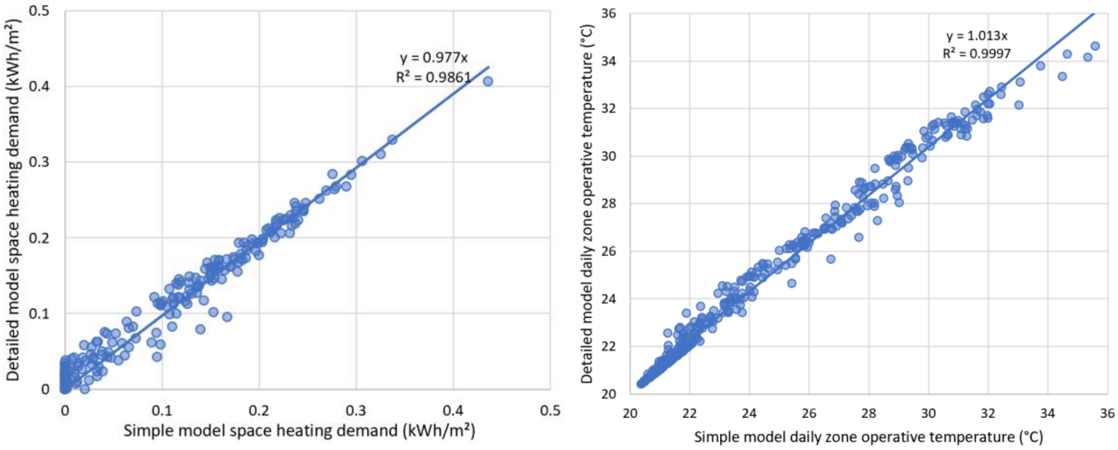


Figure 32 (Left) The daily total heating demand of the simple model (single-zone model) vs. the detailed model (multizone model), (Right) The daily average operative temperature of the simple model (single-zone model) vs. the detailed model (multizone model), Haanbaek building.

The obtained results illustrate a linear relation between simple and detailed model results for both heating energy use and operative temperature. The goodness of fit of linear regression in both cases is very high, respectively R^2 = 0,986 and R^2=0,999 for energy and operative temperature respectively. It can be concluded that for the studied building typology and heating-dominated climate, model geometry simplification, mono zone approach, could be considered a feasible strategy to overcome the high workload required by detailed multi-zone model development.

4.2.3 Extended analysis of summer comfort assessment

This section presents selected simulation and monitoring results of the summer thermal comfort assessment of the two Danish demonstration cases: Haanbaek and Magisterparken. The in-depth analysis of these results is focused on assessing the constrains of model geometry simplification for credibility and relevance of the thermal comfort evaluation.

For both buildings, the modeling results are compared with monitored data for a selected summer week (week 29 for Haanbaek and week 26 for Magisterpaken). The modeling results incorporate models with 5 different levels of geometry complexities (model **Z1-Z5**) and run on standard conditions (standard setpoints, schedules, weather and loads) with the heating system being inactive for the summer. The designations Z1 to Z5 correspond to models with varying numbers of thermal zones. Specifically, Z1 refers to models with a minimal number of thermal zones, essentially one-zone models, while Z5 designates models with the greatest number of thermal zones, treating each room as an individual thermal zone, Figure 33.

The main difference between the two buildings is the approach to the model ventilation system. The ventilation system for all models of Haanbaek is balanced ventilation with heat recovery. For the Magisterparken the simulation results are divided into two sets: one set representing a simple approach to modeling natural ventilation in the building (model **1**Z1- model **1**Z5), and an advanced approach, represented by the airflow network (model **3**Z1- model **3**Z5).

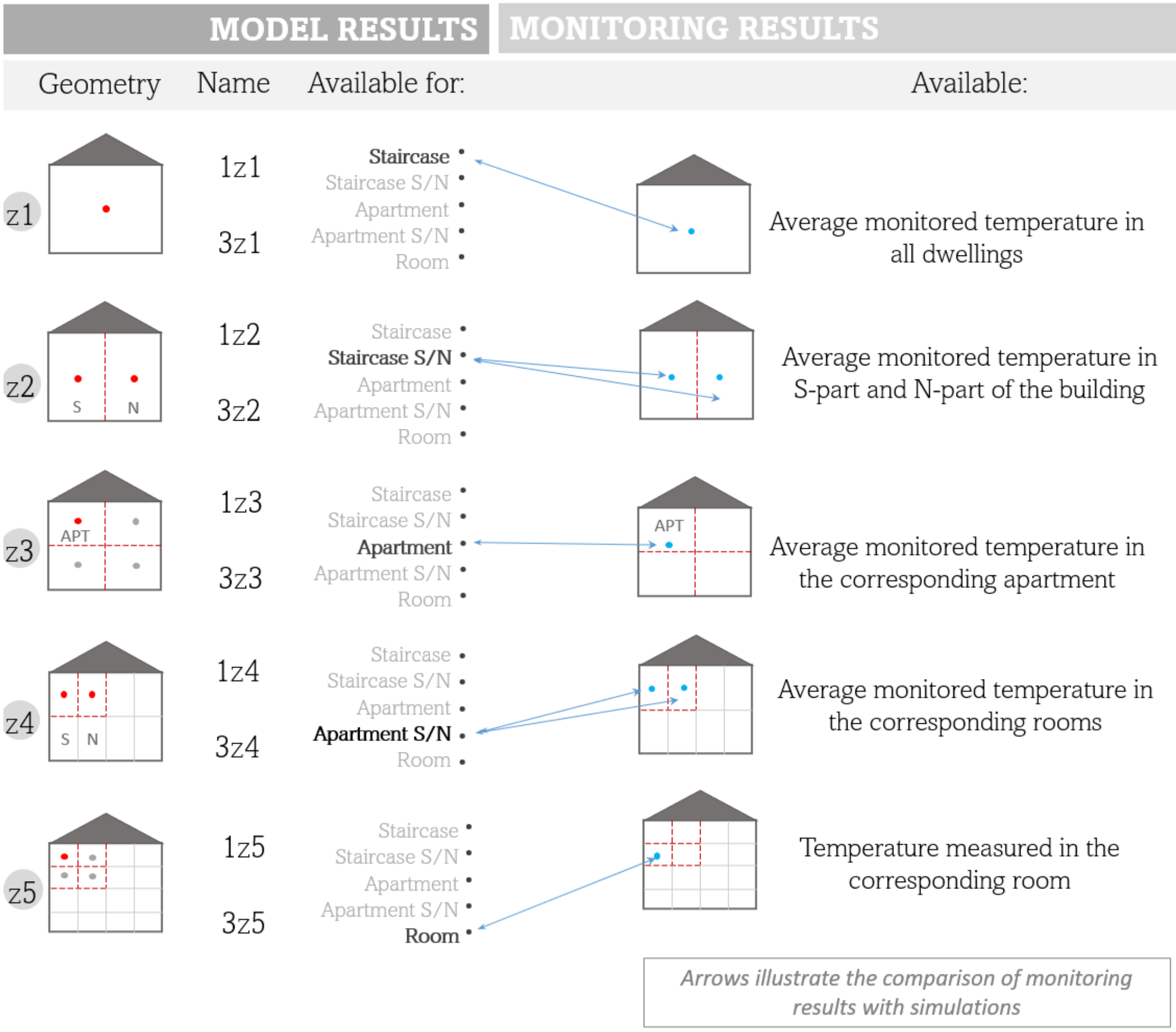


Figure 33 Illustration of the comparison between simulation and modeling results made on an example of Magisterparken building

The comparison of modeled and monitored indoor temperature is possible as follows Figure 33:

Z1- The staircase level, where the simulated air temperature (zone air temperature) for the whole staircase is obtained from a *one-zone model* and compared against the average value of monitored temperature in all dwellings.

Z2- The South/North staircase level, where the simulated air temperature (zone air temperature) is available from a *two-zone model* of the staircase, where one zone incorporates all south-oriented rooms and the other north-oriented spaces. The simulated temperatures are then compared against the average monitored temperatures in the corresponding spaces.

Z3- The apartment level, where each apartment in the staircase is modeled as a separate thermal zone and then the simulated temperature for one apartment is compared against the average monitored temperature in the corresponding apartment.

Z4- The South/North apartment level, where each apartment in the staircase is modeled as two zones (South and North) and the simulated temperatures are then compared to the monitoring in the corresponding rooms.

Z5- The room level, where each room in the staircase is simulated as a separate thermal zone and the simulated temperature is then compared to the monitored in the corresponding rooms.

For establishing a complete methodological understanding of the above-described comparison, the reader is referred to D2.5 and D5.5.

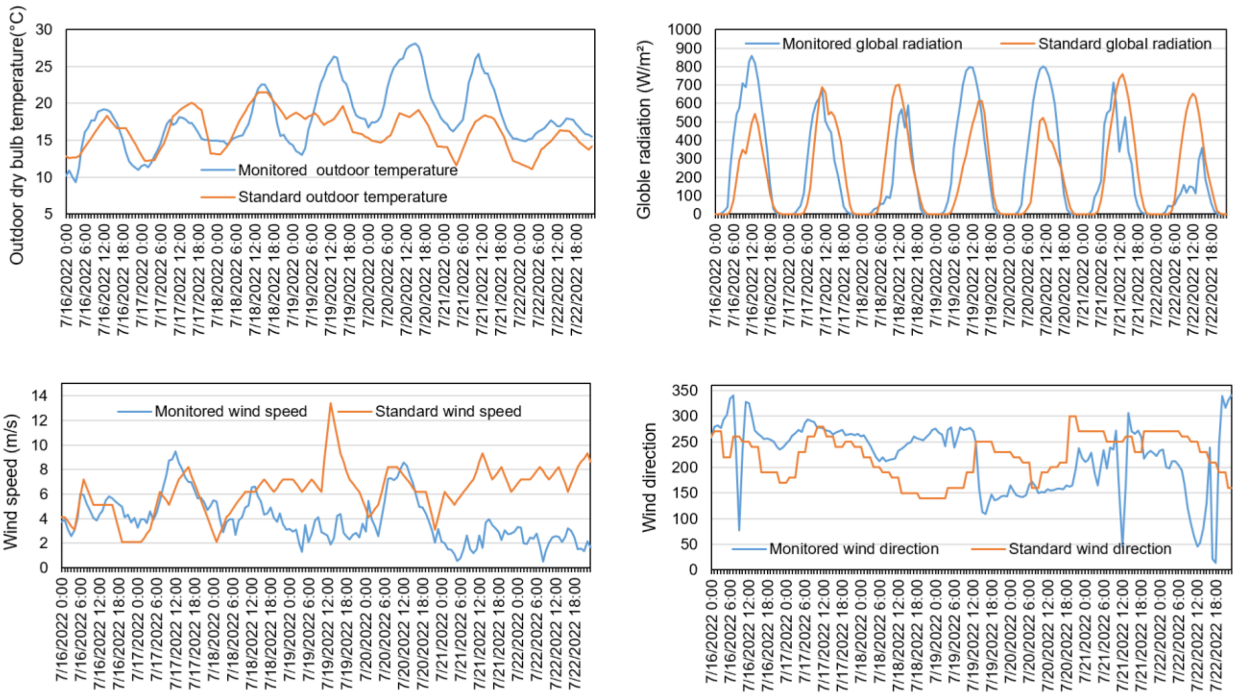


Figure 34 Comparison of the monitored weather data and standard weather data for Haanbaek in week 29

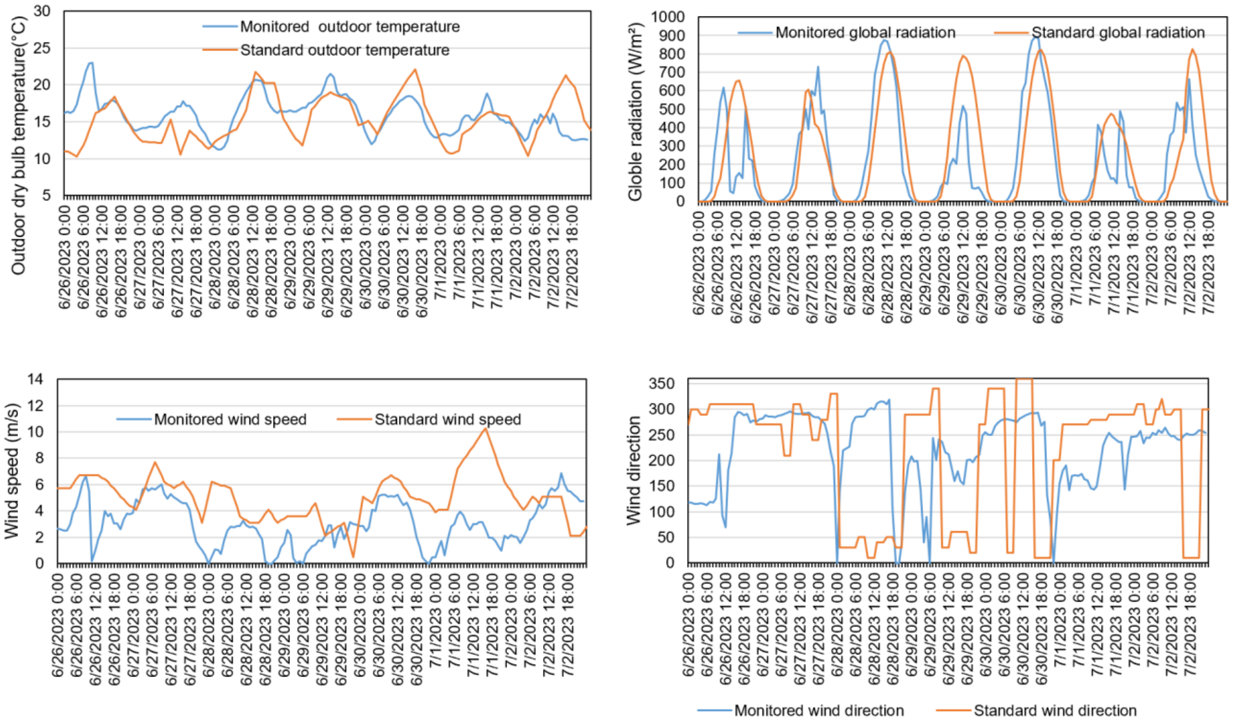


Figure 35 Comparison of the monitored weather data and standard weather data for Magisterparken in week 26.

The comparison between the monitored weather conditions and the standard weather conditions, which are used as boundary conditions for the simulation, is executed for both demonstration buildings. Figure 34 presents the comparison for Haanbaek, while Figure 35 depicts the same for Magisterparken. Additionally, the monitored outdoor temperature displays a more significant fluctuation compared to the standard outdoor temperature during the specified week. The average of the monitored outdoor temperature is 18.06 °C, while the average of the standard outdoor temperature is 16.19 °C. The monitored total global solar radiation is 40.0 kWh/m², while the standard total global solar radiation is 36.4 kWh/m².

In the assessment of Magisterparken, the monitored outdoor air temperature is similar to the standard outdoor temperature in week 26 (Figure 35). The average monitored outdoor air temperature is 15.96°C, while the average standard outdoor air temperature is 15.31 °C. The monitored total global solar radiation is 36.4 kWh/m², while the standard total global solar radiation is 42.6 kwh/m².

Continuing from the preceding examination of the boundary conditions for Haanbaek simulation, Figure 36 demonstrates a consistent pattern of higher simulated indoor temperatures when compared to monitored values. Notably, all models tend to overestimate the risk of overheating. This can be attributed to both inaccurate thermal boundary conditions and the absence of solar shading systems in the models. The latter were omitted in modeling due to insufficient information about the existence and utilization of shading in the case-buildings.

Despite the disparity between the model outcomes and the measurements, the trends depicted in the simulated results align well with the monitoring across all models. Notably, the weak distinction between thermal conditions in the southern and northern spaces is also accurately reflected in the models. Thus, this study opens the door to contemplating the implementation of simpler models—such as two-zone models (Z2, south/north staircase) which produces results comparable to the most advanced models.

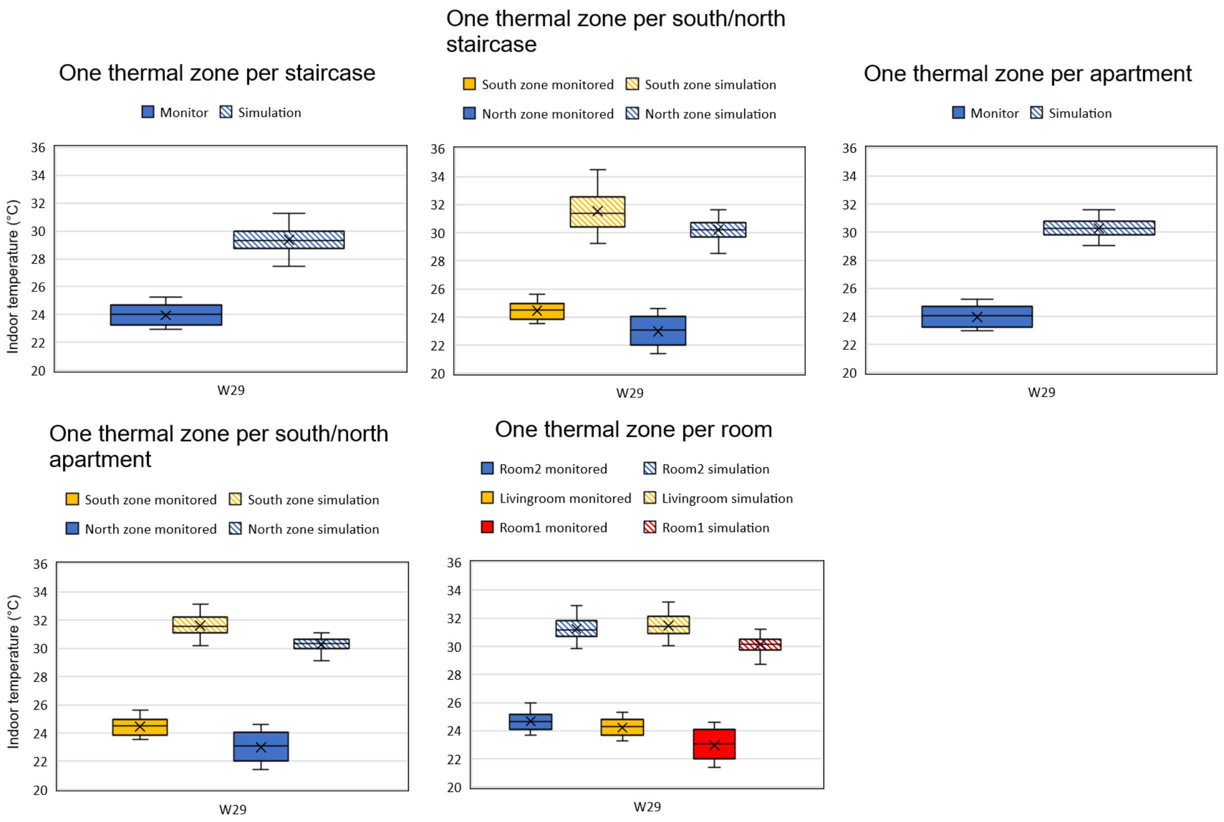


Figure 36 The hourly indoor air temperature of the monitored data and simulation results of week 29 for Haanbaek case building. The results on apartment and room level are analyzed for the apartment, 1794 2tv.

In Magisterparken the modeled indoor temperature is higher than the one measured (Figure 37), albeit the difference is less pronounced than that observed in the Haanbaek case building. A contributing factor to the narrower gap between simulation and monitoring results in Magisterparken is the better alignment between the standard weather conditions incorporated into the simulation models and the actual weather conditions registered during the monitoring period. Certain differences can be observed between the model results with zone ventilation (1Z) and airflow network (3Z).

The variation observed in indoor temperature throughout the evaluated week is comparatively smaller in the monitored data than in the simulations. These differences could stem from the activation of solar shading, a factor not accounted for in the models. Both monitored data and simulation of Magisterparken indicate that the south zones maintain slightly higher temperatures than the north. Specific attention can be directed towards the interquartile range of the box plots, which documents some differences in the simulation results while monitoring results remain almost independent of orientation. On one hand, these observations together with those for Haanbaek indicate certain values of the spatial distribution of sensors during monitoring, but also the arrangement of thermal zones when constructing simulation models. On the other hand, this value is not strongly pronounced in the monitoring, potentially due to open doors between the rooms in the apartments and thereby reduced impact from the orientation. Thus, in this study, detailed model geometry does not appear to be critical for accurately simulating thermal comfort in dwellings. Nevertheless, under different circumstances, simplification of the model geometry may lead to the exclusion of crucial instances of temperatures that could be excessively low or high and therefore must be carefully considered.

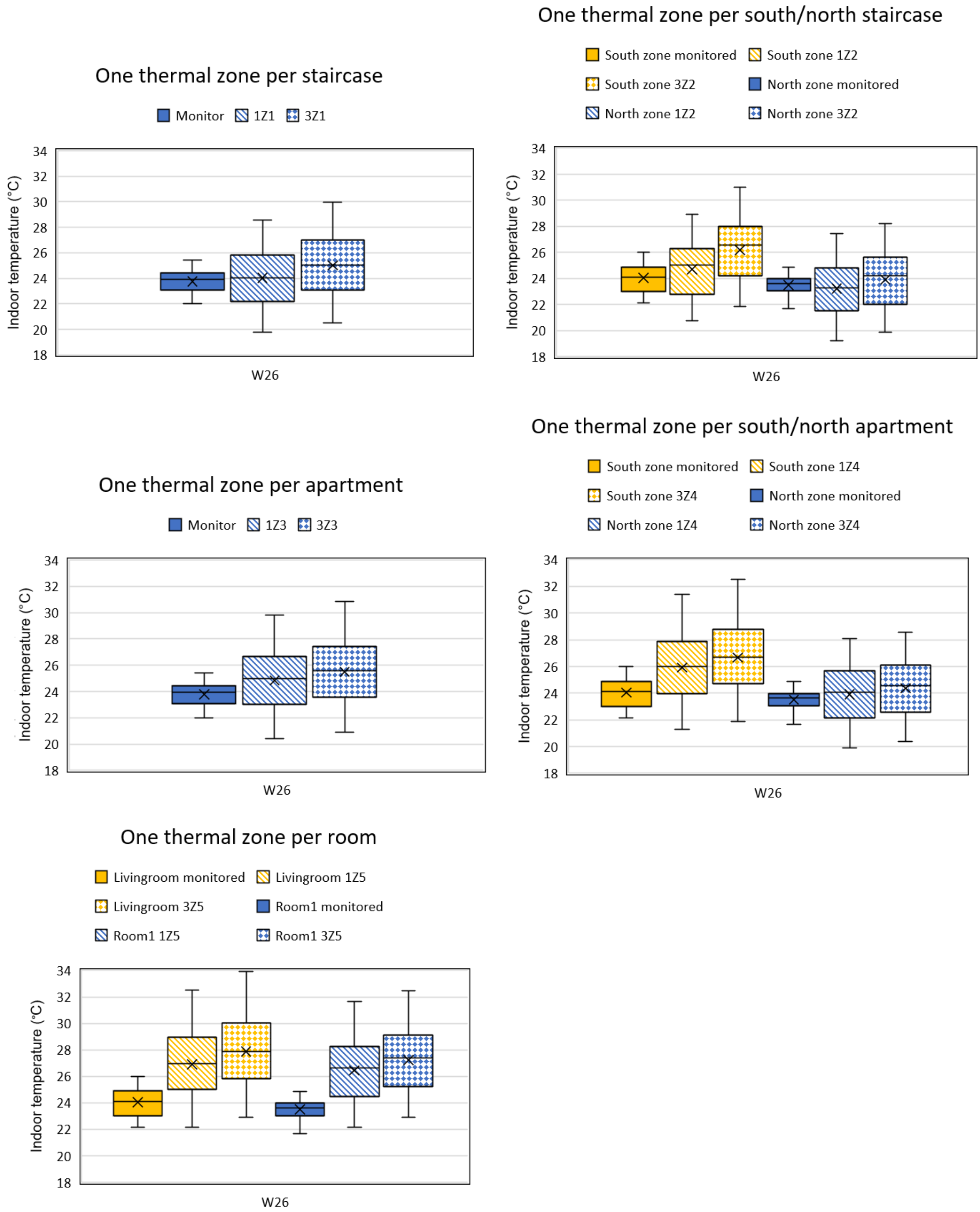


Figure 37 The hourly indoor air temperature of the monitored data and simulation results of week 26 for Magisterparken.

4.2.4 Adapted conditions toward closing the performance gap

The performance gap is defined as the difference between the operational (real) and theoretical (simulated) performance of a building. The reduction of PG in E-DYCE is addressed in two steps. First, is the application of the dynamic calculation engine EnergyPlus to overcome the current inability of steady-state energy labeling approaches to accurately reflect the dynamic conditions inside and outside the building. Second, the differentiation of occupancy, loads, schedules, and set-points in the models is introduced to better describe the dynamic behavior within the building. If nothing is known about the building's use and operation, standard conditions (acc. to EN ISO 52000-1 and EN 16798-1) are assumed for computing the performance gap. An example of such a calculation is given in the previous section of this report (section 0). However, if additional information about the building use is available, then the model can be adapted accordingly, and the PG is then calculated for a more representative scenario of the building use and operation. Such a scenario in the E-DYCE context is referred to as *adapted conditions,* and to a certain degree, it anticipates the actual building use and operation.

In this section, our objective is to demonstrate the potential of applying adapted conditions to reduce the performance gap. This is achieved by implementing various sets of adapted conditions within the existing Haanbaek building models (as detailed in section 0) and subsequently observing the resulting reaction in terms of performance gap reduction. For illustrative purposes, we focus on assessing the impact of adapted heating set-point temperatures and internal loads on the simulation of heating energy and the consequent change in the performance gap. The conditions tested in this study encompass both standard and several sets of adapted conditions. The following list outlines the specific conditions that were examined:

- Weather conditions integrated into the models are set according to the local weather station, thus *the adapted weather conditions are used*.

- Internal loads (people load and schedule) - both standard and adapted conditions are used. Adapted conditions are defined based on the inspection of the dwellings performed according to the inspection plan, see D2.2 through which the total number of occupants in most of the dwellings was established.

- Heating set-point – only adapted conditions are used. The monitoring data includes room temperature from 15 different room sensors which constitutes 4 out of 8 apartments in one staircase. In the models, the set-point temperatures are defined depending on the model geometry.

Section 0 of this report elaborates on models of Haanbaek with different model geometry structures (Z1-Z5). The designations Z1 to Z5 correspond to models with varying numbers of thermal zones. Specifically, Z1 refers to models with a minimal number of thermal zones, essentially one-zone models, while Z5 designates models with the greatest number of thermal zones, treating each room as an individual thermal zone. Furthermore, Energy Plus offers several options for modeling the heating system, and three of these were subjected to testing in this study: (1) Electric convector, (2) Electric radiator, and (3) Water-based heater. The results from all five geometry typologies (Z1-Z5) and three types of heating systems (1-3) are included in the following figures, see Figure 38 and Figure 39. The results are labeled using a notation like 'nZx,' where 'n' indicates the heating system typology incorporated in the model, and 'Zx' indicates the specific model geometry employed.

The simulation was conducted across all 15 models (1Z1-3Z5) under two different sets of adapted conditions. The results were then aggregated at the staircase level, allowing us to calculate the annual and weekly heating energy use for each model within the staircase. The two types of adapted conditions employed in this study are outlined below, and the corresponding results are presented in Figure:

a. Adapted (actual) weather conditions, adapted (actual) heating set-point, standard people load.

b. Adapted (actual) weather conditions, adapted (actual) heating set-point, adapted (actual) people load.

From Figure 1, it is evident that all models exhibit improved performance when the internal load in the models is adjusted to match actual conditions (conditions b). Furthermore, consistent with the findings presented in section 4.2.2 regarding model geometry simplification, it can be observed that the model's accuracy is not significantly influenced by the model's geometry, as evident in both annual and weekly assessments. Notably, the most substantial performance gap is found during the spring season (weeks 9-14).

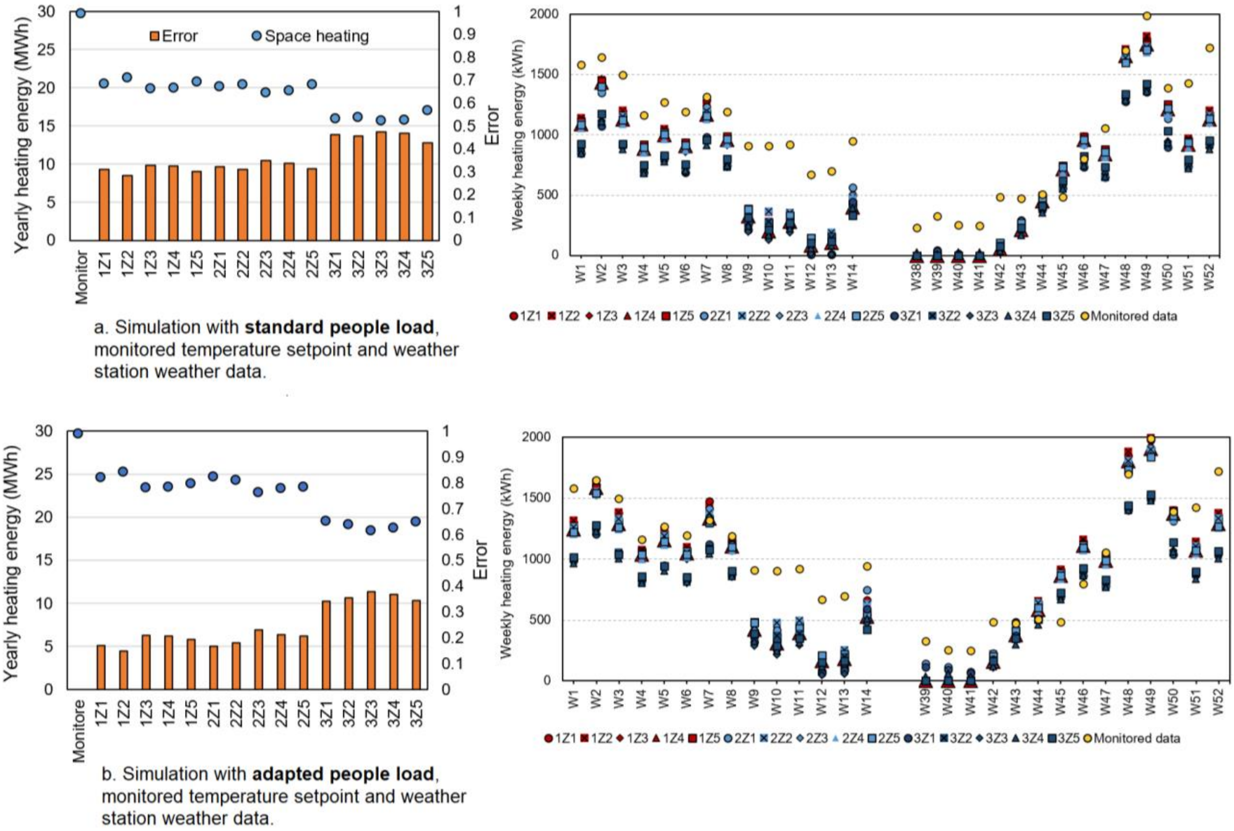


Figure 38 Annual and weekly heating demand for all models simulated for the two sets of adapted conditions (a and b). The heating demand is calculated for the whole staircase. The results are labeled as 'nZx,' where 'n' indicates the heating system typology incorporated in the model, and 'Zx' indicates the specific model geometry employed. The error is the absolute daily error between monitored and simulated values calculated as average for the whole period (1 year).

Next, three types of adapted conditions are tested (a, b, c) and the results are presented for 4 different apartments in Figure 39. Only the models able to provide data at the apartment level are analyzed (Z3-Z5). Adapted conditions (a) and (b) are the same as described above, while condition (c) is as follows:

c. Adapted (actual) weather conditions, adapted (actual) heating set-point (monitored temperature for each room), adapted (actual) people load.

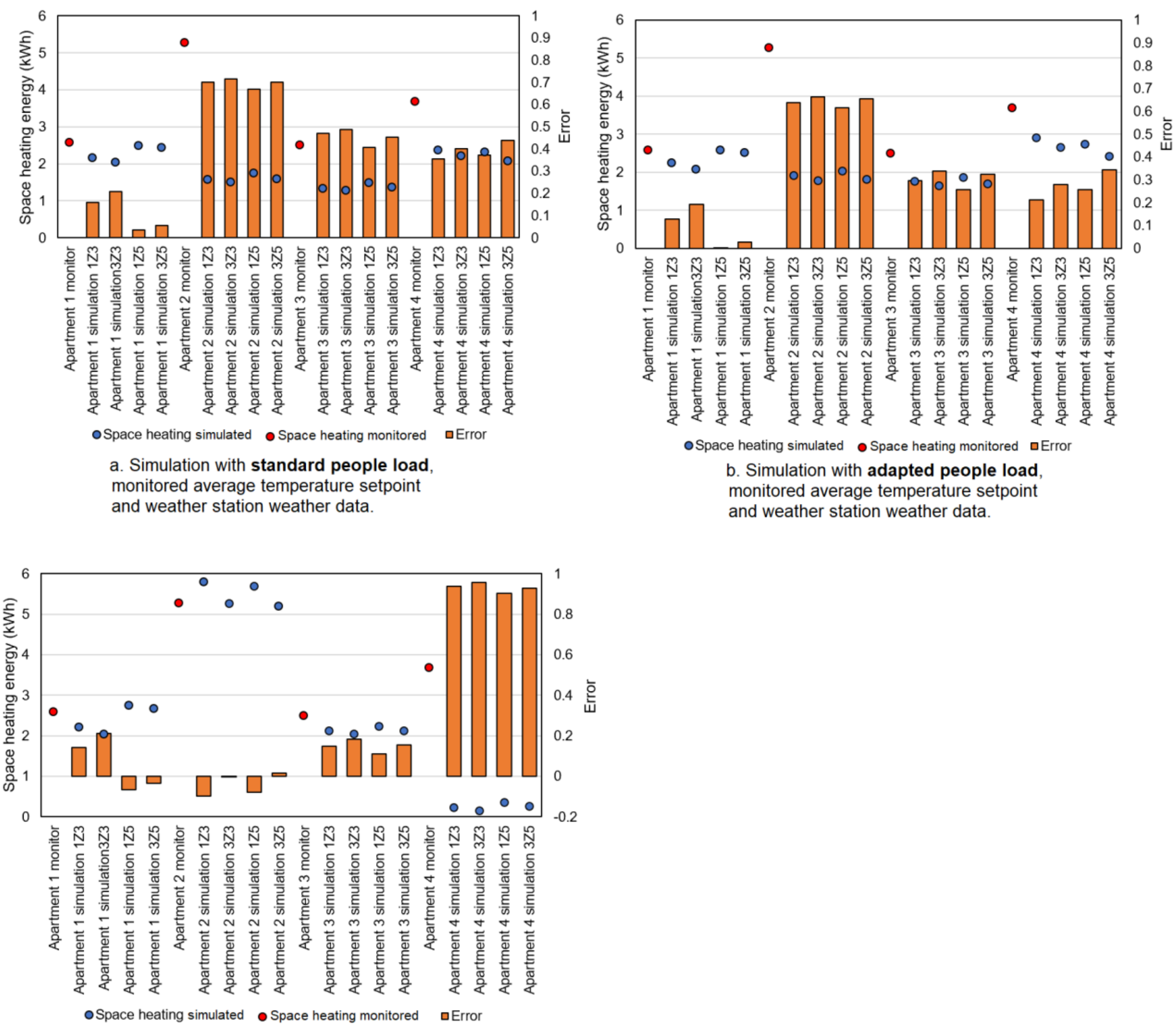
The space heating, as observed at the apartment level for all tested adapted conditions in Figure 39, clearly illustrates the enhanced quality of simulation outcomes with a higher level of detail incorporated into the employed adapted conditions. This is evident through the diminished performance gap apparent in the respective simulation results for all apartments, except for Apartment 4. The discrepancy in Apartment 4's results can be attributed to its sole reliance on a single temperature sensor, which led to a misrepresentation in defining the adapted conditions specific to that dwelling. **In the example of**

Apartment 4, we can also argue for the importance of careful design of the monitoring program, as inconsiderate one-room monitoring can hinder more than aid in the performance gap reduction.

In a wider context, discrepancies across all models, arising from variations in facility or geometry definitions, result in a performance gap ranging from 5-15% per apartment. Notably, the most significant errors in calculating heating demand are linked to inaccurately defined set-point temperatures, as observed during the transition from adapted conditions (b) to (c), as well as variations in internal people load when transitioning from adapted conditions (a) to (b). This suggests that these factors exert a more significant influence on the credibility of heating demand calculations compared to the facility definition (whether detailed or not) within the model. Hence, when analyzing the results for adapted conditions (c), —depicting the scenario with the most precise heating set-point and internal load definitions—it becomes evident that all models perform comparably well. Some models may excel in precision for particular apartments, while others demonstrate superior accuracy for different apartments.

Another noteworthy observation drawn from these results is that models utilizing geometry at the apartment or even room level are indeed capable of predicting heating demand with a high degree of accuracy. With sufficient information available about set-point temperatures and occupant loads, these models achieve a notable level of precision, reducing the average daily error to as low as 5%. This observation emphasizes the potential benefits of the effort put into refining the thermal zones within the model.

Step 2: Apartment level - heating demand



a. Simulation with **standard people load**, monitored average temperature setpoint and weather station weather data.

b. Simulation with **adapted people load**, monitored average temperature setpoint and weather station weather data.

c. Simulated with **monitored heating setpoints for each room**, **adjusted people load** and weather station real weather data.

Figure 39 Annual heating demand for all models simulated for three sets of adapted conditions (a, b and c). The heating demand is calculated per apartment. The results are labeled as 'nZx,' where 'n' indicates the heating system typology incorporated in the model, and 'Zx' indicates the specific model geometry employed. The error is the absolute daily error between monitored and simulated values calculated as an average for the whole period (1 year).

4.2.5 Heat signature (space heating and DHW)

Current tools for compliance and building energy simulation are inadequate for accurately measuring energy use in domestic hot water (DHW) systems. These tools often rely on simplistic or static values related to building layout or other parameters like floor area and number of occupants. Additionally, the proportion of energy used for DHW in total building energy consumption is on the rise. Currently, the most reliable way to assess DHW energy use is through heat measurements (operational assessment).

In the context of the project, a new algorithm [3] aimed at smart heat meters has been developed to address these shortcomings. This algorithm takes into account data available from these meters to estimate the energy use for space heating and DHW in individual households. Direct measurements can be used for more precise estimates if available. This report assesses the impact of the DHW usage on the buildings' energy signature when direct measurements are available.

Building-case and measurements description

The measurements dataset comes from the Danish demo case - Haanbaek. The building is located in Frederikshavn, Denmark. Data on space heating and DHW energy measurements are collected in four apartments.

Concerning the systems within the apartment building, the space heating operates via a single mixing loop that is connected to the district heating and situated in the basement's technical area. Although this loop delivers a uniform temperature to each apartment, in-building line losses can result in temperature variances. Each stairwell features mechanical ventilation with heat recovery and a heating coil, which also taps into the primary mixing loop. Centrally produced DHW is provided through a standalone heat exchanger that circulates water to every apartment via a loop system. Individual flow meters are installed in each apartment to record energy usage. A Danfoss ECL 310 controller manages both the centralized space heating and DHW system.

Occupancy heating habits

To make sense of the data collected from heating measurements, it's essential to first understand the heating usage patterns of the occupants. Knowing how residents interact with their heating systems is crucial for interpreting the data. To gather this information, a brief questionnaire was distributed to and completed by the apartment residents. The crucial outcome of the interview can be seen in Table 4.

Table 4 Occupancy habits regarding space heating and DHW in each apartment

	Apt. A	Apt. B	Apt. C	Apt. D
OCCUPANTS				
Nr. of adults	1	3	2	1
Nr. of children	0	2	0	0
Weekly occupancy	Not at home from 9-12h and Thursdays from 12-15h	Adults always at home. Children at school from 8-15h	Always at home	Out of apartments in the afternoons
AIR QUALITY				
Which rooms are vented?	All rooms	All rooms	Bedroom and bathroom	Bedroom (every day) and living room (summer only)

How long and when do you vent the apartment?	Each day bedroom, bathroom, and living room 2-3 times a week. Long venting in summer (every day) and short in winter (10 minutes)	Summer: All day Winter: 1-2 h in the morning	Summer: All day Winter: 1-2 h per day	Summer: All day Winter: 3-4 h in the morning
THERMAL COMFORT				
What is the setting on radiator thermostats?	Bedroom is set to be cold (setting 1). Bathroom set on 2.	Different settings in the rooms.	Only radiator in living room is open (setting 4-5). Underfloor heating in bathroom (operating).	All radiators set on 3. Radiator not used in the bedroom. Bathroom underfloor heating always in use.
Is temperature in the apartment uniform?	-	Yes, except one bedroom (where no heating is used)	-	-
ENERGY SAVING MOTIVATION				
Do you pay too much for energy?	Yes	Yes	No	No

The Table 4, can be summarized as the following:

- Apartment A is expected to be the most low-energy consumption apartment. There is only one dweller and only vents the apartment a few times a week for short periods. The radiator thermostats are set to low, except for the bathroom.

- Apartment B might be the least energy-efficient apartment. The occupants are a family of 5 with children (with 3 adults and 2 children). The apartment is always occupied, and the occupants vent the apartment all day in the summer and 1-2 hours per day in the winter. The radiator thermostats are set to different levels in each room.

- Apartment C might be a bit more energy efficient than Apartment B. The occupants are a couple with no children. The apartment is always occupied, but the occupants only vent the bedroom and bathroom in the summer. The radiator thermostats are set to high in the living room and low in the bedroom.

- Apartment D probably is the second most energy-efficient apartment. The occupant is single and only vents the bedroom and living room in the summer. The radiator thermostats are set to medium in all rooms.

Heat signature analysis

This analysis aims to focus on the thermal characteristics and performance of the heating systems (space heating and DHW), capturing the energy usage patterns within residential spaces. By closely examining heat signatures, we can gain valuable insights into the efficiency of space heating and domestic hot water (DHW) systems, as well as identify areas for optimization. This section will also consider the role of occupant behavior in shaping these heat signatures, thereby offering a comprehensive view of how heating energy is used and potentially misused.

In Figure 40, one can see the measurements recorded regarding the energy demanded for space heating and DHW per apartment. From the graph, it's evident that the space heating demonstrates a seasonal pattern, influenced by fluctuating outdoor temperatures over the months. On the other hand, DHW usage displays a more unpredictable, stochastic behavior, marked by sporadic fluctuations. However, these fluctuations do operate within a specific average range. To better illustrate this average trend in DHW consumption, **Fejl! Henvisningskilde ikke fundet.** presents the daily DHW demand per month over the same period previously examined in Figure 40. Another crucial highlight is the order of magnitude between the space heating and DHW demand in Haanbaek case. As one can observe, apartments A and

D, have a larger demand for space heating over DHW, while the opposite is seen for apartments B and C. The main reasons behind this are that the occupant's interactions with their space heating systems are different (e.g., using only a few radiators with low settings compared to using all radiators with high valve settings) and DHW needs increase significantly when the number of dwellers increases. Another factor that accounts for a large difference in space heating demand over DHW, is the heating control taken in place in the building by the company Neogrid, which causes the temperature difference between the incoming and outgoing water of the district heating (ΔT) to be lower for the space heating systems. While, the DHW systems have larger temperature differences of hot water, to account for hygiene regulations.

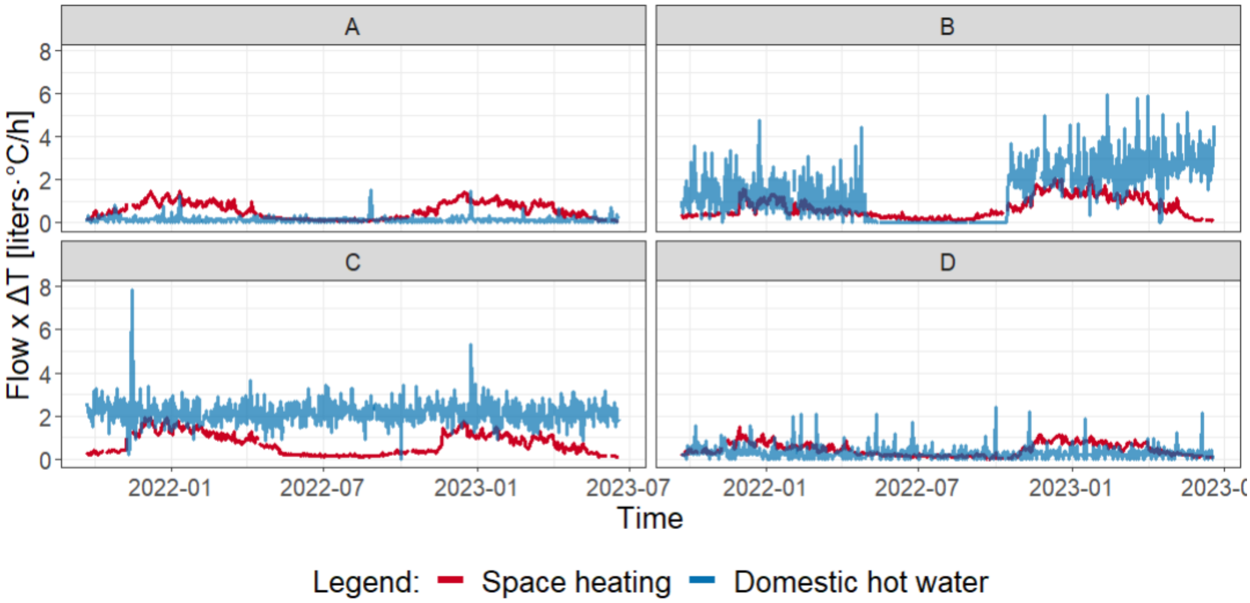


Figure 40 Time series of the space heating and DHW energy usage per apartment

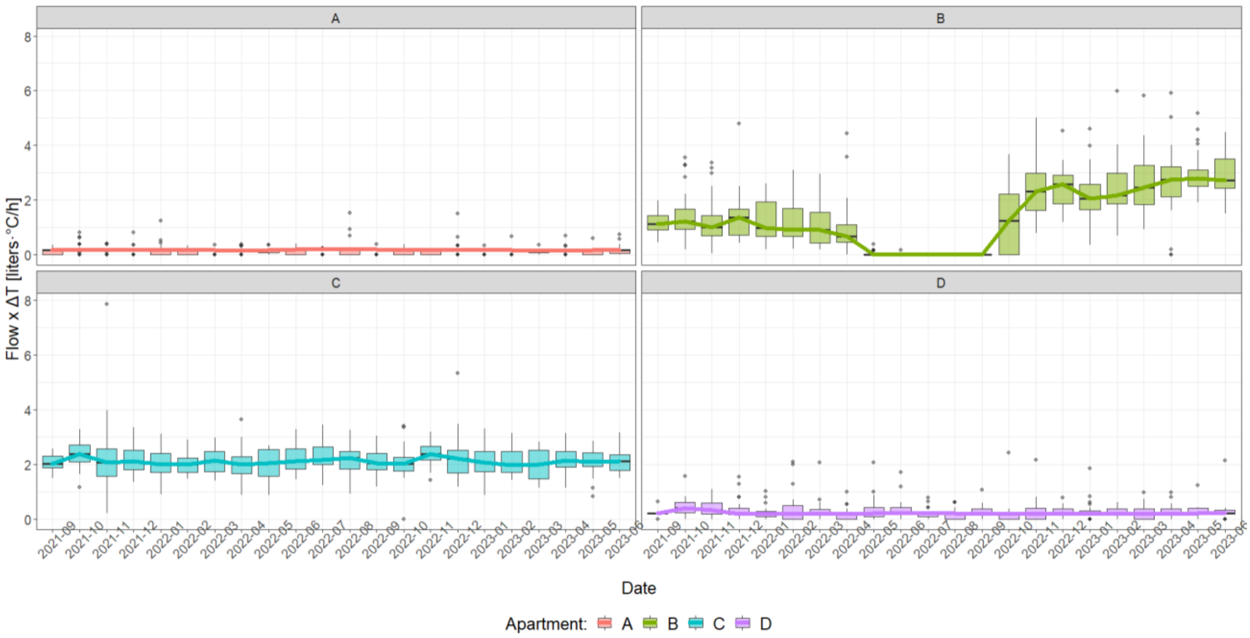


Figure 41 Monthly distribution of the daily DHW demand per apartment

By examining the monthly trends, seen in the boxplots above, it reveals that most apartments exhibit similar patterns in DHW usage—except for Apartment B. According to the data gathered from Apartment B and conversations with its occupants, it was found that different residents lived there in April 2022 and then vacated, leaving the apartment empty from May to September 2022. A new family moved in after

September, and their DHW usage was noticeably higher than that of the previous occupants. Another observation from the graph is that the magnitude and variability of the DHW usage seem to correlate with the number of residents in each apartment. For instance, the baseline usage in Apartments A and D, which each have only one resident, is notably lower and less variable than in the other units. This supports previous research findings suggesting that the number of occupants and their daily routines significantly influence DHW consumption patterns. From these two figures, one can see, that the DHW has a significant variation through its daily demand, however when plotted on a larger scale (in this case, monthly), a constant trend is observed, which is barely influenced by the seasonality of the outdoor temperature variations throughout the year.

By taking the above results in mind, it is plotted the energy signature for space heating and DHW demand in **Fejl! Henvisningskilde ikke fundet.**.

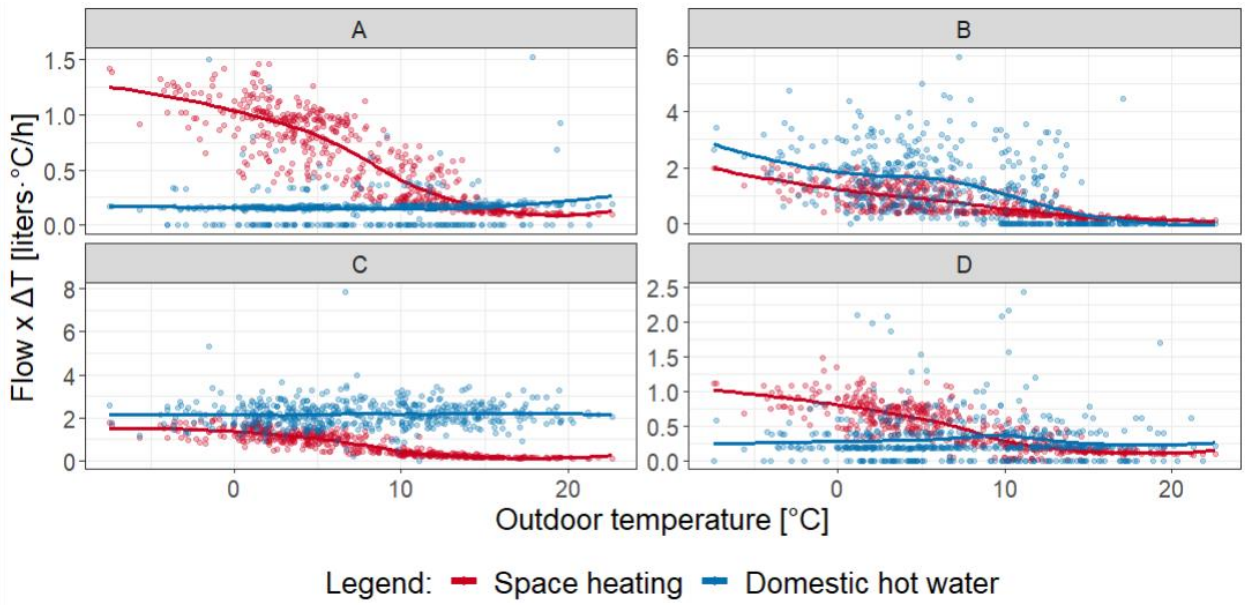


Figure 42 Heat signature of space heating and DHW per apartment (Note: the y-axis of each apartment is not scaled to better visualize the differences between the heat signatures).

The scatter plot shows the relationship between the energy usage and the outdoor temperature. As argued above, the space heating shows a seasonality pattern while the DHW displays a constant demand throughout the year. The only cases, where this constant demand is not observed are in apartments B and D. In apartment B, this seasonality occurs due to the dwellers changing in the middle of the measurement campaign. While, in apartment D, a constant DHW demand occurs, but large stochastic outliers. The point where the space heating demand starts to follow a constant demand is called the change-point temperature – CPT (inflection point). These inflection points occur similarly for the four apartments at around 10°C outdoor temperature. This means that for larger temperatures than this point, the space heating demand drops significantly and that is not dependent on the outdoor temperature, which is a pattern consistent with the summer period. There are also outliers in the plot. These outliers are the points that fall outside the overall pattern of the relationship, and as seen, they are mostly due to DHW production. Because the systems are the same for each apartment, we can establish that these extreme DHW patterns are caused by occupancy usage alone.

Proposed plots support the assessment and understanding of the performance of the different heating systems that interplay in the buildings. Right visualization helps to better understand the impact of the occupancy, daily habits and their role in the overall energy performance of the buildings.

4.2.6 Renovation roadmap

The example of the renovation roadmap and E-DYCE contribution is presented using results developed for Magisterparken building as an example. The approach is based on expert and analytical approach. If desired the approach can accommodate different modeling, steady-state/dynamic, and mono/multi-zone to reflect modeling uncertainty and sensitivity to modeling approaches. The proposed approach that is presented in this chapter was in more detail elaborated in [1],[2].

Expert approach

The Danish steady-state EPC tool BE18 (mono-zone) and the dynamic building energy simulation tool Energy Plus (mono and multi-zone) are utilized to calculate the renovation roadmap. In BE18, the entire building is represented as a mono zone, with a consistent indoor climate and distribution of solar gains. The heat capacity of internal walls and floors is treated as a single node. On the other hand, the dynamic mono-zone model treats all apartments as one zone (refer to Figure 3b), with uniform indoor climate and even distribution of solar gains. The attic and basement are modeled as separate unheated rooms, and the heat capacity of internal walls and floors is considered as a single node. In the dynamic multi-zone model (depicted in Figure 3c), each room is treated as an individual zone. This allows for the distribution of internal heat capacity to rooms where solar energy enters through windows, resulting in a more diverse indoor climate compared to the mono-zone model. As a consequence, heating requirements may increase as north-facing rooms necessitate heating while south-facing rooms receive surplus heat from the sun. The mono-zone model and the multi-zone model utilize the same energy-saving measures and associated costs. The expert approach focuses on a limited number of energy conservation solutions related to envelope insulation and window improvement, which are commonly recommended in EPC guidelines.

$$CEP = \frac{\text{Investment [€]}}{\text{Annual energy savings [kWh] * Lifetime of measure [years]}}$$

The CEP indicator, although not accounting for capital cost or energy price changes, is still effective for comparing actions and selecting the most cost-effective option. This simplification is largely acceptable and seldom results in incorrect decisions.

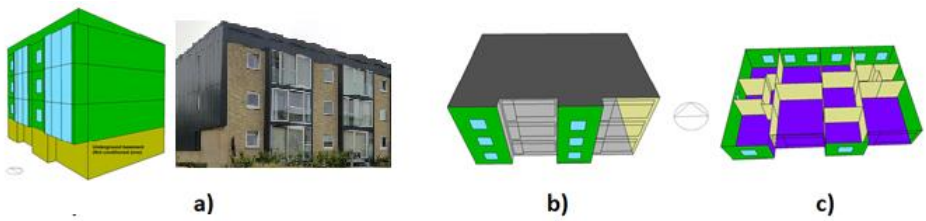


Figure 43 From left: a) Building from the outside, b) mono-zone model – one staircase as thermal zone, c) multi-zone model – each room as a thermal zone.

Table 5 The U values of the envelope before and after the expert energy upgrade suggestions. 1 The U-value for the roof includes the resistance of the attic and the roof covering.

	U value_ref (W/m²K)	U value_upg (W/m²K)
External wall	1.11	0.28
Roof[1]	0.37	0.12
Ground floor	0.30	
Basement wall	0.42	
Basement floor	0.43	0.22
Window	2.8	1.0

Analytical approach

The analytical approach uses a dynamic simulation platform, described in [2], that allows for massive sensitivity analysis of main design parameters. The analytical platform is linked to environmental variables like indoor comfort models, temperature levels, and energy. The platform uses EnergyPlus as the simulation engine and includes a personalized KPIs calculator module.

An example of renovation actions and their ranges are given in Table 6.

Table 6 Renovation actions

	Range [m] / For window: U-value/g-value/LT	Step [m]
Add external wall thermal insulation	[0.05-0.30]	0.05
Add roof thermal insulation	[0.05-0.25]	0.05
Add basement ceiling thermal insulation	[0.05-0,25]	0.05
Substitute window glazing:	0.79/0.46/0,66	#
	1.50/0.57/0.75	#
	2.71/0.70/0.78	#
	5.78/0.82/0.88	#

Selected results

Expert results: Models with higher detail levels show lower annual energy savings for glazing upgrading. CEP values for cavity wall and attic insulation are below the cost for district heating across all models, while dynamic models show higher CEP values than the stationary calculation for insulation towards the unheated basement due to the dynamic models' treatment of heat losses to the basement as a separate zone with its own temperature profile.

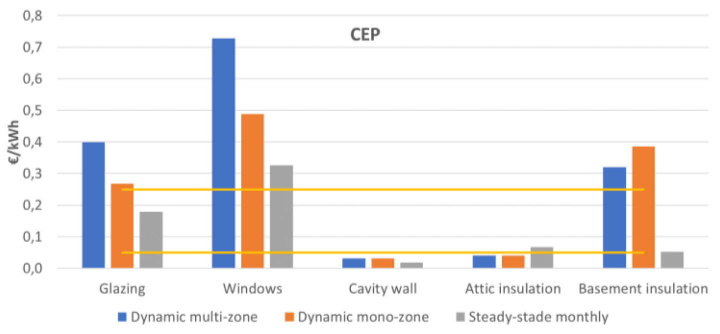


Figure 44 Cost efficiency parameter [€/kWh] for energy saving measures. Horizontal lines represent the price span for district heating in Denmark

Analytical results: aids graphics to help users grasp the effects of retrofit solutions on KPIs. In Figure 45, the relationship between insulation thickness in walls, ceilings, and basements and the reduction in heating energy consumption is depicted. Notably, external wall and roof insulations have a significant effect. However, it should be noted that mono-zone models may slightly underestimate the requirements for space heating compared to multi-zone models. Figure 45 and Figure 46 provide further insights, demonstrating that increasing envelope insulation reduces winter energy demands but simultaneously increases the number of hours of summer overheating, necessitating the implementation of countermeasures. This is evident from the distribution of operative temperatures concerning the outdoor running mean. To address this issue, the platform could explore shading systems or ventilative cooling technologies to determine if natural methods can mitigate the risks of overheating, striking a balance between minimizing heating needs and ensuring comfort during hot weather conditions.

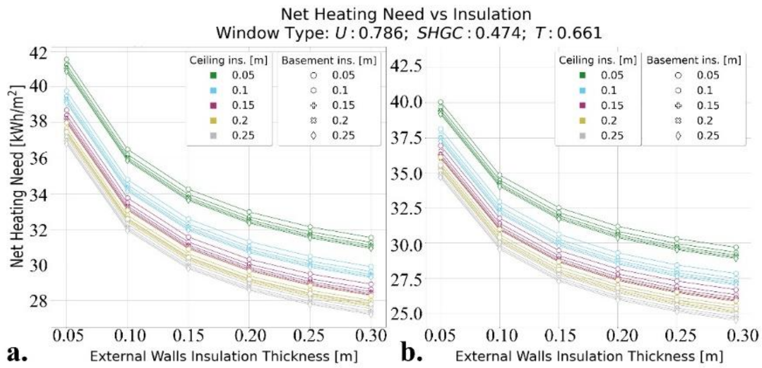


Figure 45 Heating energy needs versus insulation with triple glazing a) multi-zone model b) mono-zone model.

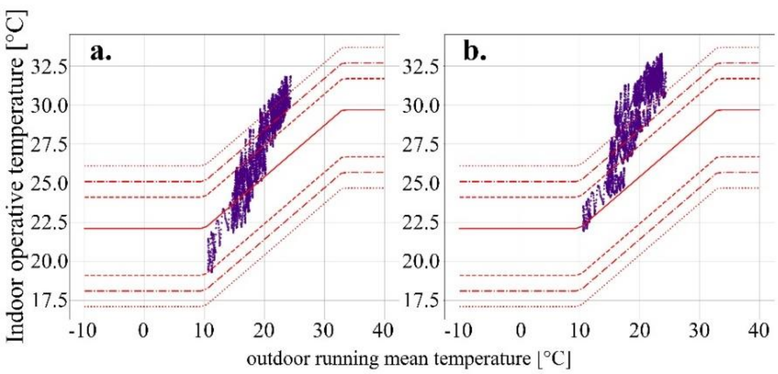


Figure 46 Adaptive comfort model points distribution considering the outdoor running mean temperature in categories for the multi-zone model in a) the least insulated case and (b) the most insulated case.

To conclude, the recommended approach for developing renovation roadmaps involves an expert conducting a thorough examination of the building and making choices based on factors such as available space, costs, additional work required, building tradition, and regulations. This method minimizes the need for extensive calculations, which is advantageous for non-linear cost estimations that cannot be directly applied to an analytical approach. However, relying solely on the expert approach's limited calculations and emphasis on cost, energy, and preservation (CEP) may not guarantee a comprehensive solution and could potentially result in inadequate indoor comfort. On the other hand, the analytical approach enables the efficient execution of multiple simulations using a building model, generating heatmaps that highlight the statistical impact of each decision on selected key performance indicators (KPIs). These two approaches can complement each other, with the analytical approach identifying a range of optimal solutions and the expert approach selecting the most cost-effective and compliant option based on national building traditions and regulations. In terms of the expert approach and calculating energy savings for three different levels of model detail (monthly single zone, mono-zone dynamic, and multi-zone dynamic), quick conclusions can be drawn regarding the specific case. However, the analytical approach reveals that increasing insulation levels may lead to a higher risk of overheating in summer, necessitating the verification of thermal comfort conditions and consideration of appropriate countermeasures. By incorporating a wide range of input variations, the designer can conduct a sensitivity analysis to comprehend the impact of retrofitting choices on various KPIs, thereby enhancing their awareness of the consequences associated with their decisions.

4.2.7 Weather and energy forecast

Weather and energy forecasts have been developed by partner CORE and consider weather predictions and heat use predictions. The work is presented in report D3.4. The predicted weather variables are: outdoor temperature, global insolation, direct insolation, and diffuse insolation. The predicted energy use concerns heat power. Predictions were developed using historical data and aimed short (24-hour ahead), middle-long (7 days ahead), and long (month ahead) forecasts. In this chapter are provided example results of predictions focusing on thermal energy results. In the chapter can be found elaborations on the possible application of the results and future perspective of the use of the results.

Figure 47 presents examples of the 24-hour, week, and month-ahead forecasts for Haanbaek building. The forecasts are integrated in the FusiX middleware solution and can provide real-time updated forecasts to end users. The application of short-term forecasts (24h ahead) can support the understating of daily energy use and can potentially contribute to demand response control and avoidance of peaks, f. g. morning and evening peaks that challenge the district heating grid and production. The information could be also valuable to deciding on the method to produce domestic hot water, either in the heat exchanger or in the storage tank. The middle-long (7 days ahead) forecasts can be used to detect anomalies and wrong trajectories of energy use that could be caused by misbehavior or faulty operation of systems. Moving towards long monthly predictions these can be used to monitor successful or faulty application of energy conservation measures and can support the detection of buildings drifting away from the past trajectories.

Figure 47 Examples of heat energy predictions for 24h, 7 days and 1 month ahead predictions.

4.3 Applications in Italian demo sites (B2)

Italian demo buildings include 2 schools and 3 residential houses, as described in deliverables D5.1 and D5.3 – see Figure 48. All demo buildings are characterised by an end-user interest in knowing their IEQ building behaviours and general energy considerations. Different extended functionalities have been applied and developed in line with special national and local topics. Results are here summarised with the scope to evaluate the extended potentialities of the E-DYCE methodology in supporting extra features in addition to the DEPC protocol application.

Figure 48 Italian demo buildings

Figure B2X *– Italian demo buildings*

In particular the following extended functionalities have been verified and are here discussed:

- **IEQ extended analyses:** two additional analyses are performed exploiting measured data and PREDYCE tool functionalities. A first extended verification is performed on demo B2.1 (school) and demo B2.5 (residential) by analysing their comfort conditions (thermal and IAQ) using the measured data elaborated in terms of KPIs by the PREDYCE approach – See Section 4.3.1. A second verification analysis is also performed focussing on IAQ ventilation performances in the demo B2.1. This demo building is particularly relevant for the topic because, thanks to the E-DYCE project, three Detached Mechanical Ventilation (DMV) units were installed to analyse their potential in treating IAQ and ventilative cooling compared to the other naturally ventilated classrooms. The analysis compares EnergyPlus simulations, expanding PREDYCE with EMS functionalities, and measured data by applying different control logic. An end-user involvement test to improve IAQ based on measured values is also reported – See Section 4.3.2.

- **Free-running analyses:** additional research about the fictitious cooling indicator is presented here, focalising on one side on the differences between the three methods to evaluate energy needs in free-running buildings (I.: by adding a virtual HVAC without bioclimatic strategies; II. by adding a virtual HVAC supported by bioclimatic strategies, such as ventilative cooling and shading systems in summer, and III.: the fictitious cooling approach translating adaptive thermal discomfort into energy needs) and on another side on the meaning behind a variation in the definition of the comfort thresholds activating energy needs. The analysis is performed on the residential demo B2.5 – see Section 4.3.3.

- **Renovation analyses**: taking advantage of the PREDYCE tool functionalities (see D3.1 and D3.2), the E-DYCE renovation roadmap approach – see deliverable D4.2 – has been tested in the Municipality school building B2.1 – see Section 4.3.4. Nevertheless, considering the local conditions, some modifications have been performed in the cost analysis to increase the connection with the dynamic simulation platform. Hence, in this test, a cost heatmap analysis has been implemented and is described in the mentioned section. This test allows to verify in the Italian context the application of the renovation roadmap approach suggesting design and retrofitting actions. Additionally, a post-intervention analysis is also presented in Section 4.3.5. The latter takes advantage of the E-DYCE monitoring solution to allow users to verify the impact of renovation actions during building operational phases. In this case, a comparison in monitored environmental conditions is conducted for the residential buildings B2.3 and B2.4 – see also Deliverable D5.4 – allowing the verification of extra-functionalities in the building renovation topic, such as post-intervention building performance checking.

- **Performance gap analyses:** additional considerations on performance gap results on the two main demo cases considered in Part A, hence B2.1 and B2.5, are presented in Section 4.3.6. The calibrated models of the two demo cases are adopted to verify performance gap resilience over time and utility of adopting a standard and an adapted version of the model to better follow the actual buildings behaviour. This work may help in highlighting main potentialities and drawbacks of the E-DYCE methodology. Results show that the adapted model setting based on accurate building inspection allows to follow the monitored trend better than the standard setting, but the accuracy of the results are highly variable throughout the year since several operational settings, from occupancy to natural ventilation habits, strongly vary because of a multitude of factors. Hence, the E-DYCE KPIs can allow to have a general overview of the building behaviour, that most of the times can be more accurate than a standard or static vision, but the same indicators can fail if the goal is to give clear suggestions to maintain thermal comfort and air quality at optimal level at the present moment.

- **Simplification analyses:** two principal studies are reported here. Different model and measurement simplification studies have been performed on the Italian demo buildings. A geometrical model simplification study, including applying the different studied approaches on demo B2.1. In addition, a simplification analysis is here reported – see Section 4.3.7 – comparing the variation in modelling strategies with their impact on the PREDYCE calibration scenario – see also D3.1 and D3.2. This point compares model simplification with the consequent changes in the calibration process by including the measured temperature data. Results show that it is possible to divide complex buildings into smaller models to support faster simulation processes adapted to automatic dataflows such as the ones of the proposed E-DYCE dynamic simulation platform. Finally, an extensive analysis is performed on the measured data for different Italian demo sites with the scope to compare temperature and CO2 data variations among several sensors installed in the same building. Italian demos include per-room details in terms of IEQ sensoring, and this point analyses if room variation details are sufficient to justify a so large number of sensors, or if sensor simplifications may occur – see Section 4.3.8.

- On the **energy point of view**, TPM demo buildings do not have cooling systems, being Torre Pellice located in a mountain valley. Looking at the heating consumptions, energy savings are underlined in all the five demos during the E-DYCE project period. In particular, for B2.1 it is possible to analyse natural gas bills. The heating system is composed by a small district heating solution serving three public buildings, including the demonstrator. Looking at bills and heat meters, the **B2.1** consumption is calculated to be 34% (average) of the total district heating, allowing to analyse variations (the national conversion factor from standard cubic meter of natural gas to kWh is assumed, i.e. 10.69 kWh/smc). Assuming winter 2020-21 as the reference, a saving of 5% is underlined for 2021-22 and of 24% for 2022-23 (better balancing window opening in the post-covid conditions). Focussing on measured heat meter values, it is possible to compare the March-to-May 2022 and 2023 periods. In this case an even higher energy saving is underlined reaching 39%. Considering demo **B2.2** it is possible to compare the measured heat meter values for the same periods (March-to-May 2022 and 2023), underlining an energy reduction of -14%. Considering the residential demo **B2.3**, a comparison in the natural gas bills is performed, considering as reference year winter 2019-20 (before the project) and as testing year winter 2022-23, after the renovation action performed during the E-DYCE period – see also D5.4 and Section 4.3.5. Bills underline an energy saving of 27% (-4991 kWh). By comparing the measured heat meter data of March-to-May 2022 and 2023, a saving of 53% is underlined in demo **B2.4**. Tenants report a change in activation profiles and a slight reduction in the setpoint temperature (from 19.8°C of 2022 to 19.3°C of 2023) to also consider the positive effect of the renovation action – see D5.4 and Section 4.3.5 – that increases the first-floor temperatures, but not affect the room of the thermostat. Finally, for **D2.5** they are underlined a reduction of -12% in the natural gas bills by comparing 2021 and 2022, and a saving of 5% in the March-to-May period (2022 vs 2023) for the space heating heat meter and of 35% for the DHW heat meter. **E-DYCE verification comments**: in the Italian demonstrator any actuator or direct management action is performed on the heating systems, although a reduction in energy consumption is underlined in all demos. This is due to an increase in the end-user engagement, including in some residential cases self-renovation actions. On the general point of view, it is possible to confirm that the sole installation of monitoring solutions can lead to energy savings, resulting in a rise of the general interest and engagement.

4.3.1 IEQ extended analyses: monitored data performances

This Section focuses on providing some relevant outputs regarding thermal comfort in demo buildings on the base of KPIs elaboration exploiting the PREDYCE code ability in treating measured data – for simplification the analyses are conducted extracting by the dynamic simulation platform the specific coding parts. The following KPIs are considered:

- PMV/PPD thermal comfort indicators, based on the Fanger model and conceived for mechanically treated buildings – see ISO 7730 and EN 16798-1 – calculated in line with the mentioned standards as described in both D1.2 and D3.2. This analysis is applied to the heating seasons. A time-series plot showing PMV value fluctuations is retrieved considering EN 16798-1 comfort classes (Cl. I: ±0.2 PMV, Cl. II: ±0.5, Cl. III: ±0.7, Cl. IV: ±1).
- Adaptive thermal comfort indicator (ACM model), based on EN 16798-1 and conceived for free-running buildings – see both D1.2 and D3.2. The analysis is applied to the summer and neutral season: any Italian demo has a cooling system. The typical ACM graph, plotting the operative temperature versus the running mean, is adopted.

Considering thermal comfort, the verification process of this deliverable focuses on demo B2.1 and B2.5. Results for B2.1 are reported in Figure 49. In all cases slightly cold environments are detected, although daily hours are localised in the Cat.II profile, in line with expectations. In line with EN 16798-1, usages of floor F00 require a lower setpoint. The measured behaviours show a good heating management avoiding peaks, while maintaining during occupation the correct expected temperatures. Looking at the free-running season, a difference between floors is underlined and as expected upper floors are showing higher temperature profiles, while the last floor also shows a higher cold to hot variation being the most exposed to radiative night and day exchanges. For the last two floors, where hotter conditions are recorded, it may be suggested to consider, for future renovations, to include a smart shading and a controlled natural ventilation solution to support passive cooling strategies during occupation. Nevertheless, the school building is almost not used in the hottest period (July and August) due to student vacations.

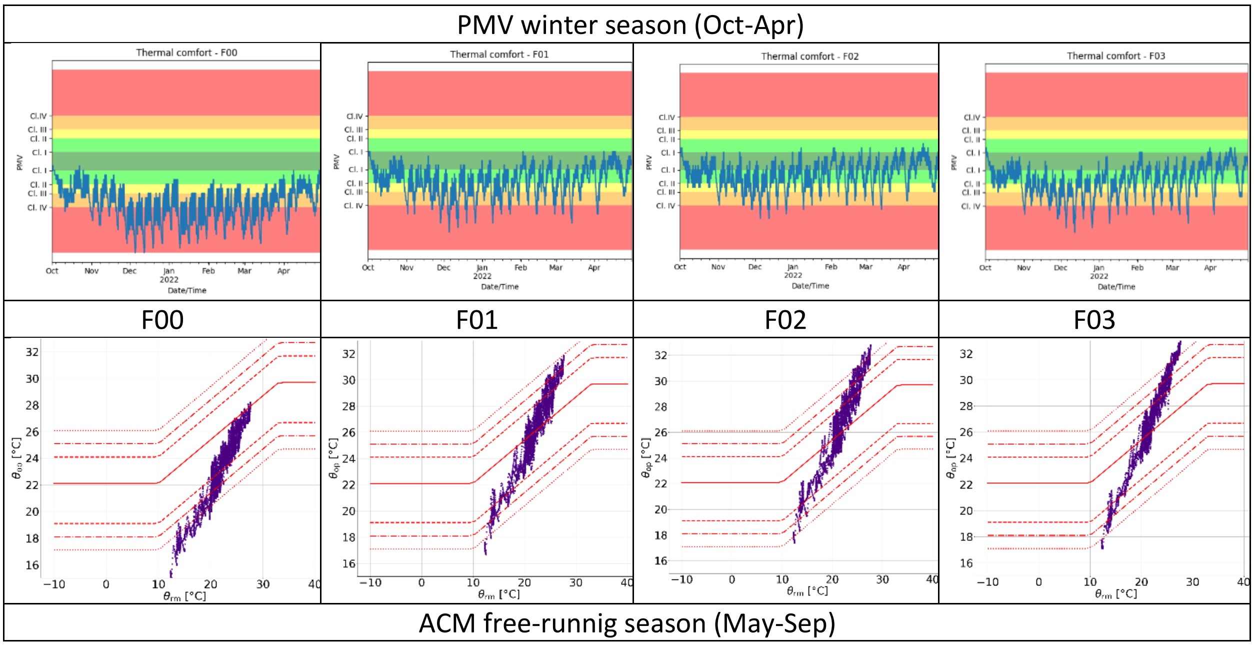


Figure 49 Thermal comfort behaviour – average values per floor – considering winter and summer seasons. PREDYCE elaborated measured data – Demo B2.1.

Focussing on B2.5, Figure 50 shows that on the winter period (top graphs) the PMV values define fully comfortable spaces, both fo the sleeping area and the main used daily space (kitchen). The living room, mainly used during the free-running period, is behaving correctly, with a slight cool perception aligned with the true usage profile. The higher variations in the kitchen are due to the wooden stove activation that generates fluctuations around PMV 0 (stove activation and ventilation). The activation of the latter is analysed in the following figure.

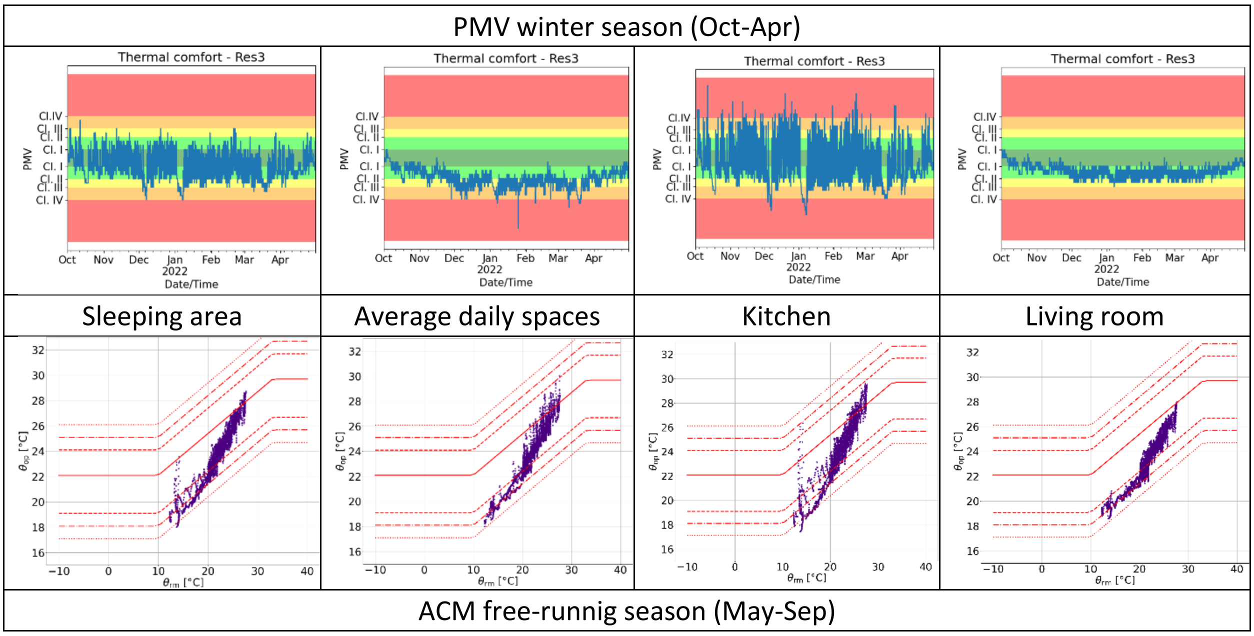


Figure 50 Thermal comfort behaviour – bedroom and average kitchen and living room spaces – considering winter and summer seasons. PREDYCE elaborated measured data – Demo B2.5.

Additionally, for demo D2.5, a comparison between heat-meter measurements for DHW and space heating is performed. The considered flat has a single heater able to produce both DHW and radiator heat, while monitored solutions measure the DHW and heating lines independently. Figure 51 shows the scattered, but yearly continuous use of the DHW system (top-left carpet plot), while the heating behaviour is evident by the second graph (top-right). Looking at one-year period (May 2022 – April 2023) the DHW is responsible for 7% of total thermal flows. The latter underlines a change in the heating profile between the winter season 2021-22 (not heating activation from midnight to 6:00am) and the winter season 2022-23, where it is possible to underlined two moments in the day (early morning and evening) in which a change from setback to set point show a more intense activation of the heater. Looking at monitored data, a 5% of energy savings is underlined between march-to-may 2023 in respect to 2022. The other two carpet plots (bottom) compares the activation profiles of the radiator and of the manual wooden stove in the kitchen living area. Profiles are analysed on the base of two temperature probes, see D5.4, underlining a prevalent use of the natural gas heater in the morning period and a prevalent use of the stove during evening periods when occupant(s) come back to home.

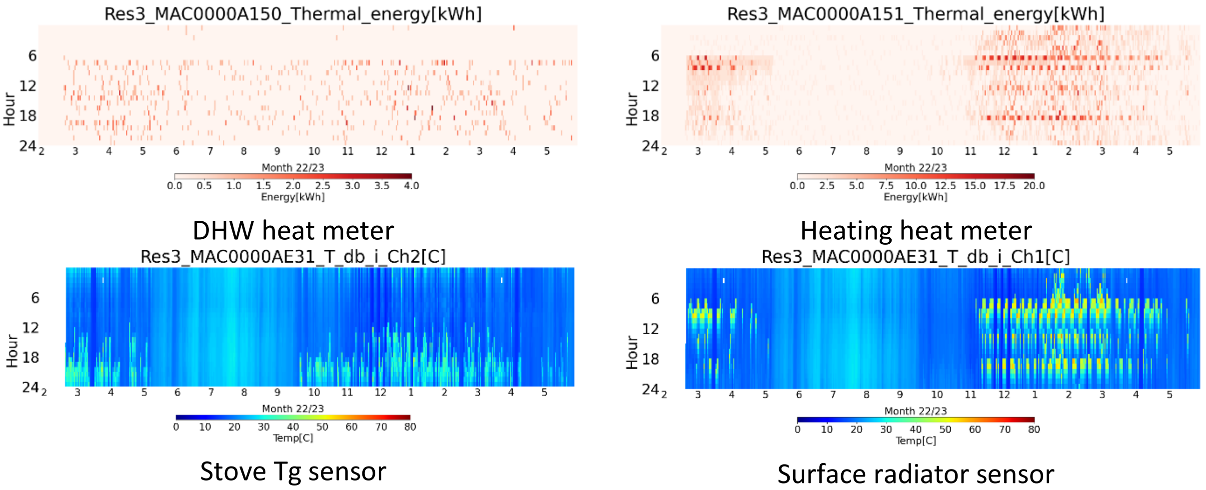


Figure 51 Heater activation profiles – comparison between DHW (top-left) and space heating activations (top-right), and comparison between manual wooden stove (bottom-left) and radiator (bottom-right) activations in the kitchen – Demo B2.5

Residential demo B2.3 only has limited heat meter data due to the renovation action on the heater performed by tenants that has delayed the installation and activation. Nevertheless, Figure 52 show the scattered activation of the smart fireplace (termocamino) allowing to strongly contribute to the home space heating. A change in the radiation profile shown in the bottom right carpet plot is underlined before and after the renovation, where the high temperature and almost continuous activation of winter 2021-22 is substituted by a discontinuous activation at lower temperatures in 2022-23. The fireplace sensor was unfortunately active only in later 2022.

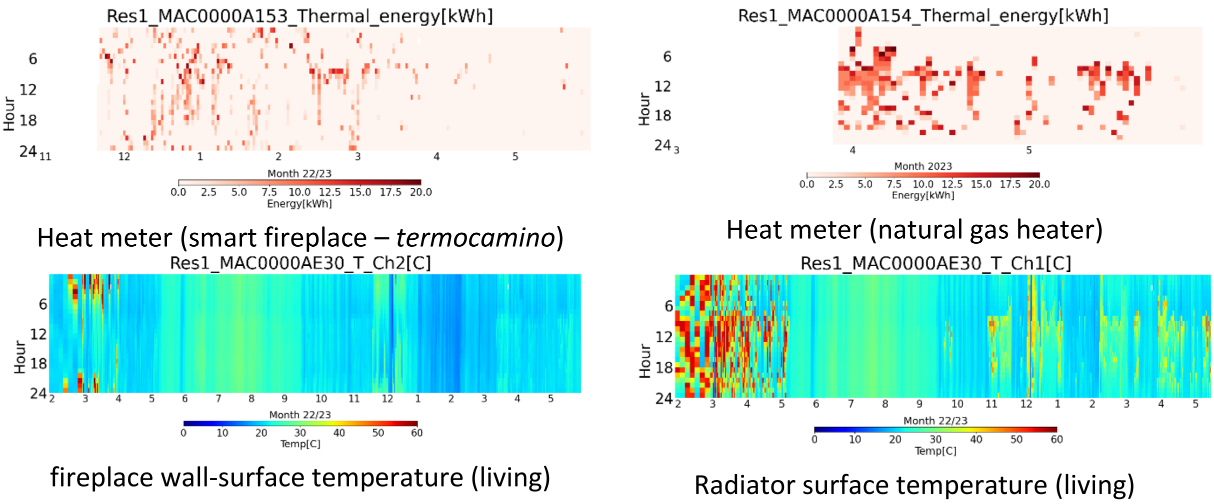


Figure 52 Heater activation profiles – comparison between the smart fireplace (top-left) and the natural gas heater (top-right), and comparison between smart wooden fireplace (bottom-left) and radiator (bottom-right) activations in the living room – Demo B2.3

Similarly, the presence of heat meters allows to analyse the heating system behaviour allowing to identify, in a reverse approach, the adopted profiles, e.g. turning on schedules, to improve the adapted simulation and correlated analyses. For example, Figure 53, shows the heat meter profiles for the residential demo B2.4. It is possible to see that the pellet heater follows a double activation profile: a morning activation and a late-afternoon and evening one. Focussing on the second heat meter, the solar panel contribution is limited in intensity, but shows a similar profile. Differently, by Demo B2.5, the fireplace is here rarely used and doesn't perform a true contribution to space heating. The radiator sensor (bottom-right) has been repositioned by the tenants during summer 2022 losing the possibility to follow the winter 2022-23, although during the previous winter the monitored data follow the same path of the heat meter not having a thermovalve.

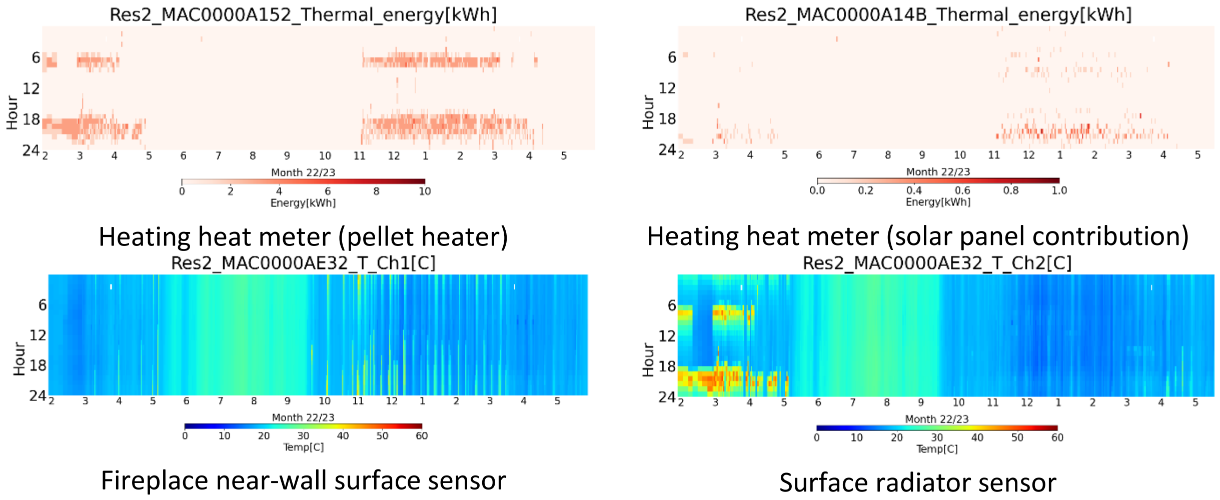


Figure 53 Heater activation profiles – comparison between the pellet stove heater (top-left) and the solar panel contribution (top-right), and comparison between manual wooden fireplace (bottom-left) and radiator (bottom-right) activations in the living room – Demo B2.4.

Figure 54, plotting the heat meter data of the high school demo B2.2, confirms the above verifications. For this demo it is possible to identify a primary turning on period covering main classroom hourly profiles, followed by afternoon points referring to energy needs by spaces used during afternoon times. The school has a potential set-back temperature confirmed by the presence of less intense points also during evening and night periods. A pre-heating period is underlined, starting at around 6:00, and since December 2022 also before.

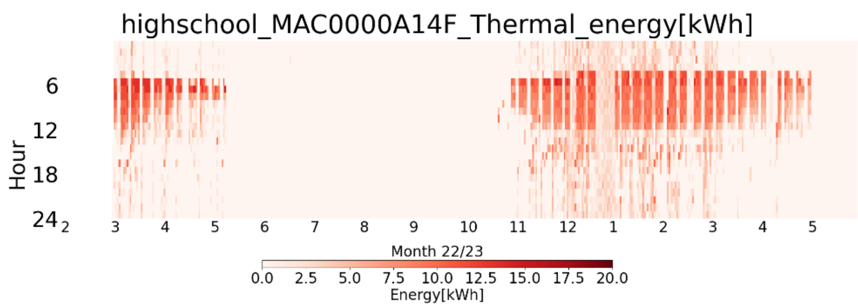


Figure 54 Heater activation profiles –Demo B2.2

IAQ analyses based on CO_2 concentrations are deeply discussed in the following sections, including a focus on demo building B2.1.

E-DYCE verification comments

The E-DYCE installed monitoring solution is able to support a large series of analyses helping different categories of end-users. In this section, it underlined how the installed probes allow to analyse thermal comfort in different building typologies. Results help to i.) understand the correct management of the heating system or identify issues, ii.) understand thermal comfort behaviour in summer and eventually identify criticalities, iii.) analyse use profiles in terms of heating, DHW, personal heating system activation (e.g. stove, fireplaces) to inform professionals and tenants helping them in optimising heating profiles.

4.3.2 IEQ extended analyses: Public building mechanical vs controlled natural ventilation – Demo case B2.1[3]

As detailed in Deliverable D5.4, three detached mechanical ventilation (DMV) units Helty Flow M800[4] have been installed in three rooms on the three middle-school floors in January 2022. The units are inserted within a closet and can refresh indoor air by pumping up to 800 m^3/h of fresh air with ten different fan speeds. They can be both controlled on-site through a control panel on the closet or remotely using Modbus RS485 protocol. Several tests were performed to test the machines effectiveness in maintaining a healthy indoor air quality and their ventilative cooling potential. Particularly, several control strategies currently adopted in the literature based on CO_2 concentration and indoor/outdoor air temperature were tested by remotely managing the units. For the control strategies tested in the school, a hardware setup based on a RaspberryPi equipped with B6RS485 can hat has been set up in June 2022 by POLITO [4]. The RaspberryPi board behaves as a Modbus Master to send control signals to the mechanical ventilation units through four wires copper shielded cable to change flow rates and heat recovery states. The Modbus Master simulator implemented on RaspberryPi was coded using the Pymodbus Python library[5]. For all the tests, another classroom "similar" (e.g., position, known use) to the tested one has been used as baseline. Moreover, simulation on the calibrated school model have been also adopted to test the machines effectiveness in a more standardized (despite adapted) operational settings – the specific results are expected to be published in a devote paper.
CO_2-based control strategies were tested in the school in September 2022, despite it was not possible to create a controlled environment, hence natural ventilation habits have a strong impact on the results. Ventilative cooling strategies have been tested during July 2022, with controlled building conditions since the unoccupied period. Moreover, additional tests on best found strategies were repeated in April 2023 to verify their resilience, exploiting Easter holidays for ventilative cooling tests. Obtained results can then be compared with a long-term analysis of CO_2 concentration in the school, keeping in mind that over the last three years rules and habits for natural ventilation have drastically changed going from keeping windows always open (also during winter) to avoid COVID-19 spread to the current more common state, with windows open in during morning intervals and to avoid overheating in the spring and autumn months. Moreover, it was tried to test the effectiveness of other IAQ awareness possibilities, leading to a supervised natural ventilation scheme: the red light equipped in the CO_2 Capetti sensors installed in the classrooms – see Deliverable D5.4 – can be set to lighten up if the concentration is measured above a given threshold (e.g., 1000 ppm) giving a visive and immediate suggestion to the teachers to open the windows and ventilate the environment. These supervised natural ventilation tests were also supported by educational activities, devoted to increase awareness about the installed sensors potentialities and E-DYCE project ambitions, and by direct contact with the schoolteachers and personal.
Table 7 and Table 8 shows the results on the CO_2-based control strategies implemented on the DMV units in the school. Several approaches have been tested: constant air-flow (ASHRAE 62 and 62.1[6], single and double threshold approaches [6,7] Obtained results show that based on the intended goal, the choice of the best strategy could be different. If a healthy indoor condition is the main goal, but without wasting too much energy, all the single and double thresholds strategies can be employed, even though the single threshold ones causes significantly more on/off cycles of the unit, which can shorten its lifetime; if the priority is given to electrical consumption, then the single threshold strategy that uses 800 ppm as lower threshold should be used, as it consumes about half of the other approaches. In addition, from the tests emerged that also the 1000 ppm single threshold strategy can be considered, since it is in practice an easily reached concentration in the classrooms' environment. It is possible to notice how the results obtained in September and in April (same scholar year) show some strong difference in the monitored

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[3] Manuela Vigliotti is thankfully acknowledged for having developed and initially tested remote control strategies for the installed detached mechanical ventilation units during her master degree thesis.
[4] https://www.heltyair.com/prodotti/vmc-community/flow-800/
[5] https://pymodbus.readthedocs.io/en/latest/
[6] ASHRAE, (2013). Ventilation for Acceptable Indoor Air Quality. American Society of Heating, Refrigerating and Air-Conditioning Engineers

average and peak values, and consequently on the strategy mitigating impact. This could be explained by the different natural ventilation approach adopted in the classrooms in late summer (still quite hot weather) and in early spring (with quite cold days). However, the random impact of natural ventilation, that in some cases (e.g., during winter) could also cause heating dispersion, is difficult to be avoided in this type of buildings. Hence, a supervised education to new ventilation habits to the school personal should come together with a potential diffusion of these machines on a larger scale. Although, here-below are also shortly analysed the behaviours of nearer sole naturally ventilated classrooms to verify if the traditional approach (natural ventilation directly controlled by users) can guarantee goof IAQ conditions.

Table 7 Results of the indoor air quality monitored strategies in September 2022.

	ASHRAE 62	ASHRAE 62.1	600 ppm Single Threshold	800 ppm Single Threshold	600 ppm Double Threshold	800 ppm Double Threshold	1000 ppm Single Threshold	1000 ppm Double Threshold
DMV unit electric consumption	2.49 kWh	3.14 kWh	0.29 kWh	0.08 kWh	0.69 kWh	0.41 kWh	0.59 kWh	1.07 kWh
Average indoor CO_2 – occupied	858 ppm	593 ppm	638 ppm	454 ppm	605 ppm	460 ppm	776 ppm	668 ppm
Average indoor CO_2 peak value	1118 ppm	707 ppm	795 ppm	594 ppm	649 ppm	703 ppm	1000 ppm	811 ppm
Total on/off cycles - DMV unit	3	1	10	5	3	3	9	3
Average indoor CO_2 reduction ratio – occupied	8.72%	14.68%	1.08%	26.54%	35.50%	22.30%	-12.14%	30.12%
Average indoor CO_2 peak value reduction ratio	35.93%	32.21%	11.67%	25.38%	33.78%	12.56%	-5.49%	52.04%

Table 8 Results of the indoor air quality monitored strategies in April 2023

	ASHRAE 62	800 ppm Single Threshold	800 ppm Double Threshold
Number of testing days	6	8	7
DMV units electric consumption	2.99 kWh	2.59 kWh	2.31 kWh
Average indoor CO_2 – occupied	924 ppm	854 ppm	881 ppm
Average indoor CO_2 peak value	1360 ppm	1233 ppm	1276 ppm
Total on/off cycles of the DMV unit	7	17	6
Average indoor CO_2 reduction ratio – occupied	48.69%	50.66%	49.35%
Average indoor CO_2 peak value reduction ratio	32.98%	36.16%	36.13%

In line with the current Italian DPCM guidelines on school ventilation[7] (3 august 2022), the adoption of mechanical ventilation units is suggested when the sole natural activation of windows is not sufficient to dilute the indoor air pollutants considering especially those cases in which the correct activation of the natural ventilation is not sufficient to guarantee a good IAQ quality. For this reason, the proposed analysis also includes a comparison between the CO2 levels measured in the DMV classrooms and the nearer naturally ventilated ones. Figure 55 compares the measured multi-year CO_2 behaviours of the three classrooms with the DMV unit (MAC: B317, B31F, B31D) with three near classrooms without DMV but with similar characteristics. Comments are reported in the mentioned figure. Additionally, the same Figure 55 allows to underline potential variations before and after the DMV installation that arrives during the Christmas holidays of 2022 (the first January represented in the carpet plots).

As can be seen from the graphs, the improvements in air quality are only slightly appreciable when comparing the period before and after DMV installation in the 3 classrooms. This is because still due to anti-Covid regulations, air exchange by natural ventilation was already strictly manually managed in 2022, by almost leaving windows opened during occupation hours. However, an improvement in performance can be seen if one goes to compare the year 2023 for the classrooms with mechanical ventilation compared to their adjacent classrooms with natural ventilation. Specifically, the best results were evident on the ground floor and second floor when rooms are smaller, with a drastic reduction in CO_2 values recorded during occupancy hours.

[7]DPCM 26 July 2022, "Linee guida sulle specifiche tecniche in merito all'adozione di dispositivi mobili di purificazione e impianti fissi di aerazione e agli standard minimi di qualita' dell'aria negli ambienti scolastici e in quelli confinati degli stessi edifici", 22A04476, Gazzetta Ufficiale, Serie Generale N. 180, 3 August 2022. Accessible online at: https://www.gazzettaufficiale.it/atto/serie_generale/caricaDettaglioAtto/originario?atto.dataPubblicazioneGazzetta=2022-08-03&atto.codiceRedazionale=22A04476&elenco30giorni=false (last view 17/07/2023)

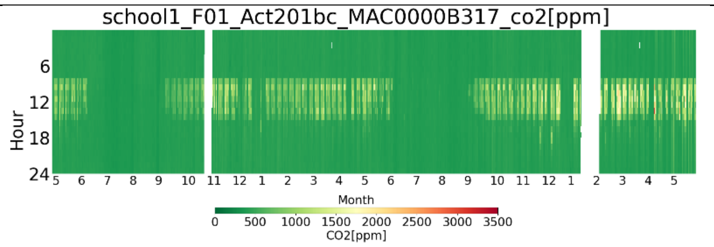
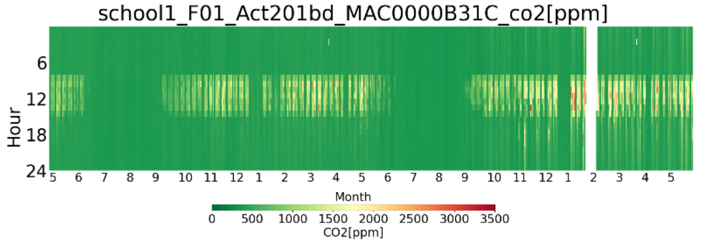
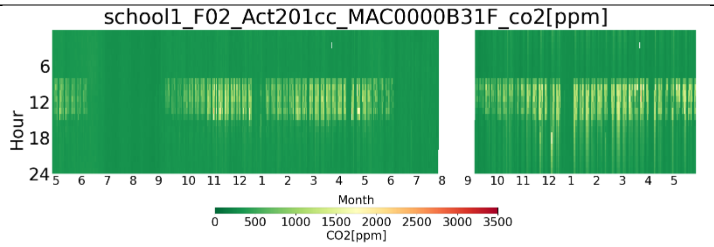
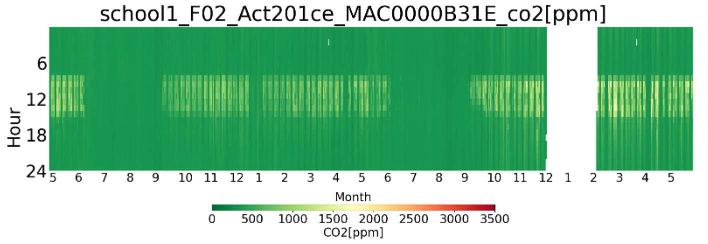
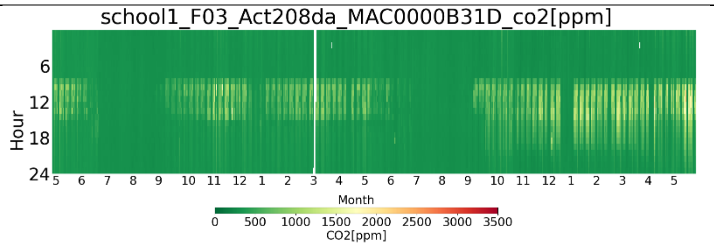
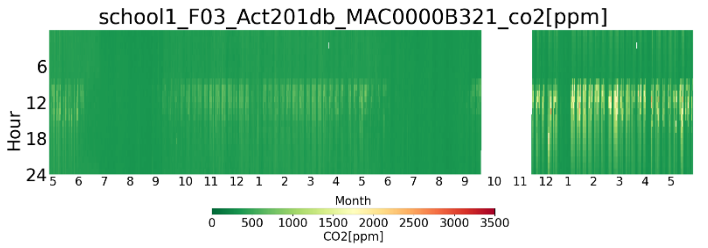
F01 Act201bc (mech) vs Act201bd (nat)	 	The largest differences are evident from January 2023, where in the mechanically ventilated classroom (act201bc), co2 concentration rarely reaches values greater than 2500 ppm (in orange).
F02 Act201cc (mech) vs Act201ce (nat)	 	Not much difference is found between the two classes, partly due to some missing data for the naturally ventilated classroom during the winter season 2022-23, around January 2023.
F03 Act208da (mech) vs Act201db (nat)	 	Here we can see that there is a large gap, for the naturally ventilated classroom, from 2022 to 2023, probably due to the less stringent anti-covid norms in the last period. However, this difference turns out to be much smaller when looking at the heatmap for the mechanically ventilated classroom (act208da)

Figure 55 Heatmaps of hourly CO2 from May-2021 to May-2023.

The differences described above are even more apparent in the following graphs Figure 56, which represent the ranking of all occupancy hours in each comfort/discomfort range in percentages. Specifically, it can be seen that, in the graphs in the second column (classrooms with natural ventilation), the red and orange bars, representing CO_2 values superior to 2000 ppm, are much more visible, showing that the mechanical case guarantees a higher IAQ level, especially for the testing room in the ground and last floor.

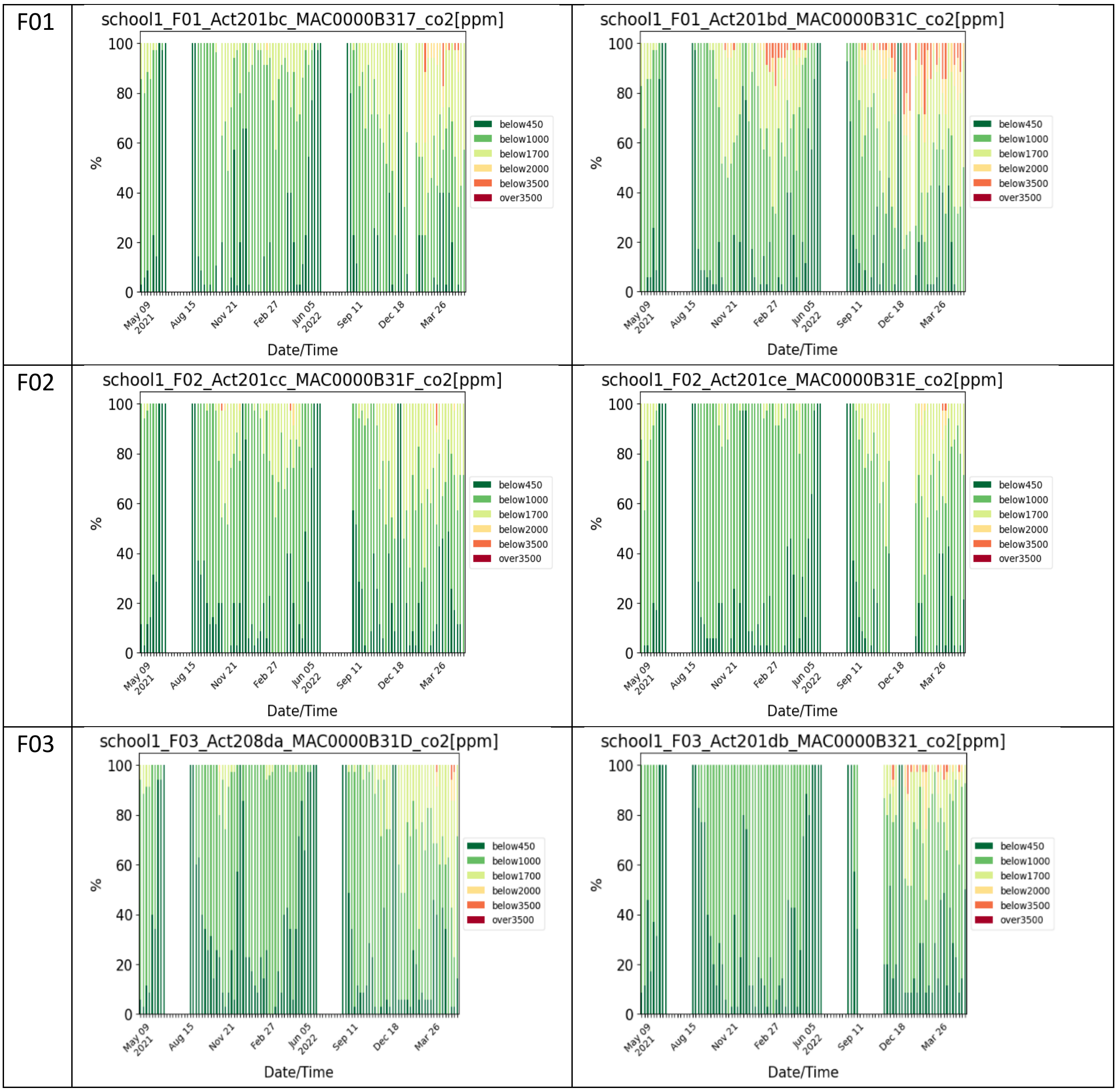


Figure 56 Percentage distribution of Co2 hourly concentration from May-2021 to May-2023.

In addition, a 3-week test was performed in three rooms by "activating" self-student actuation of windows on the base of red blink alerting provided by the installed Capetti CO_2 sensors. These sensors have in fact the possibility to activate a LED signal when a certain level of CO_2 is overpassed. The test involved 2 naturally ventilated rooms and one mechanical ventilated room. During the testing period, the DMV unit installed in the latter was turned off. For this test, we set an 800ppm threshold for the two natural ventilated rooms and 1000ppm for the usually mechanically ventilated room.

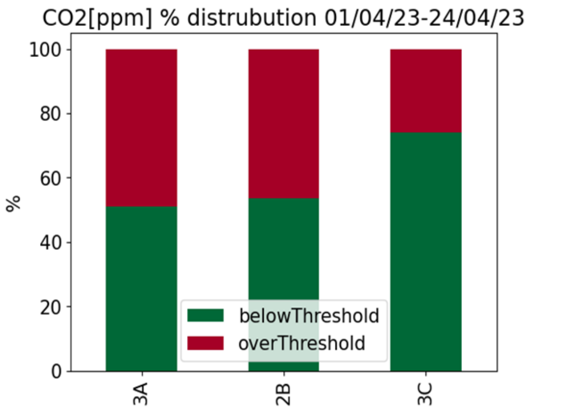
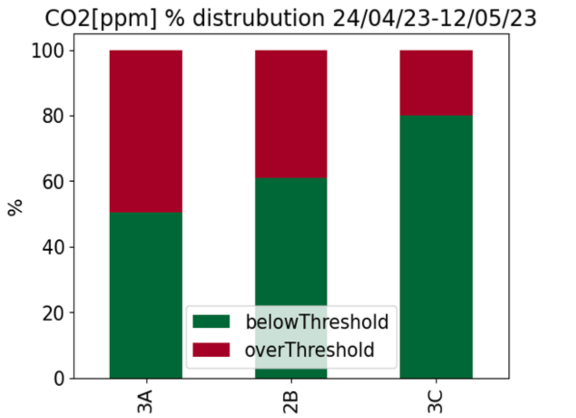
Baseline: 1 Apr – 21 Apr	Testing period: 22 Apr –12 May
	

Figure 57 Classroom CO2 concentration comparison in baseline period vs. test period

As shown in Figure 57, during the testing period, controlled ventilation through the use of sensors perform better than in the previous period: in percentage terms, classrooms 2B and 3C are about ten points higher, while the results are almost unchanged for room 3A. In the latter case, however, the comparison is between the testing period with controlled natural ventilation and the previous period when the room was mechanically ventilated. Results suggests that a proper control logic may support IAQ via a correct activation of the natural ventilation.
Looking at Figure 58, which shows the average value of the 3 examined classrooms, it can be seen that during the test period, manual controlled natural ventilation made it possible to completely eliminate the previously detected peaks of CO_2 concentration above 2000 ppm, increasing the overall percentage of comfort hours during the hours of occupancy.

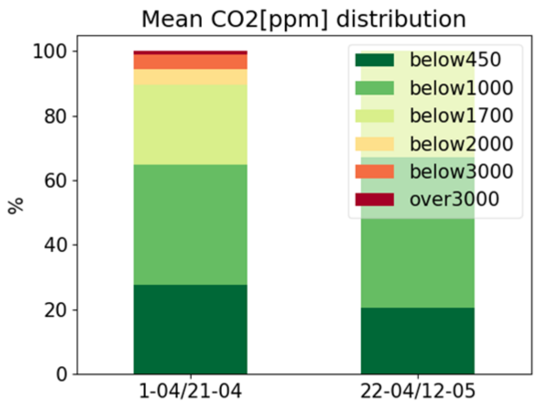
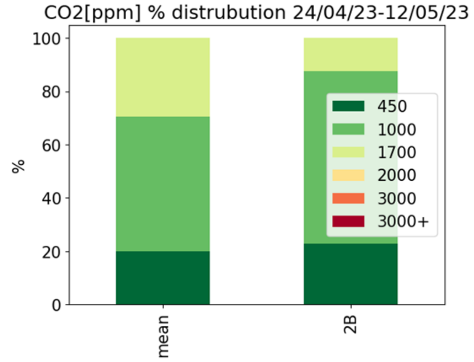
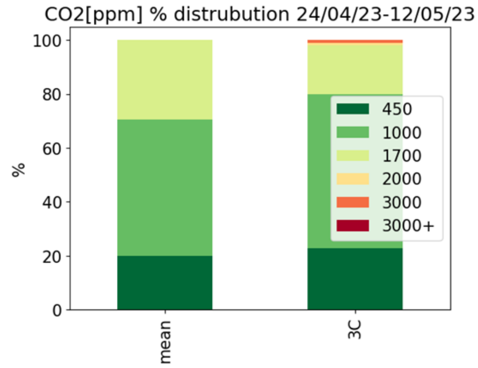


Figure 58 Mean CO2 concentrations – percentage of occupied hours per classes. On the left the baseline period, on the right the test period.

In the final analysis, graphs are shown for two of the three classes, which results to have the “best” and “worst” performances during the test, comparing the measured values with the average one of the whole building. Comments and results are shown in Table 9.

Table 9 IAQ test best and worst performances compared with the building average values

F01		The "best" performing class at the end of the testing period. In this case 90 percent of total hours below the set threshold value (800ppm) is reached. Additionally, this room shows an air quality about 20 percentage points higher than the average of the school.
F02		The "worst" performing class at the end of the testing period. Almost 80% of the total hours record a value below the established threshold (800ppm). However, even if small peaks above 2000ppm were measured (discussing with students they mainly arrive during written tests), the air quality is below the building average showing a positive behaviour.

E-DYCE verification comments

Results show that a good window control may guarantee IAQ levels, although it requires that the school master and teachers continuously propose a window opening scheme. The activation of alerting solutions may support a proper window opening control to reduce the heat losses in winter, although it results to be more complicated in its applicability in the long run with respect to a general window opening scheme, potentially requiring a deeper educational activity to make the alerting light detection a practice. Concerning DMV, the tests show a very high potentiality in assuring IAQ levels, even in crowdy classrooms, especially when high ventilation rates or sensor-controlled ventilation rates are adopted. Considering the Italian school building stock, it is suggested to: 1. Consider the installation of CO_2 probes to analyse IAQ levels and define specific actions, 2. When CO_2 levels are not controllable with the sole natural ventilation, MV solutions can be considered, in line with the mentioned DPCM. In the latter cases, DMV can be a valid solution not requiring a large centralised system or distribution channels that may be very difficult to be integrated in typical existing spaces. Additionally, DMV may be installed in critical rooms, such as the ones with bad ventilation potentialities or with a smaller m^3/student ration.

4.3.3 Fictitious cooling: meaning and applications – Demo cases B2.1 and B2.5

The Energy labelling of a free-running building, operating without a system (heating/cooling) or with the system turned off, is an open challenge, such as underlined in the E-DYCE Deliverables D1.2 and D3.2. Several traditional and historical buildings in different European regions are acting, at least for one of the seasons, in free-running mode, taking advantages of local climates and bioclimatic building management. However, these buildings are not valorised, even when reaching comfort conditions for the occupants, in current energy labelling schemes, or not classifying them or releasing a label by assigning a virtual heating (or cooling) system with a low efficiency[8]. In E-DYCE, they have been underlined three potential approaches to face this issue – see D1.2 and a recent paper at the CISBAT conference [8]:

I. The addition to the free-running building of a virtual (heating/cooling) system without considering the activation of free-running strategies, such as ventilative cooling. Defined the useful energy for standard setpoints, a typical COP/EER value is assigned.
II. The addition of a virtual (heating/cooling) system including the positive effect of free-running strategies, such as ventilative cooling activation in summer.
III. The calculation of a new KPI defining the fictitious heating/cooling needs based on local discomfort conditions. This approach expands the ISO TR EN 52018-2:2017 approach to slightly valorise free-running buildings, which is defined in Annex D.

The latter is based on a simulation flow that includes two parallel models of the same building simulated under the same climate file: one without systems working in free-running and one with a mechanical heating/cooling system. The previous is analysed in terms of adaptive thermal discomfort, while the second reports hourly energy needs. When the free-running model overpass a certain threshold of discomfort intensity a percentage of the parallel model energy need is assumed as a fictitious need considering system activation. Two adaptive thermal comfort thresholds are assumed, mimicking the ISO approach, defining a linear weighting activation of the fictious energy from an initial limit [0%] to a limit over (cooling) or below (heating) which the fictitious cooling or heating is set to 100% of the parallel simulation energy need. The significance of the fictitious cooling and heating is introduced in the D1.2 and verified in terms of significance in D3.2, in where very high correlations are underlined between discomfort intensity of a building model run in free-running and energy needs of the same model when run in a mechanically heated/cooled mode. In addition to this verification, a discussion on the choice between different adaptive thermal comfort threshold categories is here reported expanding the work reported in the above-mentioned paper [8] by applying the fictitious cooling and heating approach to the Italian residential demo B2.5 considering different activation thresholds. In particular they are considered for the cooling season: a.) the methodological case I.; b.) the methodological case II.; c.) the fictitious cooling assuming as [0-100%] thresholds the adaptive thermal comfort category upper limit II^+ and III^+; d.) Cat. I^+ and Cat II^+; e.) Cat. 0 (central line) and Cat II^+; f.) the sole Cat.0; g.) the case with the sole Cat.0 without ventilative cooling and shading for a direct comparison with results of the methodological case I. The same analysis is also conducted for the fictitious heating by reversing the upper with the lower category limits. The B2.5 demo is simulated using the model mentioned in D5.4, but supporting standard usage conditions and the following adaptations. The heating period is set between October to April, in line with local adapted conditions, while the cooling season is assumed from May to September. During the summer period a dehumidification control is set, for the virtual mechanical systems, to 70% of relative humidity, in line with Cat. III of standard EN 16798-1. Ventilative cooling is assumed during the sole summer season limiting the activation when the indoor-outdoor difference is higher than 2K and indoor temperature are not falling below 18°C in order to avoid overcooling. Shading is activated when outdoor temperature and global horizontal irradiation are overpassing respectively 24°C and 120W/m^2, blocking solar beams.

Table 10 reports the total cooling results (useful energy [kWh]) for the three described methodologies and the seven cases. In contrast, the same results for total cooling useful energies are reported in Table 11. Finally, table 12 focuses on the fictitious heating results.

[8] Certificazione-Energetica.it 2017 Certificazione-energetica-per-immobili-senza-impianto-di-riscaldamento-come-fare? Certificazione-Energetica.it (last view June 2023)

Table 10 Total cooling useful energy needs [kWh] for residential demo case B2.5 – TPM climate

↓ Useful energy [kWh]	May	Jun	Jul	Aug	Sep	May-Sep
a.) Qc	-12	-77	-365	-156	-16	-626
b.) Qc_vent	-37	-108	-152	-145	-56	-499
c.) Fictitious II^{+}-III^{+}	0	0	0	0	0	0
d.) Fictitious I^{+}-II^{+}	0	0	0	0	0	0
e.) Fictitious 0-II^{+}	0	0	-26	0	0	-26
f.) Fictitious 0	0	-4	-167	-2	0	-174
g.) Fictitious 0 no vent.	0	-65	-363	-147	-7	-582

Table 11 Sensible cooling useful energy needs [kWh] for residential demo case B2.5 – TPM climate

↓ Useful energy [kWh]	May	Jun	Jul	Aug	Sep	May-Sep
a.) Qc	0	-46	-260	-95	-8	-409
b.) Qc_vent	0	-7	-73	-16	-1	-96
c.) Fictitious II^{+}-III^{+}	0	0	0	0	0	0
d.) Fictitious I^{+}-II^{+}	0	0	0	0	0	0
e.) Fictitious 0-II^{+}	0	0	-20	0	0	-20
f.) Fictitious 0	0	-3	-125	-1	0	-130
g.) Fictitious 0 no vent.	0	-44	-259	-93	-6	-401

Table 12 Heating useful energy needs [kWh] for residential demo case B2.5 – TPM climate

↓ Useful energy [kWh]	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Oct-Apr
a.) Qh	752	2325	3359	3487	2970	1949	1012	15855
b.) Qh_vent	772	2325	3359	3487	2970	1949	1012	15875
c.) Fictitious II^{-} - III^{-}	750	2325	3359	3487	2970	1949	1012	15852
d.) Fictitious I^{-} - II^{-}	752	2325	3359	3487	2970	1949	1012	15855
e.) Fictitious 0-II^{-}	752	2325	3359	3487	2970	1949	1012	15855
f.) Fictitious 0^{-}	752	2325	3359	3487	2970	1949	1012	15855
g.) Fictitious 0 no vent.	752	2325	3359	3487	2970	1949	1012	15855

Cooling results differ between Method I and Method II, especially for the sensible cooling case. This outcome is connected to the local climate conditions of Torre Pellice that are relatively cold and humid (semi-mountain site). If compared to the results discussed in the paper mentioned above, in a hotter and drier climate (Rome) assuming a typical building with less thermal masses, this difference is more evident and also impacts the total cooling result. In all cases, Method I cannot consider the positive effect of natural cooling solutions, while Method II allows to evaluate them positively. Fictitious cooling reports very positive results, almost nulling the cooling needs, aligning with the thermal sensation reported by the local tenants that have never considered installing a cooling system perceiving all the time summer comfort conditions. In contrast, the Rome shoebox example of the mentioned paper shows that in hotter climates, where summer discomfort arrives, the fictitious cooling shows intermediate behaviours between Method I and Method II according to the chosen adaptive thermal comfort thresholds. A similar result is obtained by calculating the fictitious cooling of the demo model B2.5 simulated under the Rome climate. Table 13 reports the sensible cooling results.

Table 13 Sensible cooling useful energy needs [kWh] for residential demo case B2.5 – Rome climate

↓ **Useful energy [kWh]**	May	Jun	Jul	Aug	Sep	May-Sep
a.) Qc	0	-82	-471	-400	-31	-985
b.) Qc_vent	0	-22	-172	-160	-2	-355
c.) Fictitious II^{+}-III^{+}	0	0	0	0	0	0
d.) Fictitious I^{+}-II^{+}	0	0	0	0	0	0
e.) Fictitious 0-II^{+}	0	-1	-35	-42	0	-79
f.) Fictitious 0	0	-15	-217	-202	0	-434
g.) Fictitious 0 no vent.	0	-79	-471	-400	-24	-973

The three approaches show similar results regarding the heating period not considering variations in special passive heating techniques. In this case, it is interesting to underline how the variation in the fictitious cooling thresholds does not affect results. This point confirms the relation between free-running discomfort and energy needs, and suggests, such as expected, that in winter all the three methods may be applied with similar results.

E-DYCE verification comments

The main conclusions suggest that the current Method I can be applied to the winter season as a valid alternative. Even additional studies are suggested in future to verify this outcome under hotter climate conditions. Considering the summer season, Method I cannot consider the natural cooling support. Methods II and III are valid alternatives, even if the fictitious cooling indicator (Method III) is very sensible to the chosen boundary conditions for summer. Although, even if the development of a methodology able to valorise the EPC free-running buildings is highly needed and even if the fictitious approach can represent a valid starting point, additional works are required to understand better the impact that thresholds have on different climates to support proper applicability of this KPI. Both Method II and the fictitious cooling/heating are not considered to evaluate energy poverty but to support the correct valorisation of traditional and low-energy solutions exploiting free-running potentialities and bioregionalism.

4.3.4 Renovation analyses – Renovation roadmap – Demo case B2.1 [9]

Demo case B2.1 (Municipality school), built in the 70s and described in Deliverables D5.1 and D5.4, features construction characteristics in line with most Italian schools built in the same period. Since it has never undergone a deep renovation process, it is selected to develop a renovation roadmap to demonstrate the potentiality of the tools developed inside the E-DYCE project for this purpose.
Different modelling solutions have been tested over the project, and for this purpose, a complete model of the school, with a detailed surrounding, is selected. The model is built exploiting the DesignBuilder software[10], which allow to export an IDF file as input for an EnergyPlus simulation. The inside of the school building – see Figure 59 – is modelled merging in a single thermal zone all the main environments (classrooms, corridors and offices) while other small environments with limited significance (e.g., toilets, warehouses) are not included in the merging, such resulting in four main thermal zones, one in each floor. Indoor temperature simulation results on the four thermal zones were compared to the average monitored behaviour to calibrate the model. The calibration process was carried on during the unoccupied summer periods to avoid the impact of random operational settings. Particularly, this specific model was selected among other solutions (e.g., fully detailed model, North/South thermal zones aggregation) considering the best obtained calibration results and resilience over time [9]. Figure 60

[9] Davide Mecca Cici is thankfully acknowledged for having worked on renovation roadmap definition, with devoted market analysis, during his master degree thesis. Dr. Diego Ferrando (POLITO) has also contributed to the economic analysis.
[10] https://designbuilder.co.uk/ last view 08/2023

shows the calibration signatures [10] at the beginning and at the end of the calibration process: the error is kept under 5%, in line with ASHRAE reference suggestions for model calibration[11].

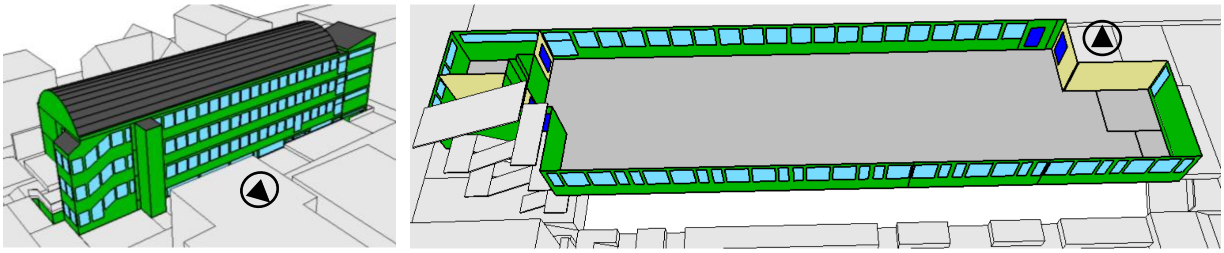


Figure 59 Model of the school with full view and insight on the first floor (3° level).

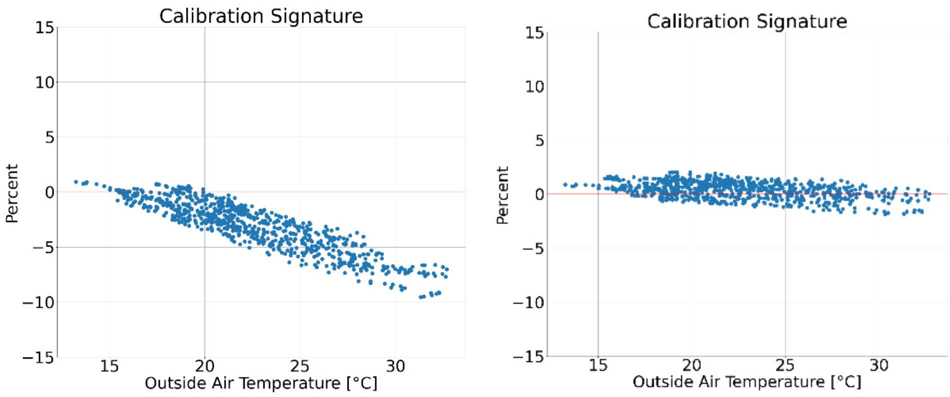


Figure 60 Calibration signatures at the beginning and at the end of the calibration process.

As described in the D5.4, the school walls composition has been determined by inspection during the installation of the three detached mechanical ventilation units. Moreover, a series of short-term (about one week) monitoring actions using the LSI U-value monitoring kits were also performed, assessing the current U-value of the walls in a specific range. This information was used inside the calibration process and the final obtained value for the boundary walls U-factor is 0.63 W/(m^{2}K). The roof instead, viewed during an in-situ inspection, does not present any visible insulation with the exclusion of a light concrete layer with expanded clay on the outermost layer of the last slab. Similarly, the floor of the basement is supposed to be only slightly insulated, exploiting typical construction solutions of the construction period. Final calibration values for the roof floor and for the basement floor are respectively 0.76 W/(m^{2}K) and 0.18 W/(m^{2}K), while the roof features a U-value of 1.78 W/(m^{2}K). Infiltration through the un-conditioned cold roof shows a final value of 0.75 ACH by also considering the presence of small holes. Windows instead are the same for the whole building, characterized by a double glass filled with air and a wooden frame. Final values reached during the calibration process are: 2.08 W/(m^{2}K) and a solar heat gain coefficient of 0.62. infiltration through the windows shows a final value of 0.1 ACH. Since the calibration process was carried on during a summer vacation period with indoor air temperature as target variable, only envelope characteristics were considered.

Operational settings of the school model are defined considering both standard conditions defined in Deliverable D2.4 and real usage habit derived from inspection (see the E-DYCE inspection methodology reported in D2.2) and monitoring long-term analyses. Considering the specific purpose, people, equipment, and lights daily schedules are defined according to realistic building use to avoid overestimating of energy needs. Figure 61 shows the adopted weekly schedules for the kindergarten (basement floor) and for the middle school (ground to second floors): the winter holidays and other short vacation periods are not considered, while for the summer, a standardised holiday period is adopted (July

[11] ASHRAE, ASHRAE Guideline 14-2014 - Measurement of Energy, Demand, and Water Savings, 2014.

and August), despite the kindergarten and middle school usually adopt slightly different calendars. Table 14 shows maximum values for different operational parameters, which are then multiplied by the schedules (fractional modifiers): the number of people in the kindergarten and middle school are defined according to inspection, considering that it is representative of the school capacity also in the long-term; equipment, lights and natural ventilation instead are defined according to the standards adopted in D2.4. Natural ventilation is active during weekdays from 7:00 A.M. to 5:00 P.M., considered as the extended usage period (e.g., for meetings and cleaning purposes) and follows the same holidays schedule as the occupancy. The amount of airflow per hour is selected according to the norm EN 15251.

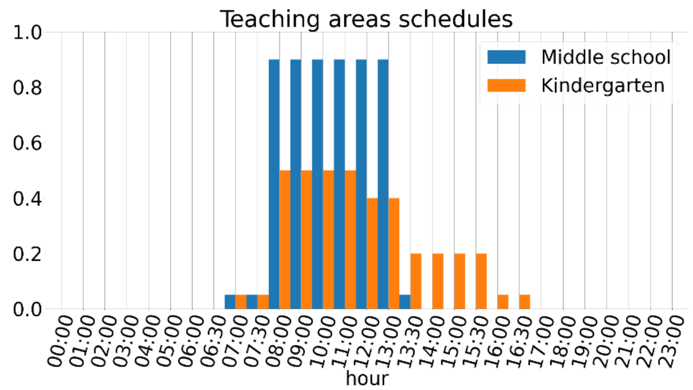


Figure 61 Occupancy, equipment and lights schedules for the kindergarten and middle school teaching areas.

Table 14 Operational settings for the school model

N. of People – Middle school	N. of People – Kindergarten	Equipment	Lights	NV – Middle school	NV – Kindergarten
0.185 people/m^2	0.263 people/m^2	8 W/m^2	25 W/m^2	0.0038 m^3/s-m^2	0.0045 m^3/s-m^2

Considering instead the HVAC system, it is modelled with the EnergyPlus simplified approach, in accordance with the general approach adopted in the E-DYCE project. The school demo building – as described in D5.4 – is provided with a large heater positioned in a buried space near the kindergarten and it is dimensioned to cover also other adjacent buildings such as the 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. The heating distribution inside demo B2.1 is based on three circuits connected to the same heater which serve the kindergarten semi-buried floor, the former offices composed by two small rooms at the middle school entrance and two on the last floor, and finally all other spaces of the middle school. Each distribution system has a zone temperature sensor, but any control is given at room level. The system actual efficiency is considered applying an average COP equal to 0.97 to the total yearly simulation results. Instead, the school is not equipped with a cooling system, as most of Italian schools despite their location. The heating system is available from the 1st of October to the 30th of April with a setpoint of 20°C from 7:00 A.M. to 5:00 P.M. every day and a setback of 16°C the rest of the time in the middle school, while in the kindergarten with the same schedule, the setpoint is set to 17.5°C and there is no setback. The setpoints are defined according to D2.4, and they have been verified to be not so dissimilar from the real use, while schedules and setbacks are adapted according to real use.
The list of possible renovation actions for the school is defined after an analysis of the current situation and of the Italian (regional) market offers, with updated costs of materials and interventions.
The considered actions are:

- ***Adding external insulation to the boundary walls:*** Installation of an external thermal insulation along the entire perimeter of the building, from the basement level up to the roof, including stairs and the elevator cab, with an additional finishing layer in plaster (thickness of 1cm), for a total surface area of 1029 m^2. The considered material is:
  - 01.P09.A04: Expanded Sintered Polystyrene panel (EPS), with a compressive strength of 100 kPa, a density ranging from 18-28 kg/m³, and a thermal conductivity of 0.033 W/mK;

- ***Adding insulation to the roof floor***: insulation panel setting on the last roof slab, stairs and toilet block included, without any cladding, for a total surface of 475.95 m^2. The considered material is:
    - 01.P09.A52: Extruded polystyrene panel (XPS), with a compressive strength of 300 kPa, a density ranging from 70-80 kg/m³, and a thermal conductivity of 0.032 W/mK;
- ***Adding insulation to the basement floor***: Construction of a new insulated floor throughout the basement level, for a total surface area of 471.38 m^2. The considered material is:
    - 01.P09.A53: Extruded polystyrene panel (XPS), with a compressive strength of 300 kPa, with a density of 32 kg/m³, and a thermal conductivity of 0.033 W/mK;

For the three selected materials 6 possible thicknesses are considered in range 10-300 mm and for each thickness the cost per area is identified; costs are inclusive of material supply and labour and are retrieved by the Regional price list. Table 15 shows the main materials' properties. The three materials are chosen as reference for the preliminary impact analysis of the intervention, to reduce the number of simulations.

Table 15 Insulation materials properties.

	01.P09.A04	01.P09.A52	01.P09.A53
Conductivity [W/mK]	0.033	0.032	0.033
Specific heat [J/kgK]	1400	1800	1450
Density [kg/m^3]	24	75	32

- ***Change the window system***: two possible improvements to the windows system are considered and described in Table 16 both solutions are characterized by the same current frame type (wooden frame), but with a thermal conductivity lower than 1 W/mK. Costs include demolition of old window, material supply, labour and reconstruction of damaged parts of the wall.

Table 16 Windows properties.

Description	Cost/m^2	Area of intervention	U-Factor W/(m^{2}K)	SHGC	Visible transmittance
Low-E double-glazed glass window	744.30	426.6	1	0.42	0.66
Triple-glazed glass window filled with Argon	833.23	426.6	0.6	0.3	0.5

- ***Add exterior shadings to South facing windows***: since the school has a North/South orientation with classrooms and offices facing South, while corridors and stairs facing North almost never receiving direct solar radiation, it was considered as a possible improvement only the addition of shading devices on the Southern façade. The school is currently equipped with interior roll shadings on the South façade. These shadings are quite old and present several problems, some cannot even lift up/down; hence, it has been proposed to install external mobile window blinds to reduce overheating. This system consists of adjustable slats automatically orientated perpendicularly to solar beam when indoor air temperature is over the setpoint temperature. Each blind is activated by a roller blind motor controlled by a central control unit, which receives an electric signal from indoor temperature sensors. The resulting total cost is 126 724 euros and it is comprehensive of entire system supply, installation and wiring of the system. The chosen shading system is implemented in the simulation by adopting a simple single-threshold control strategy based on the indoor monitored temperature: if it is higher than 24^{o}C the shading system is activated.
- ***Add detached mechanical ventilation units***: installation of the same detached mechanical ventilation units already installed in 3 classrooms during the E-DYCE project in all the main teaching areas. The units are Helty VMC Flow 800 machines, particularly indicated for crowded public spaces when there is not space for a centralised ventilation system. Additional details are present in D5.4. The resulting total cost is given by the unitary cost of 3 555.57 euros multiplied by the 17 spaces in which the system could be more useful, (actual teaching areas) for a total of 60 445 euros.
  The mechanical ventilation unit is active from 7:00 A.M. to 5:00 P.M. during the weekdays except for the considered summer holidays (from the 1st of July to the 31st of August). The flow is set to the

standard maximum value adopted for the natural ventilation, which is 0.0045 $m^3/s\text{-}m^2$ (which is deactivated when the mechanical ventilation units are installed). The flow rate of the machine is limited to the nominal value provided by the manufacturer, and similarly, the heat recovery is active with an efficiency of 0.8. This action is considered mainly to start investigating the impact of the heat recovery on heating consumption when the units are used instead of natural ventilation in winter.

- ***Add a cooling system***: it is considered also the potentiality of installing a cooling system, which is modelled in the simulation through the simplified HVAC approach. It is considered active with setpoint 26°C from 7:00 A.M. to 5:00 P.M. from the 1st of May to the 30th of June and from the 1st to the 30th of September (excluding the summer holidays). The system is considered to have a humidity control system (dehumidification) set to 70% of RH% during the activation hours (EN16798-1 Cat. III).
  The cooling function can be performed by one of the two electric heating system mentioned below and the system efficiency is considered applying an average SEER equal to 6.5.

All the described actions are applied parametrically to the building model (IDF) exploiting some PREDYCE IDF editing actions, as described in D3.1. The chosen materials are added to the database internal to the PREDYCE platform, then an input JSON file is generated, and the basic sensitivity analysis scenario used to run the massive parallel simulations. A last important action instead, hence the update of the current heating system, is handled differently. In fact, the efficiency of a heating system is currently handled after a simulation run, applying an average SCOP to the obtained results: this implies that the efficiency cannot be used as a simulation input parameter. Hence, the total heating needs are computed once and then costs and SCOP of the selected systems are applied during post-analysis.

- ***Change the heating system***: Three simulations are conducted, first with the current heater and others with two possible improvements.
    - Installation of a centralized air to water heat pump running on electricity with 630 kW of nominal power, SCOP equal to 3.74 with the capacity to produce water up 60°C;
    - Installation of 1 mono split heat pump for each teaching room, composed of one indoor and one outdoor unit, with a SCOP equal to 4.20.

The parametric actions applied to the model result in a pool of 4116 simulations, which are executed exploiting the computation power of a server equipped with two AMD EPYC™ 7662 64-Core processors that allows the parallelization of hundreds of simulations at a time. Moreover, another pool of simulations is executed applying the same actions without HVAC systems, so deactivating both heating and cooling. This is done to verify the impact of the proposed actions on the free-running building and to detect possible criticisms. The simulations are run on a Torre Pellice typical meteorological year (TMY) generated through the Meteonorm software[12]. However, since the dramatic and incredibly fast changes climate is undergoing all over the world, it is known that adopting past based TMYs could result in an overestimation of the heating needs and in a significant underestimation of the cooling needs, especially when looking at renovation roadmaps which will impact several decades in the future. Hence, in addition to the TMY, it was chosen to adopt as an example the 2022 EPW for Torre Pellice, which was generated thanks to the data collected during the E-DYCE project by the installed weather station (see Deliverable D5.6).
The key performance indicators computed via PREDYCE (see deliverables D3.1 and D3.2) are:

- Total heating and cooling energy needs (kWh).
- Energy signature 1D and 2D (external temperature and global horizontal solar radiation).
- Indoor operative temperature.
- Predicted Mean Vote and Predicted Percentage of Dissatisfied (Fanger model) to evaluate the indoor thermal comfort with HVAC system active: POR (Percentage Outside the Range) computed as the number of hours over the total in which $|PMV| > 0.7$ (so $PPD > 15\%$).
- Adaptive Comfort Model (EN 16798-1:2019) distribution to evaluate the indoor thermal comfort without HVAC system: POR (Percentage Outside the Range) computed as the number of hours over the total in which the computed category is outside Cat. II boundaries.

[12] Meteotest AG (2020) Metornom software v8, Bern

- The total cost (except for the HVAC system contribution that is added in the post-production).

Results are then post-elaborated to retrieve additional indicators:

- *Initial Investment*: this item includes all initial costs resulting from energy efficiency interventions done, including the installation cost of the new generator, in case the current one is replaced.
- *Yearly Operative Cost*: Operating cost of heating, cooling and mechanical ventilation system, considering the current price of energy vectors.

$$OC = \frac{\left(\frac{Qh}{COP}\right)}{10.69} \cdot C_{SMC} + \left(\frac{Qc}{EER} + Qv\right) \cdot C_{EL} \quad \vee \quad OC = \left(\frac{Qh}{COP} + \frac{Qc}{EER} + Qv\right) \cdot C_{EL}$$

  Qh: yearly useful heating energy needs (kWh); C_{SMC}*:* standard cubic meter (smc) cost; *Qc*: yearly useful cooling energy needs (kWh); *Qv*: yearly final ventilation energy needs (kWh); C_{EL}*:* Electricity cost per kWh_{el}, and 10.60 is the actual national conversion factor between smc and kWh. C_{SMC} and C_{EL} are considered as the last two-year average cost of energy vectors, published by the *ARERA authority*.
- *Total Cost*: initial investment plus operative costs over 20 years, discounted to the present considering a typical discount rate, r is the used discount rate, equal to 3.5%.

$$C_{Tot} = OC \cdot \frac{(1+r)^{20} - 1}{r \cdot (1+r)^{20}} + IC$$

- *Return Of Investment (ROI)*: time expressed in years in which the obtained benefits will compensate the initial investment.

$$ROI = (OC - OC_{ref})/IC$$

  OC_{ref}: the current yearly operative cost, without considering any renovation intervention.
- *Total Primary Energy*: total consumption from the HVAC system expressed in primary energy.

$$PE_{Tot} = (Qh/COP) \cdot f_{p,h} + (Qc/EER + Qv) \cdot f_{p,el}$$

  $f_{p,h}, f_{p,el}$ are conversion factors into primary energy for the specific energy vector, equal to 1,05 for natural gas and 2,42 for electricity (DM 26/06/2015).

After the KPIs computation, different typologies of plots were post-produced exploiting the structured PREDYCE output file. The heatmaps in Figure 62 show respectively the linear correlation between individual retrofit actions and variations in thermal loads and thermal discomfort, highlighting which interventions have a greater impact on energy needs and costs. Heating energy is undoubtedly the most impactful parameter in a cold environment, as in Torre Pellice. Hence, the implementation of external insulation is the factor that most significantly influences the actual winter thermal load, along with the mechanical ventilation system with heat recovery. Above all, it ensures a clear reduction in the Fanger POR and of the number of hours in ACM Cat. III down and below in the free-running case. Nevertheless, increasing the wall insulation thickness substantially increases initial costs, followed by only a minimal reduction in operating costs (Figure 63) Consequently, the optimal solution is an additional wall insulation thickness of about 0.14 m, which guarantees an acceptable payback period, accompanied by the installation of DMV units in all rooms to ensure a drastic reduction of operative costs and Return of Investment time. The basement floor and roof insulation does not improve the building's efficiency. In contrast, the insulation of the ground floor probably prevents the dissipation of heat into the ground during the summer period, resulting in an increase of the cooling load.
The heatmaps also highlight how window replacement is a crucial action for reducing the summer load (-0.72) through the limitation of solar gains. However, Figure 64 shows that the reduction in cooling energy is smaller than the energy required to compensate for the lack of solar gains during the winter period, leading to an overall increase in primary energy consumption and operating costs. The same figure shows how the lower SHGC-factor of windows causes a reduction in overheating for ACM Cat. I and II but, at the

same time, it leads to the highest number of discomfort hours for Cat. under III (+0.89) and the highest POR value (+0.86). In the end, the installation of shading systems emerges as an action with a significant impact on reducing cooling consumption but has little overall influence on primary energy consumption, with a considerable economic impact. However, if the rising summer temperatures are considered, shading systems become more relevant and can provide a quicker economic return.

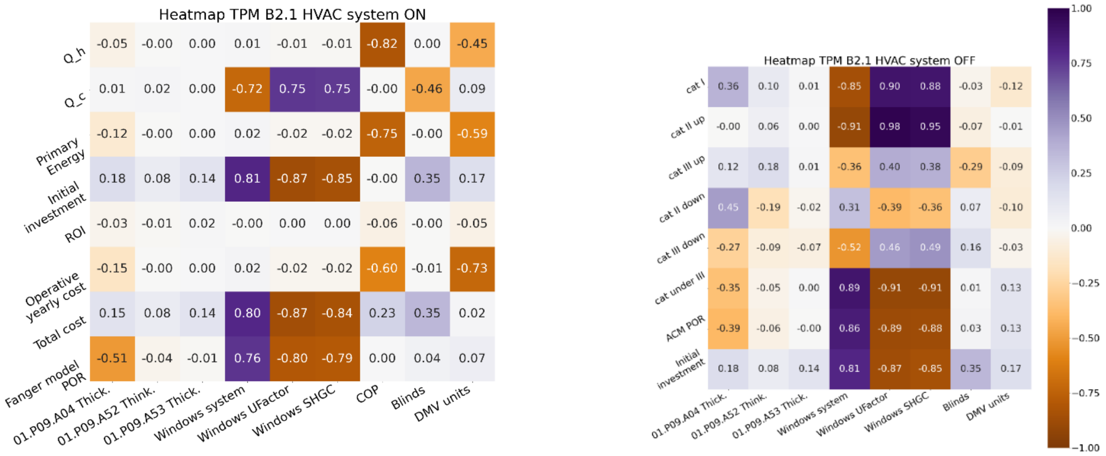
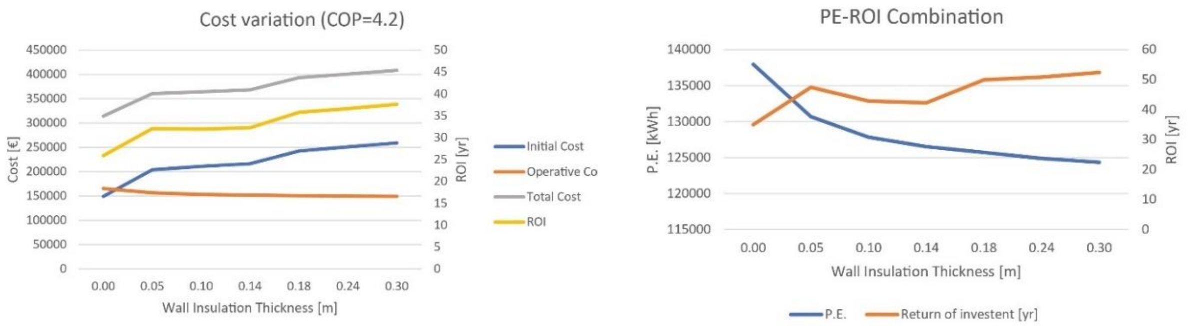
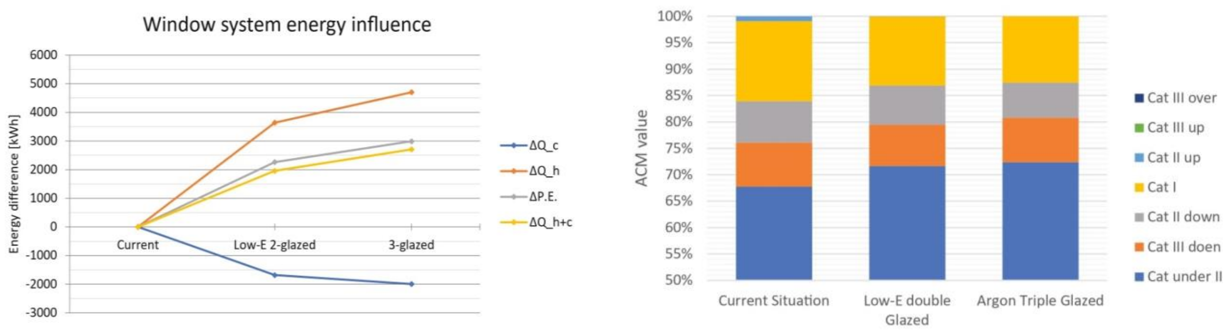


Figure 62 Heatmaps showing the linear correlation between renovation actions and KPIs with the HVAC system active in and in the free running building, with TMY weather data



(a) (b)

Figure 63 Cost variation (a) and Primary energy and Return of Investment (b) with respect to walls insulation thickness



(a) (b)

Figure 64 Cooling and heating final energy and Primary Energy trend (a) and Adaptive Comfort Model categories distribution (b) with respect to windows' systems

Once focalised some interesting renovation scenarios, it is possible to have an overlook at the plots generated through the PREDYCE platform for each simulation. Particularly, considering the case with walls insulation thickness of 0.14 m, no insulation on basement floor and on the roof, the double glazing filled with Argon windows' system, no shading system and the DMV units installed, it can be seen, for example, the specific energy signature (Figure 65) and the indoor operative temperature trends (Figure 66) in the HVAC and free-running cases. These plots could be an additional help in identifying specific criticalities.

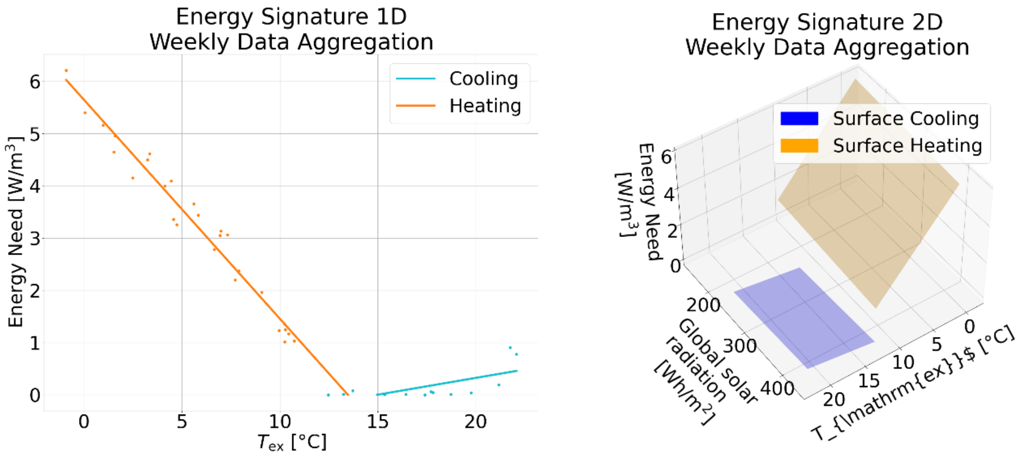


Figure 65 Energy signatures 1D and 2D on a specific renovation solution

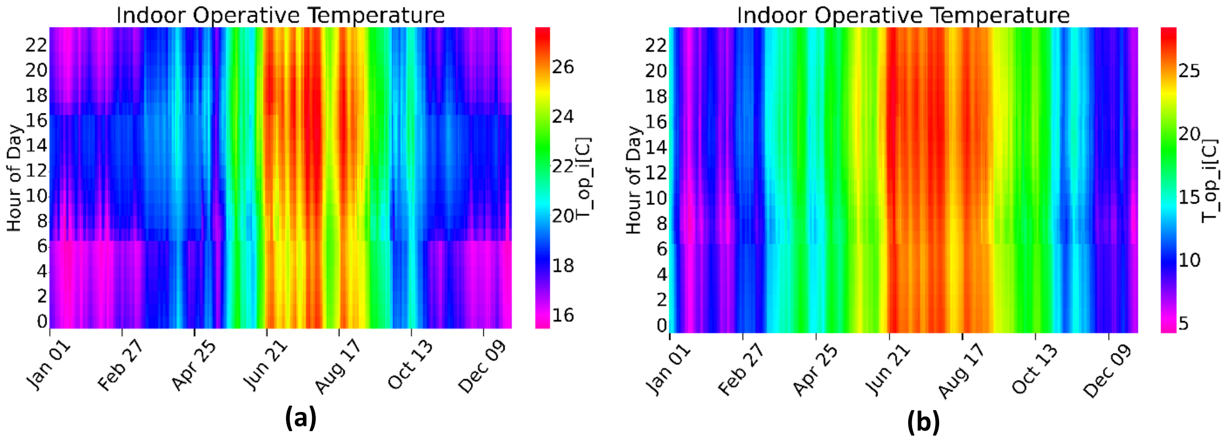
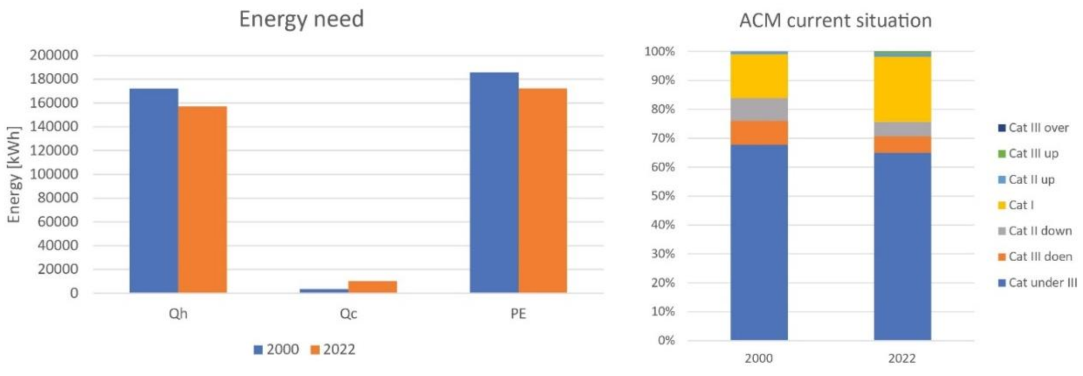


Figure 66 Indoor operative temperature on the HVAC on building (a) and on the free running building (b), with a specific renovation solution.

Focusing instead on results obtained on the monitored 2022 weather data, Figure 67 (a) shows the variations of energy related KPIs in the building before any intervention. A reduction in winter thermal load of approximately 20 000 kWh has been observed, while the energy required for cooling has increased threefold, reaching 10 000 kWh per year. This aspect becomes more significant when related to the ACM categories (Figure 67(b)), where a clear reduction in hours of discomfort in the lower categories (-10%) is found, in favour of an increase in Cat. I. Figure 68 instead shows through the heatmaps that the trend highlighted on the TMY is maintained: the most important variation is the greater impact due to external insulation, which allows for a significant reduction in the PPD value and, at the same time, a quicker return on initial investments. The importance of this intervention emerges even more through the evaluation of the ACM categories, where it causes an increase in overheating hours, surpassing the Cat. III upper threshold. Another intervention of considerable importance that emerges in this pool of simulations is the shading system. Although it does not significantly affect the primary energy or operational costs, it plays a fundamental role in reducing solar gains and consequently reducing discomfort due to overheating, being the only intervention capable of substantially reducing the number of hours above Cat. III.



(a) **(b)**

Figure 67 Energy (a) and thermal comfort related KPIs (b), on the original building conditions considering both the TMY and 2022 monitored weather.

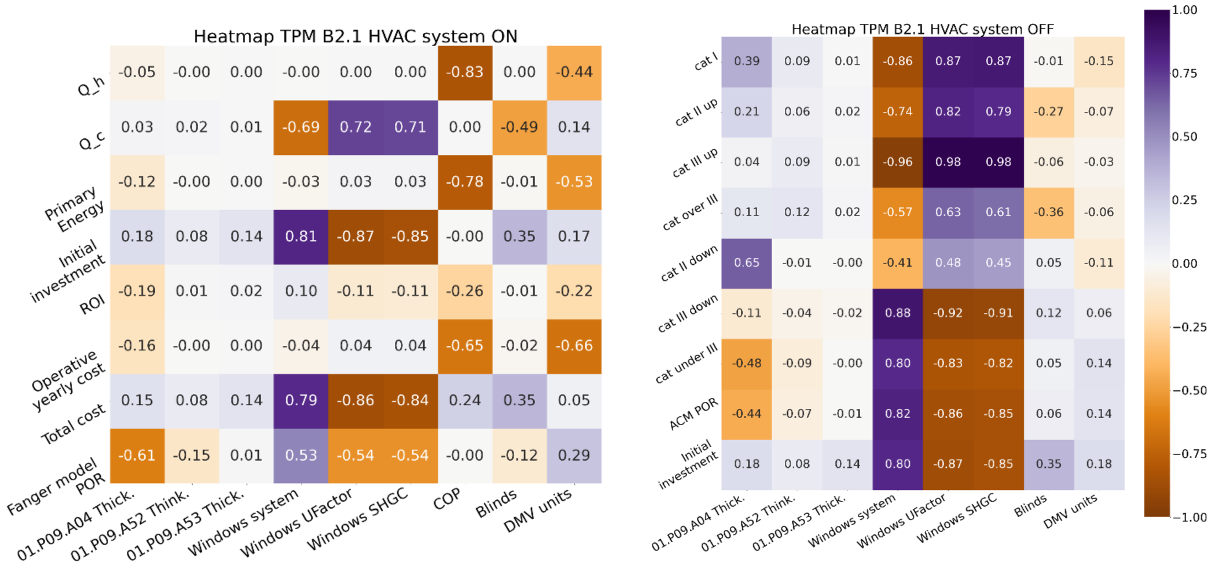


Figure 68 Heatmaps showing the linear correlation between renovation actions and KPIs with the HVAC system active in and in the free running building, with 2022 weather data.

E-DYCE verification comments

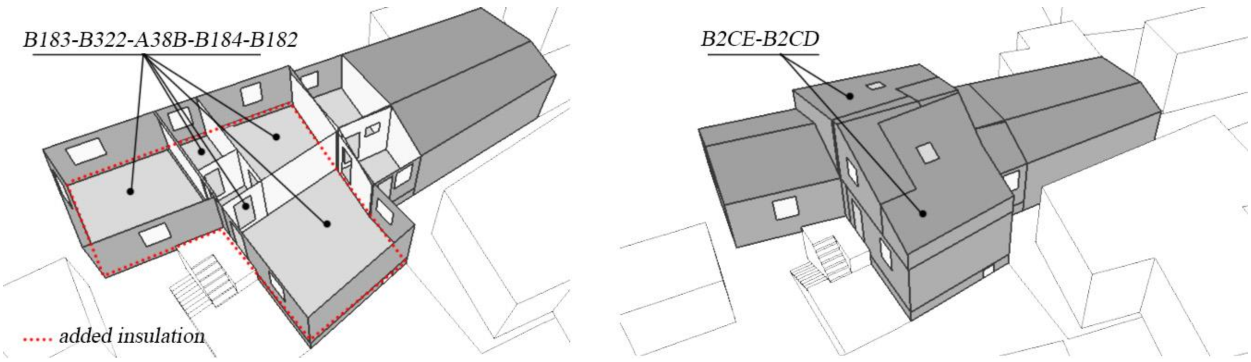
This section shows how the PREDYCE platform (sensitivity analysis scenario) developed inside the E-DYCE project can be used to verify the impact of possible renovation actions, taking support also from the developed calibration support scenario. It also underling the possibility to apply the E-DYCE renovation approach (D4.2) by adapting the platform to local conditions. This could help both expert users and residential owners to identify the direct impact of an investment and potential improvements in building management. The analysis of a specific building renovation requires a devoted study of suitable solutions, materials and the local market conditions. Still, the procedure adopted with a less targeted approach could potentially help politicians to analyse the impact of different renovation solutions at urban and territorial scales supporting incentives. To improve the applicability of this scenario in the future, it should be included in the process an optimisation procedure to find optimal cost solutions, as reducing the number of simulations and hence allowing to include more materials in the analysis.

4.3.5 Renovation analyses - post-intervention evaluation – Demo cases B2.3 and B2.4

Focalised renovation actions have been implemented during the project period in two of the residential buildings part of the Italian demonstrator, such as anticipated in D5.4. In particular, for both cases, an insulation layer was added, respectively, on the first slab (between the semi-buried un-conditioned spaces and the ground floor) for B2.3 and on the last slab (between the conditioned first-floor zones and the un-conditioned under-roof spaces) for B2.4. Additionally, in demo B2.3, ground floor doors have been substituted with the heating system. For both cases, the impact of these retrofitting actions has been analysed by exploring the E-DYCE data and monitoring infrastructure. For both buildings, the variations in the indoor thermal comfort conditions – indoor temperatures – have been analysed rather than the energy consumptions because, in the latter case B2.4, the thermostat is far away from retrofitted spaces and because, in the first case, the installation of the energy meters occurs during the retrofitting action lacking in historical data. For the two demos, the study is based on the following analyses:

- Carpet plot graphs produced via the PREDYCE tool showing the measured air temperatures throughout the testing period to evaluate if visible modifications are underlined before and after the renovation action(s).
- Percentage distribution of hours in temperature classes on a weekly base focalising previous result.
- Temperature variations in December and in June, representing winter and summer behaviours, respectively, to compare the measured values of the environmental air, nearer un-conditioned space(s), and conditioned room(s) before and after the action(s).
- 24h-averaged hourly profiles for seasonal representative months
- Box and whisker plots to display a five-number summary of measured data. The five-number summary includes the minimum, first quartile, median, third quartile, and maximum values. Boxes connect the first quartile to the third quartile. A vertical line goes through the box at the median. The whiskers go from each quartile to the minimum or maximum, while outliers are plotted as separate dots.
- Scattered plots analysing indoor temperature distributions as a function of the outdoor temperatures to detect variations between indoor/outdoor correlations and support a weather-independent discussion.

Demo building **B2.3** (residential building 1) is interested in several minor renovation actions. In particular, an insulation layer was added between the end of September and the beginning of October 2022 to the outermost layer in the slabs between the not conditioned semi-buried ground floor and the conditioned ground floor, while during the same period, the heating system was upgraded by substituting the previous heater with a new gas condenser system coupled with an intelligent thermo-fireplace – see the detailed description in the D5.4. The added insulation is based on a polystyrene rigid panel 10 cm below the bedroom, bathroom and kitchen, facing the semi-buried un-conditioned spaces. In comparison, a layer of 5 cm of polystyrene is installed below the living room facing outside. Additionally, at the beginning of 2021, the doors towards the outside of the ground floor have been substituted with insulated ones characterised by a U-value slightly below 1 W/m^{2}K. Figure 69 identify the analysed zones. Analyses are conducted on the average measured temperatures of the ground floor rooms interested by the addition of insulation and on the average of the two first floor bedrooms.



(a) (b)

Figure 69 Demo building B2.3 – identification of the selected zones (a) ground floor, (b) first floor.

Figure 70 and Figure 71 report the carpet plot variations and the weekly classification of measured temperatures in the ground and first floors. The main renovation action arrived at the end of September 2022. It is possible to underline that higher temperatures in the ground floor are visible for the post renovation period during the winter period (October to April), while an increase in temperature is visible in the upper floor till the end of October, while for the other winter months temperatures are slightly lower than before the renovation even if they do not underpass around 18°C. Discussing with the tenants, it has been confirmed that, after the renovation, the upper floor has almost never required the activation of the radiators being the thermostat always above 18°C. This explains why temperatures are not showing the previous rising peaks. Additionally, the renovation, acting on the ground floor temperature variations, also minimises the heating needs of the upper floor.

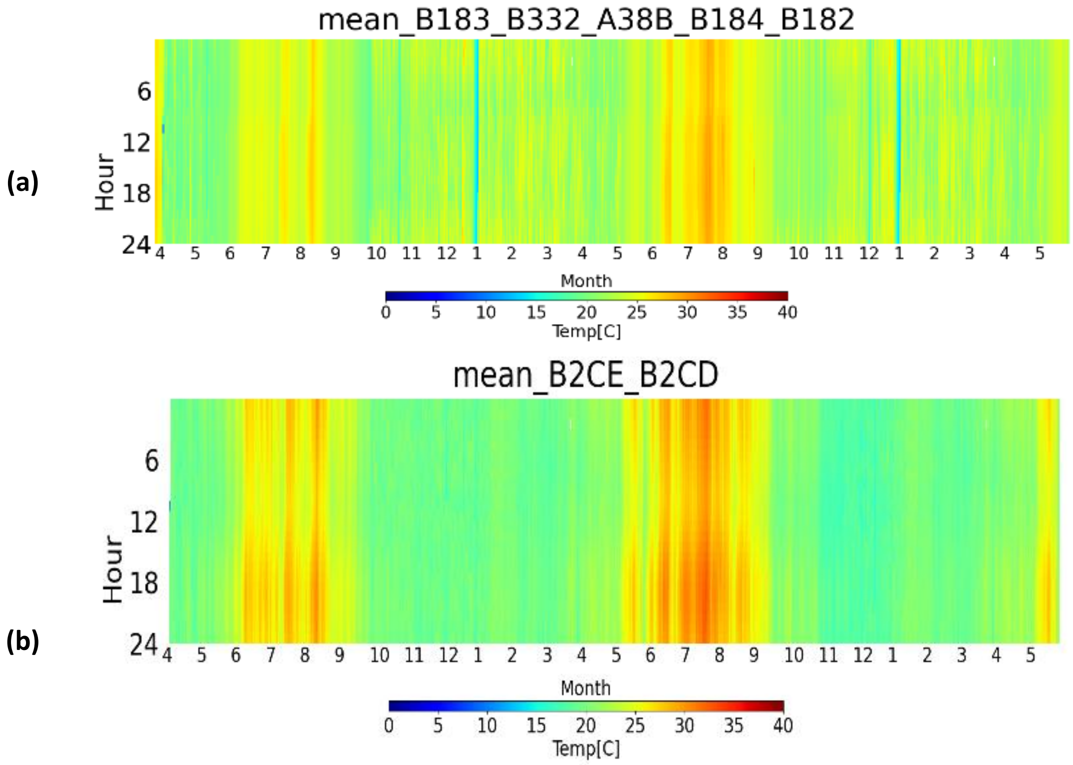


Figure 70 Carpet plots of hourly measured temperatures in building B2.3 (the main renovation arrives at the end of September 2022). (a) average of the ground floor, and (b) average of the first floor

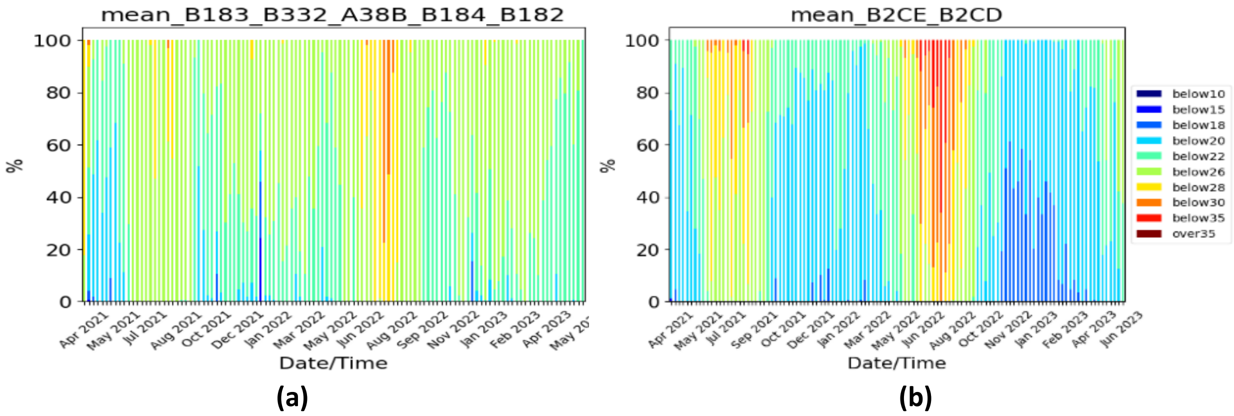


Figure 71 Weekly classification of hourly measured temperatures (percentage of hours) in building B2.3 (main renovation: end of September 2022). Averages of (a) the ground floor, and (b) the first floor

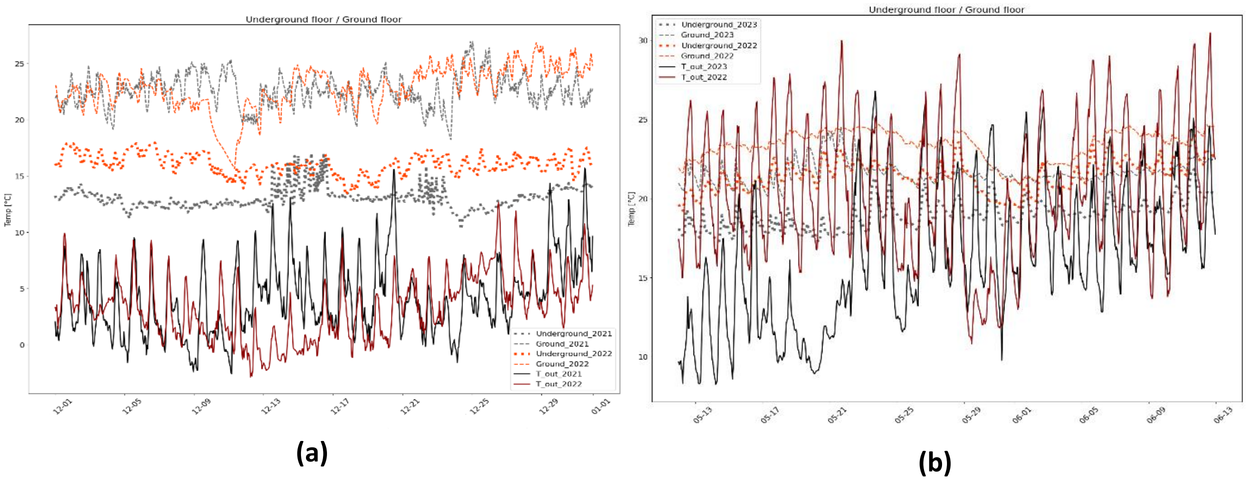
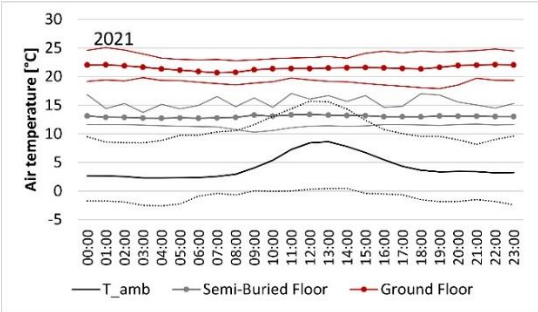
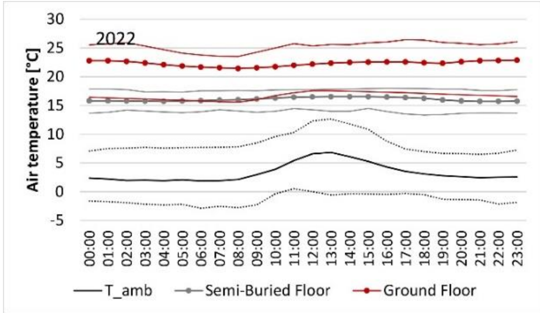


Figure 72 Monthly temperature variations in building B2.3 – Environmental temperatures: continuous lines; inhabited spaces: dotted lines; not-conditioned buffer spaces: dashed lines. Ground floor: (a) December and (b) May

Dec

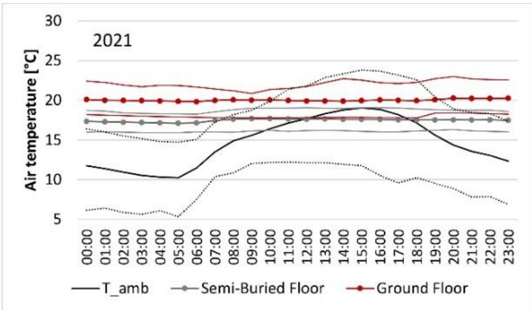


(a) Before

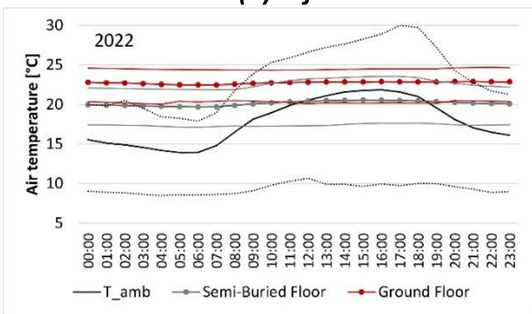


(b) After

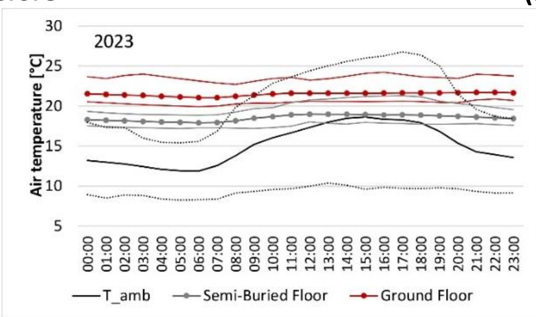
May



(a) Before



(b) Before



(c) After

Figure 73 Average 24h temperature profiles for (a) 2021, (b) 2022 and (c) 2023 (the main renovation occurred end of September 2022) – first floor of building B2.3.

Looking at Figure 72, internal ground floor temperatures in December are comparable even if after the renovation colder peaks are reduced demonstrating the ability of the intervention in activating thermal masses and reducing heat transmission via the floor. Additionally, the semi-buried un-conditioned spaces have a higher natural temperature with respect to the year before the renovation, even when the environmental temperatures are lower, reducing the difference in temperature between climatised and not-climatised confined zones. Differently, in summer (May 2022 vs May 2023), a decrease in both the ground and semi-buried floor temperatures is underlined. The same outcomes are confirmed by Figure 73, showing the 24h average hourly profiles. Although, 2022 is characterised by a long heat wave confirming to be an unconventionally hotter case. The scattered plots shown below will be hence used to verify if a variation in the internal temperatures arrives with respect to the external values. Looking at the same Figure 73 and the previous Figure 70 and Figure 71, May 2023 shows higher internal temperatures with respect to 2021, suggesting a post-intervention overheating risk. Figure 74 confirms the above-mentioned winter outcomes thanks to its box and whisker plots. It is possible to underline the slight increase in the internal temperatures on the ground floor – see the median and the lower quartile box boundary – and the decrease on the first floor. However, a limit of 18°C is maintained. Outlier points are also drastically reduced in the latter, showing a more stable temperature behaviour. Finally, graphs of Figure 75 plot the indoor temperatures as a function of the environmental one. These analyses confirm the previous discussions, showing the increase in the winter 2022-23 temperatures on the ground floor and their decrease in the first one. The early-summer trend (May-June) verifies the overheating risk dimension hidden by the heat wave of 2022, especially for the ground floor, which is the one directly influenced by the renovation action.

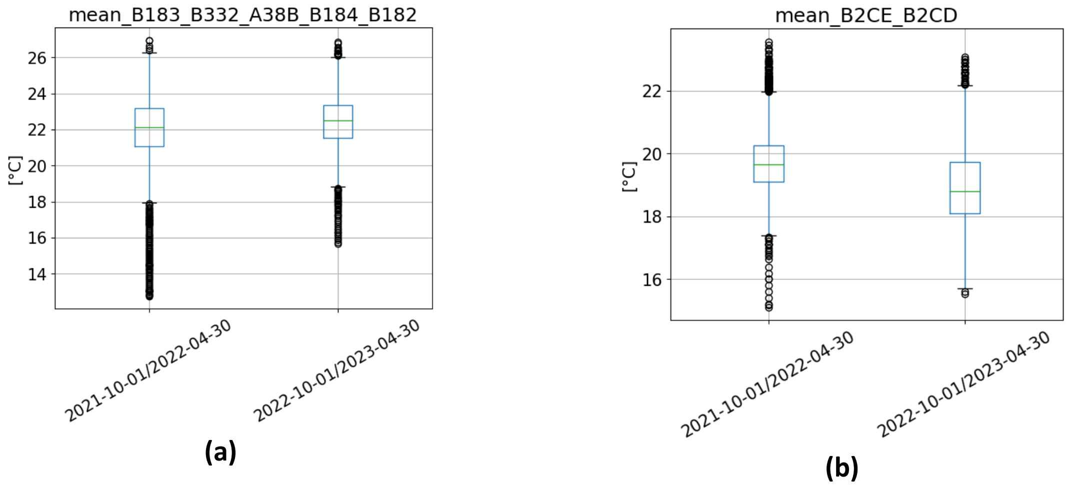


Figure 74 Box and whisker plots comparing temperature statistical variations before and after the renovation. (a) average of main spaces, (b) average of the ground floor, and (c) average of the first floor

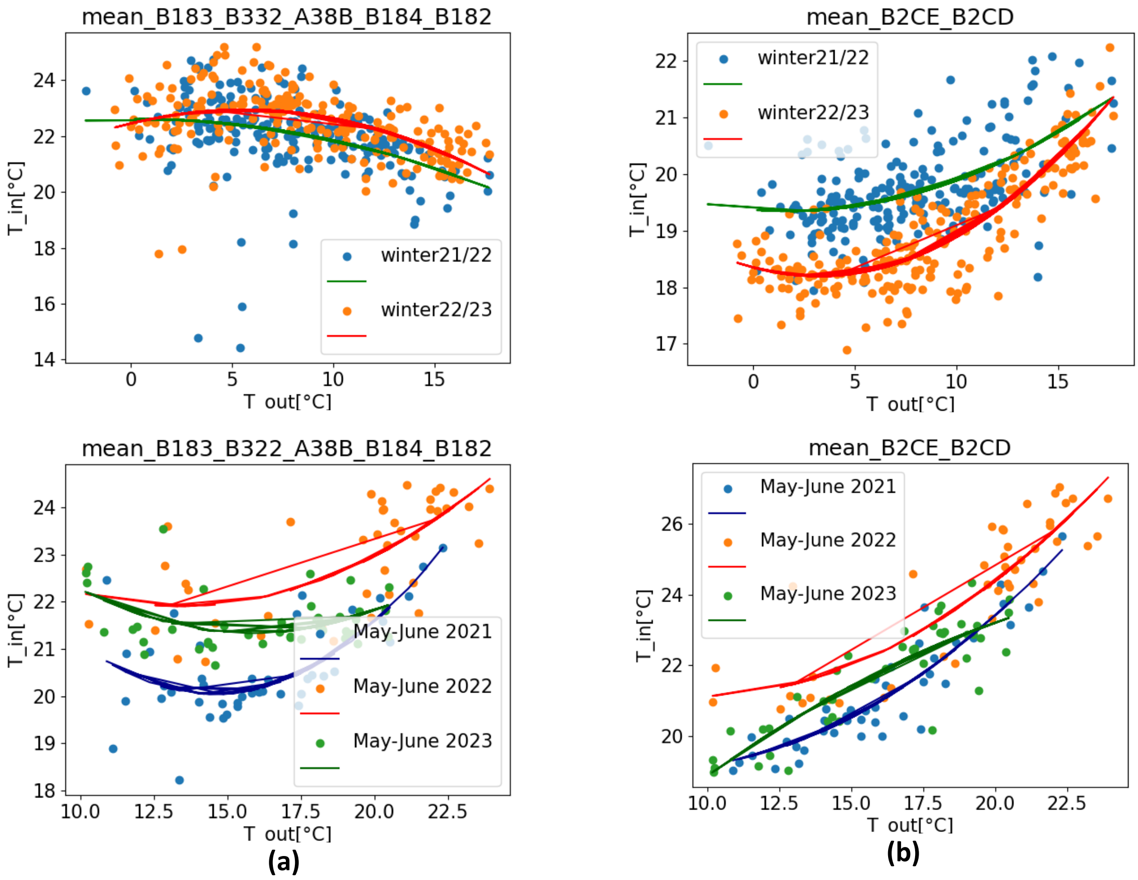


Figure 75 Measured air temperatures plotted as function of the environmental temperature. (a) average of the ground floor, and (b) average of the first floor.

The renovation intervention in the **demo** building **B2.4** consists of installing an insulation layer of 14cm (a double layer of 7 cm each) of glass wool that arrived around the 21st of January 2022. The insulation was positioned in the last slab's outermost layer between the first floor's climatised spaces and the not-climatised space (not inhabited), defining the ventilated cold roof structure. Additionally, the small basement windows have been closed during the same period acting on the temperature variations in the not-climatised buried floor. Figure 76 shortly identify the investigated zones in the building geometry.

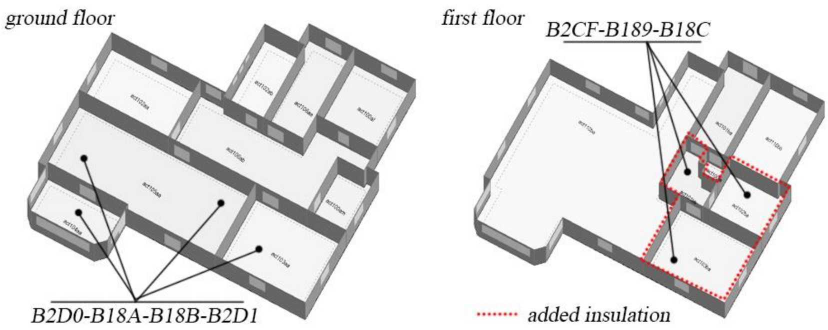
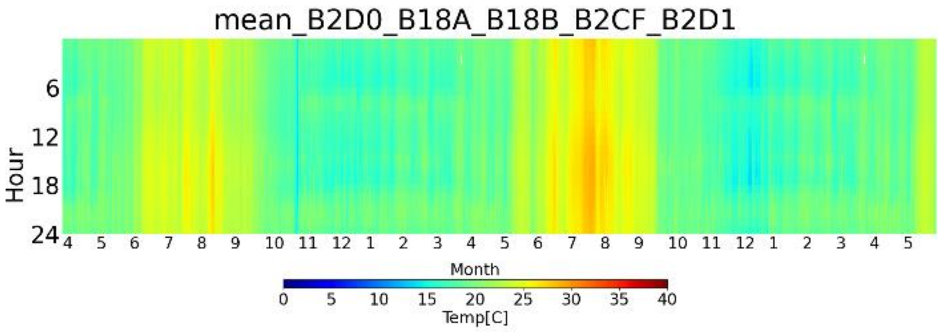


Figure 76 Demo building B2.4 – ground floor (left) and first floor (right

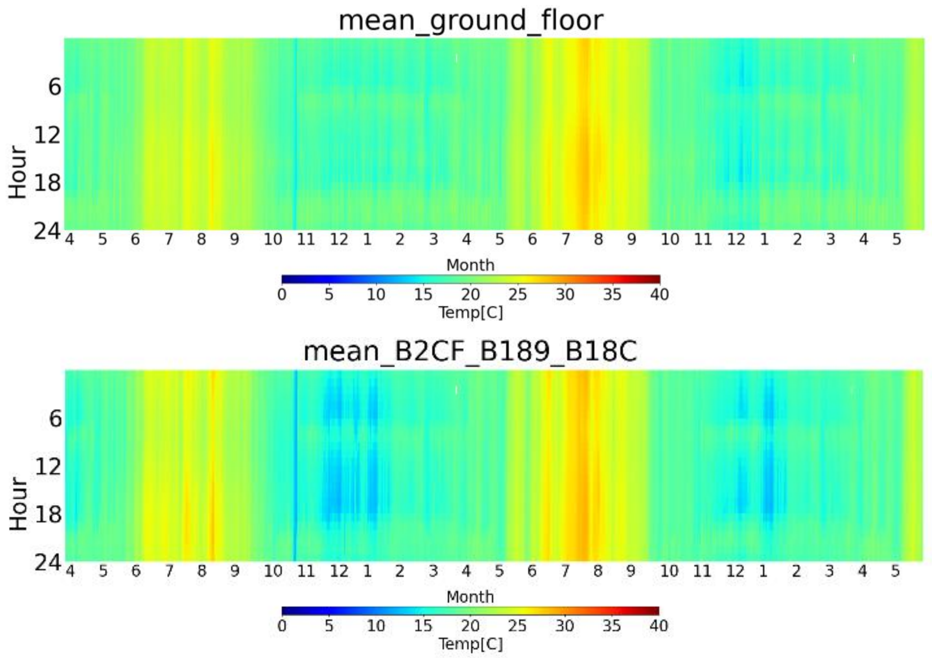
Figure YB0 *– Demo building B2.4 – ground floor (left) and first floor (right)*

Figure 77 and Figure 78 show the carpet plot and the percentage hourly distribution of the measured temperatures for demo B2.4 (residential building 2). The plot shows the average values for the whole building (main rooms), the average of the ground floor and one of the three zones on the first floor (the ones under the roof). Measured data show, on the one side, an increase in the measured internal temperatures during summer 2022 with respect to summer 2021. Concerning winter, a general reduction in indoor temperature cold peaks is visible in October and November, with a decrease of small light blue hours during the mentioned period, especially on the first floor. Nevertheless, in late September and December, the temperatures of 2022 were lower than the ones in 2021 for the whole building and the ground floor, but this outcome is not valid for the first floor. It can be underlined that, as confirmed by tenants, the general set point in 2023 is lower (19.3°C) than the one fixed for 2022 (19.8°C). Looking at Figure 79, the monthly temperature behaviours show an increase in space temperatures underlined after the retrofitting in both the not-conditioned buffer spaces and the inhabited ones, especially in summer and on the first floor. Focussing on the first floor, Figure 80 compares the average 24h hourly profiles for December and June (2021 vs 2022), showing how the inhabited space has a more stable behaviour after the retrofitting, see especially the summer case in which the increase in the under-roof temperatures doesn't correspond to a consistent rise in the temperature of the below spaces even when the weather is hotter. Inversely, even under colder weather, the conditioned room has a more stable behaviour during winter.

(a)

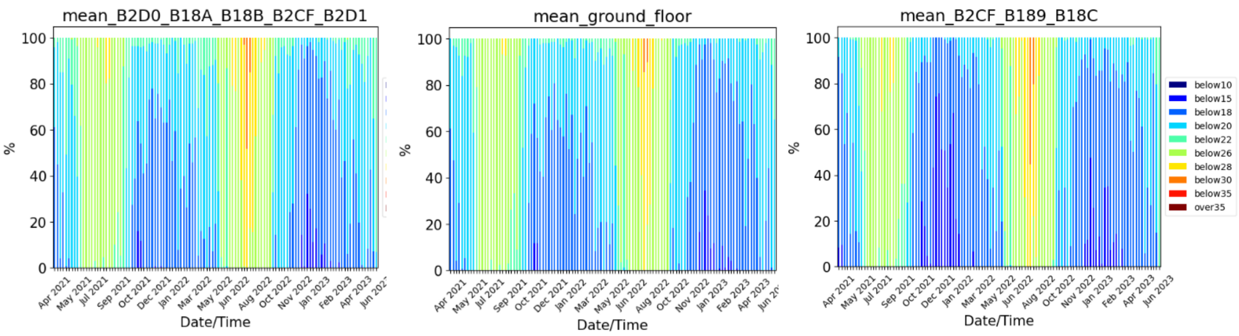


(b)



(c)

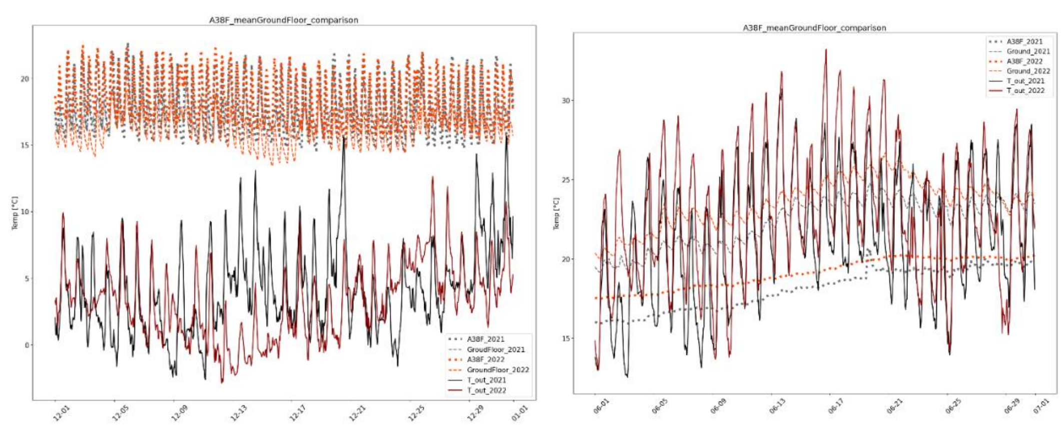
Figure 77 Carpet plots of hourly measured temperatures in building B2.4 (interventions arrive at the end of January 2022). (a) average of main spaces, (b) average of the ground floor, and (c) average of the first floor.



(a) (b) (c)

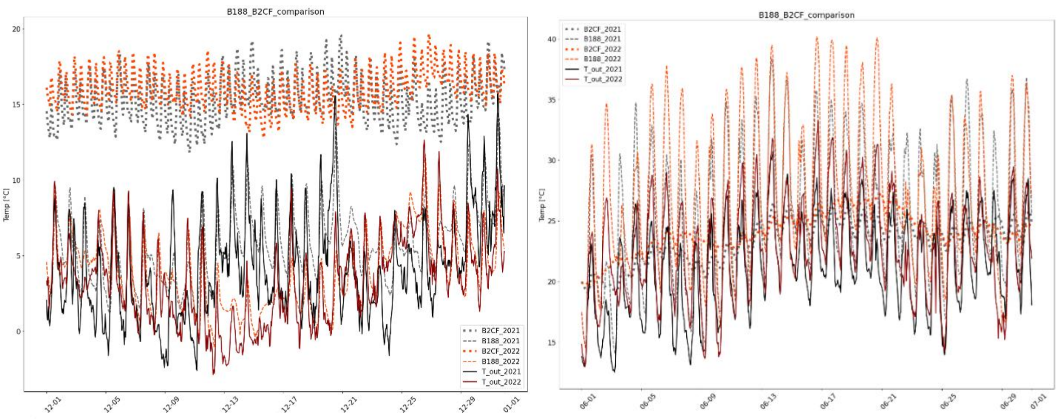
Figure 78 Weekly classification of hourly measured temperatures (percentage of hours) in building B2.4 (renovation: end of January 2022). (a) average of main spaces, (b) average of the ground floor, and (c) average of the first floor.

(a)



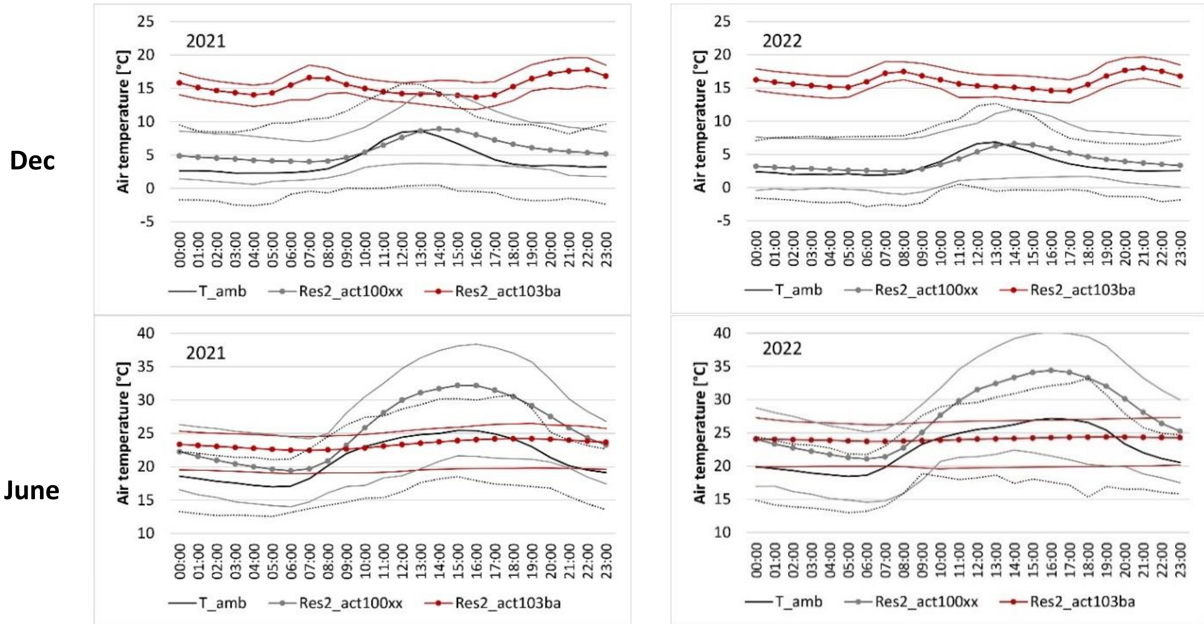
(b)

(c)



(d)

Figure 79 Monthly temperature variations in building B2.4 (interventions arrive at the end of January 2022) – Environmental temperatures: continuous lines; inhabited spaces: dotted lines; not-conditioned buffer spaces: dashed lines. Ground floor: (a) December, (b) June; first floor: (c) December and (d) June.



(a) (b)

Figure 80 Average 24h temperature profiles for (a) 2021 (before the renovation) and (b) 2022 (after) – first floor of building B2.4 – Environmental temperatures: T_amb; bedroom: act103ba; not-conditioned under-roof: act100xx.

The above outcomes are confirmed by the box and whisker plots of Figure 81. In particular, comparing the first and the third boxes allows to detect the impact of renovation actions on the measured performances. In contrast, the comparison between the second and the last boxes, representing post-renovation periods, allows to discuss the impact of changes in the set points (see above). The ground floor show, in fact, a colder median temperature and box dimension in this latter comparison between 2023 and 2022, confirming the reduction in the set-point. The variation between the other two periods (Oct-Jan 2021 – 2022) illustrates a decrease in the median. Still, it is less evident with respect to the difference between the two periods and an increase in the box dimension underlining a more significant temperature variation (potentially due to a change in the system activation schedule). Differently, for the first floor, the graph shows a different behaviour: the variations between the control periods (Feb-April 2022 – 2023) are consistently absorbed by the building (the thermostat is on the below floor), while after the renovation, the first-floor temperatures grew thanks to the positive effect of the additional thermal insulation layer on the under-roof slabs to reduce heat losses.

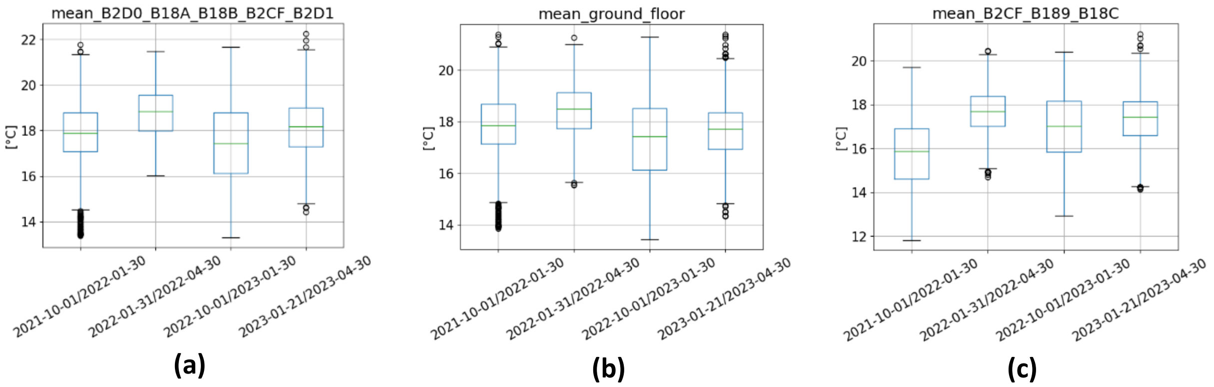


Figure 81 Box and whisker plots comparing temperature statistical variations before and after the renovation (Oct-Jan 2021 vs 2022). A control analysis is added (Feb-Apr 2022 vs 2023) to compare potential variations in user behaviours between the two years (renovation: end of January 2022). ***(a) average of main spaces, (b) average of the ground floor, and (c) average of the first floor.***

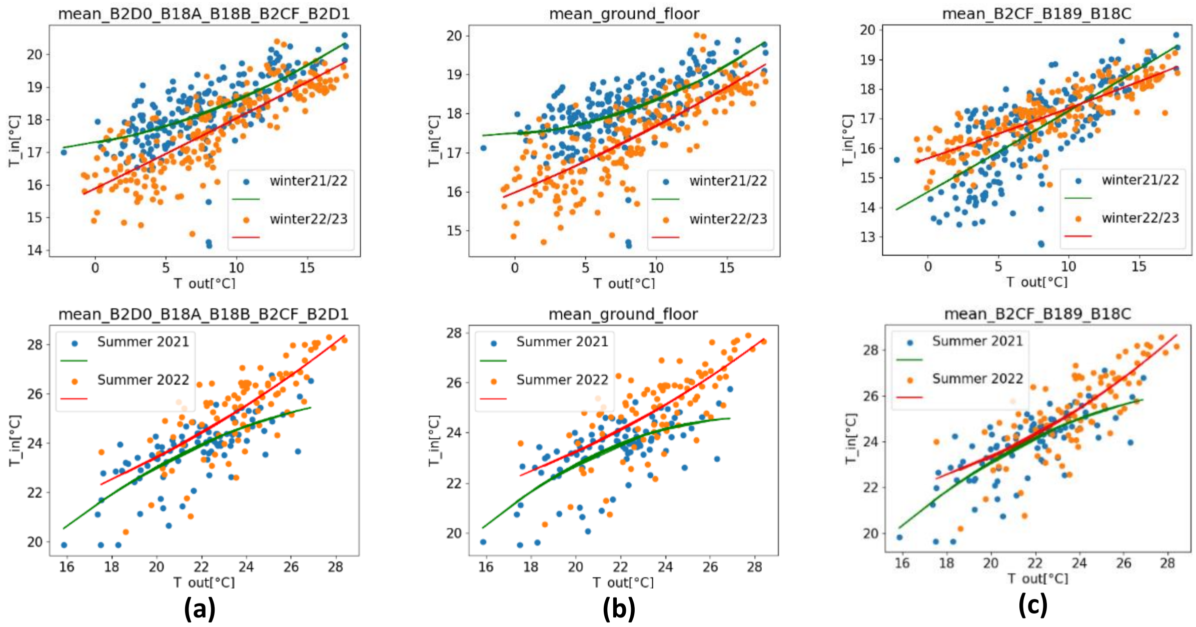


Figure 82 Measured air temperatures plotted as a function of the environmental temperature. (a) average of main spaces, (b) average of the ground floor, and (c) average of the first floor

Finally, Figure 82 analyse these variations as a function of the environmental air temperatures to verify the above outcomes independently by specific weather variations. Winter graphs confirm the above discussion (see Figure 81), showing the reduction in indoor temperatures for the ground floor and detailing the positive impact on the first floor. During the summer, post-intervention temperatures are higher in all cases, in line with expectations.

E-DYCE verification comments

This section shows how the E-DYCE monitoring solutions can be used to verify and confirm the impact of retrofitting actions and help expert users identify criticalities and variations in user or system profiles to define and activate counteractions when needed. The verification of the effect of renovation actions is helpful at different user levels: tenants and owners may understand the direct impact of an investment, and experts may identify challenges in building management to take full advantage of the intervention (e.g. an increase in winter indoor temperatures may suggest that a reduction in the set point can be applied to reduce energy consumptions), and politicians may analyse when data are available, the impact of renovation actions at urban and territorial scales supporting incentives.

4.3.6 Extended PG analyses – Demo cases B2.1 and B2.5

The core idea behind the E-DYCE project is that significant discrepancies are underlined in the literature between standardised simulated models and measured buildings' actual behaviours, requiring new approaches able to better correlate real building behaviours (measured) with simulated ones to support further coherent certification and/or other tasks such as the definition of proper renovation roadmaps. This section focuses on the detection of the performance gap comparing measured and simulated building behaviours under free-running conditions on the two Italian demo cases adopted in Part A, i.e. B2.1 and B2.5, to highlight some general considerations. Simulated buildings' envelopes are based on the verified models. At the same time, the simulation operational inputs for the standard performance gap are inputted by current standards – see EN 16798-1:2019 – overwriting some of the calibrated values (e.g. natural ventilation schedules and ACH). Adapted operational settings instead are defined considering a more realistic building use after an inspection on the field. Additional details on standard and adapted input definitions for Italian demos can be found in D5.4 and in [11], which handles, in particular, the free-running buildings' condition.
The two considered models are: i.) the demo case B2.5 – see Figure 83 – which is a residential unit composed of two main areas, an old construction area with a kitchen and a bedroom and a new construction area, primarily used as a home office and second bedroom; ii.) the demo case B2.1 – see Figure 84 – which is the Torre Pellice municipality school, mainly focusing on the basement floor which is devoted to the kindergarten section. The basement floor of the school could be considered independent from the other three floors since it has different operational settings concerning occupancy schedules, natural ventilation habits, and HVAC setpoints (which are controlled by a separate thermostat), such as giving valuable results even if considered separately from the rest of the building.

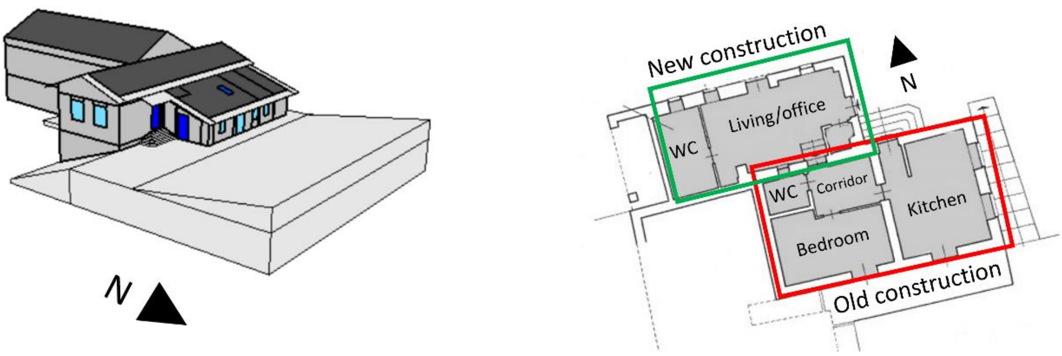


Figure 83 The considered residential building: (a) comprehensive view and (b) internal view.

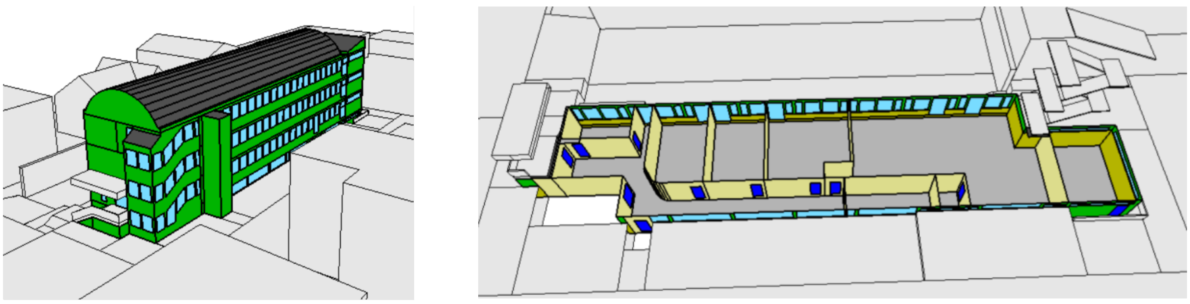


Figure 84 The considered school building: (a) comprehensive view and (b) basement floor

Concerning energy-related KPIs, Figure 85 and Figure 86 show the Q_h indicator for B2.5 with weekly aggregated data over 2022 and 2023. The gap between measured and simulated values is excellent both in the case of standard and adapted operational settings, even though the adapted one is smaller. This could be due to several reasons: i.) residential demo cases in Torre Pellice, as in most Italian mountain regions, make use of wood stoves and fireplaces to integrate the heating provided by the HVAC system, and in some of them, the stove is still the most significant heating source; ii.) the occupant schedule in B2.5 is difficultly adaptable to a more realistic use since it is highly variable; iii.) the heating schedule and setpoints are highly variable in reality since dependant from both the variable occupant schedule and the irregular use of the stove; iv.) the house is controlled by two different thermostats located in specific positions and thermovalves making their actual behaviour challenging to be replicated through a simulation. Hence, the obtained results show that for this residential case, standard conditions have a more significant and stable meaning. In contrast, in order to define proper adapted conditions for specific periods, specific work would be required. Concerning B2.1, energy-related KPIs are visualised only for the kindergarten in Figure 87 and Figure 88, which are controlled by a separate thermostat with respect to the other floors. Results show that adapted conditions allow, in this case, to follow the monitored trend, while standard settings highly overestimate the real consumption. Despite in the kindergarten, being the adapted setpoint (19°C) higher than the standard one (17.5°C), the main impact is given by the setback, which is not present (equal to setpoint) in the case of standard settings, while in the adapted conditions, during nights and weekends, the heating system is switched off. Results give a clear idea of how standard settings applied to public buildings could lead to a significant gap in consumption estimation and, consequently, in possible benefits from renovation roadmaps.

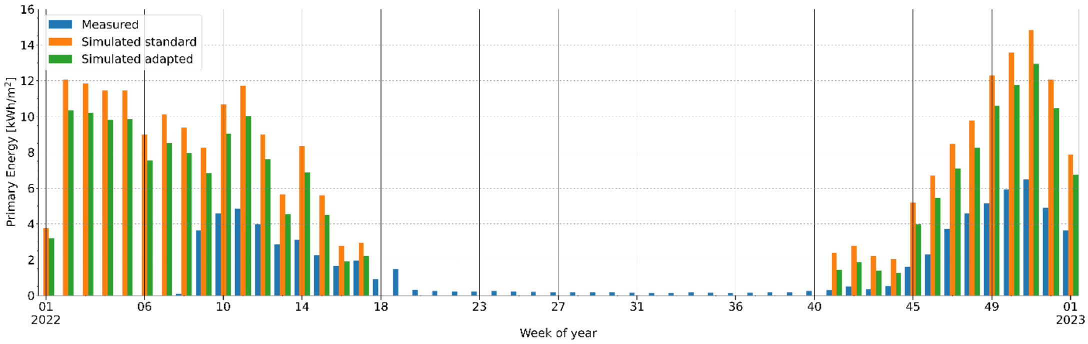


Figure 85 Q_h B2.5 Y2022 weekly plot

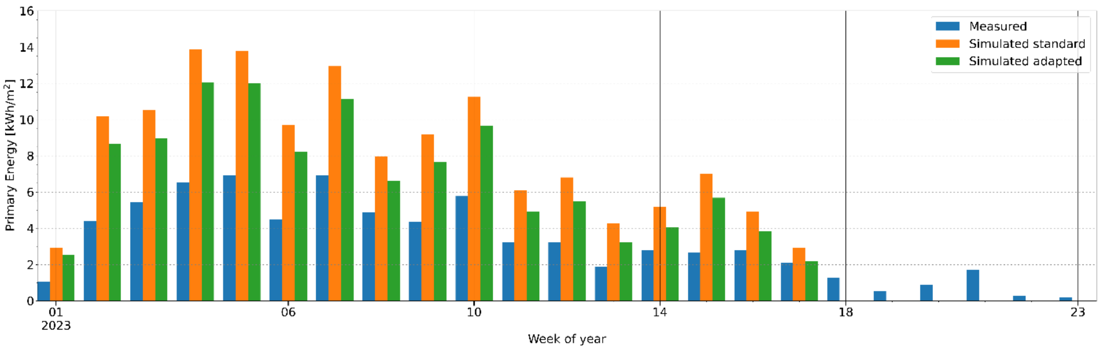


Figure 86 Q_h B2.5 Y2023 weekly plot

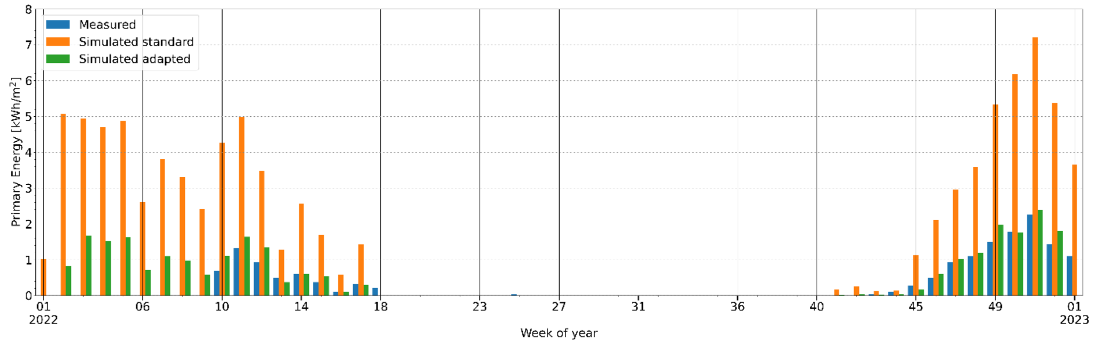


Figure 87 Q_h B2.1 Kindergarten Y2022 weekly plot

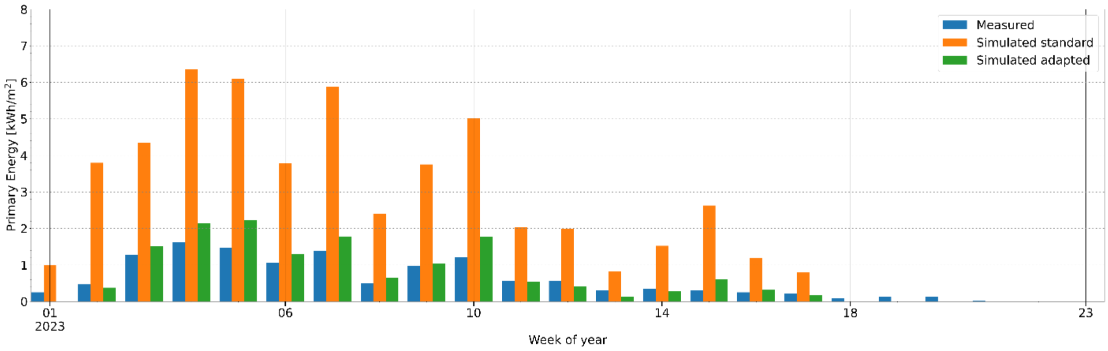


Figure 88 Q_h B2.1 Kindergarten Y2023 weekly plot

Concerning the residential demo case IEQ and IAQ indicators, just one CO_2 sensor has been installed in the most used room of B2.5, which is the kitchen, while all rooms are equipped with temperature sensors. Instead, in B2.1 kindergarten, all teaching areas are monitored with CO_2 and temperature sensors. Regarding IAQ KPIs, since B2.5 is usually occupied by only one person and the room has direct access to the garden and the balcony, which are typically used by pets, the natural ventilation of the environment is often very high, causing a dispersion of CO_2 concentration, which rarely reaches dangerous thresholds – see Figure 89. Only during wintertime possible under-ventilated periods can be detected, which could benefit from an optimised natural ventilation schedule. In this case, adapted and standard inputs have no impact on the results, also because it was not possible to define a proper adapted occupancy schedule use for the room because of its high variability – see Figure 90.

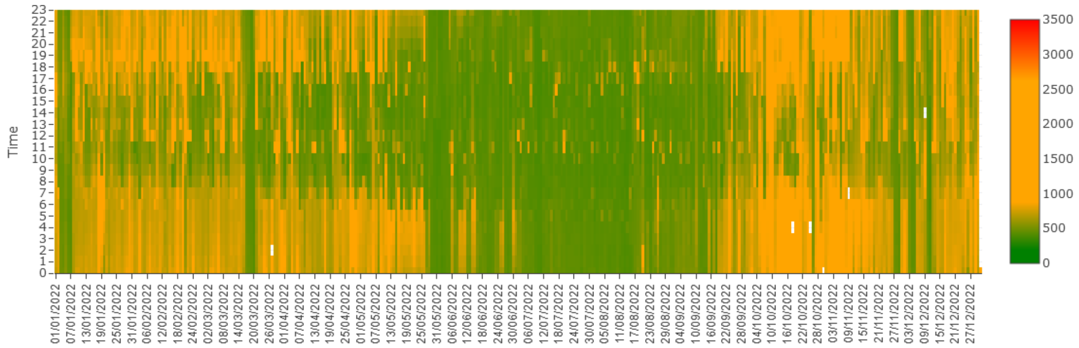


Figure 89 Carpet Plot co2_act104aa B2.5 Y2022

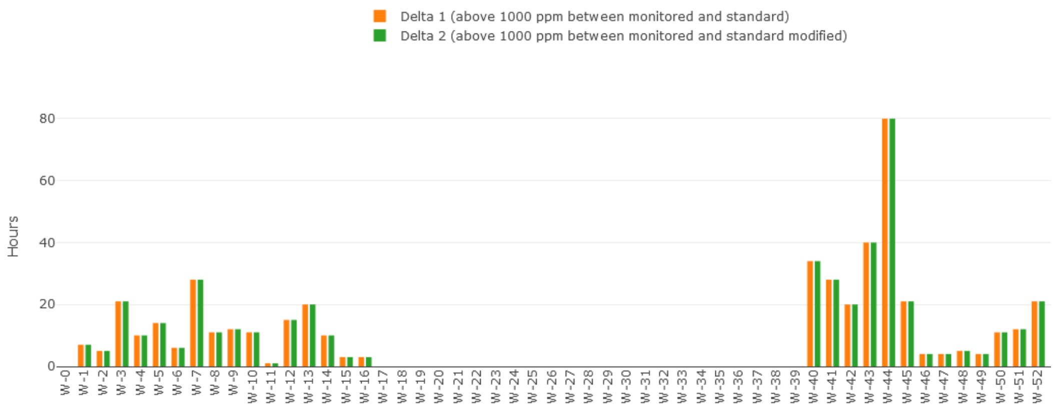


Figure 90 n_co2_aIII_act104aa B2.5 Y2022

Focusing instead on the demo case B2.1, Figure 91, if compared with Figure 93, highlights the added value of adopting a model with fully detailed inside zoning since averaging over the classrooms or the whole floors does not allow to focus potential criticalities located in specific rooms and cancels the high peaks. Since the primary responsibility for high CO_2 values is the manual natural ventilation adopted in the room, looking at each zone separately may help define and suggest specific rules for that environment. In the particular case of the kindergarten, dangerous levels above the threshold of 1000 ppm are rarely reached – see Figure 92 – hence the n_co2_aIII indicator is not very relevant. Also, for the kindergarten teaching areas, it is more challenging to define adapted occupancy conditions than e.g. on the middle school floors, since children spend a significant amount of time playing outdoors and families can pick up children from school during different time slots. Moreover, in the kindergarten, the rooms have an inhomogeneous use during the day based on different children's activities (e.g. lunch, naps, playtime), which makes it even more difficult to define an adequately adapted schedule.

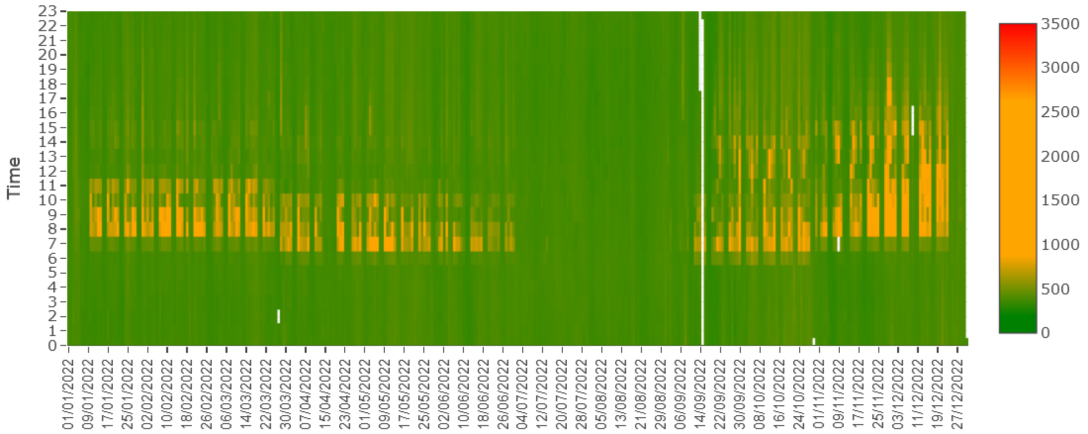


Figure 91 Carpet Plot co2_act201ab B2.1 Kindergarten Y2022

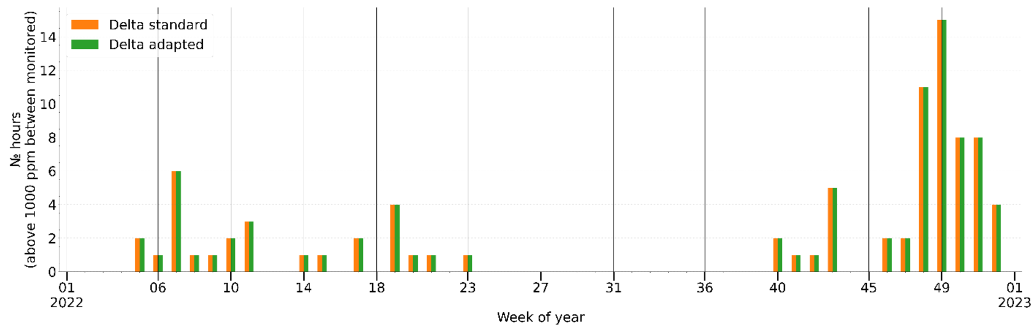


Figure 92 n_co2_aIII_act201ab B2.1 Kindergarten Y2022

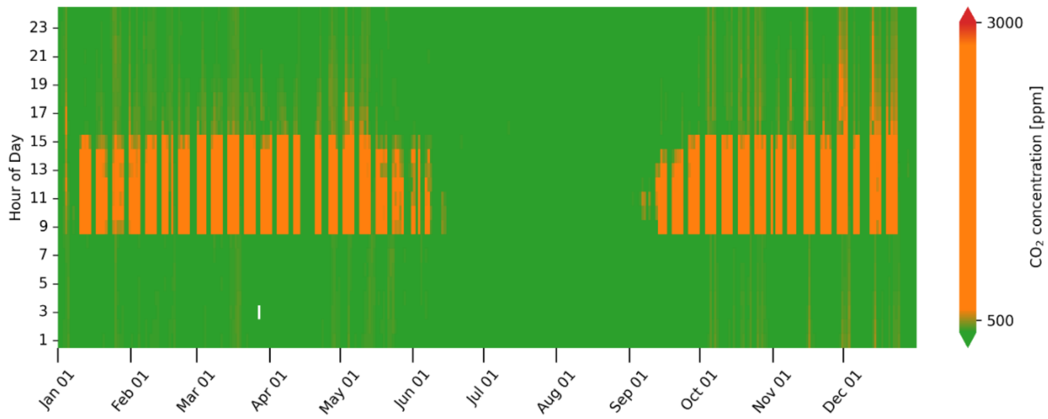


Figure 93 Carpet Plot co2_act201 B2.1 Kindergarten average of all teaching areas Y2022

Monitored temperature carpet plots, especially if combined with CO_2-related information, could help identify possible over- or under-ventilation conditions. In general, because of the mountain region in which Torre Pellice is located, the main problem is to heat enough both during the winter and mid-seasons outside the legal heating period. Commonly, temperatures are very low, and only during summer could high values be reached, but only during the months in which the school is closed (July-August). Figure 98 shows the average temperature in all teaching areas in the Kindergarten. It is very similar to the results obtained in the single rooms (Figure 97). As demonstrated in section 4.3.7, the school structure and orientation allow to obtain results close to reality on indoor temperature, also aggregating by orientation or by the whole floor in the model. Instead, Figure 94 shows that this result is not replicable in the residential case B2.5, which presents substantial differences between specific rooms (Figure 95 and Figure 96) and the average.

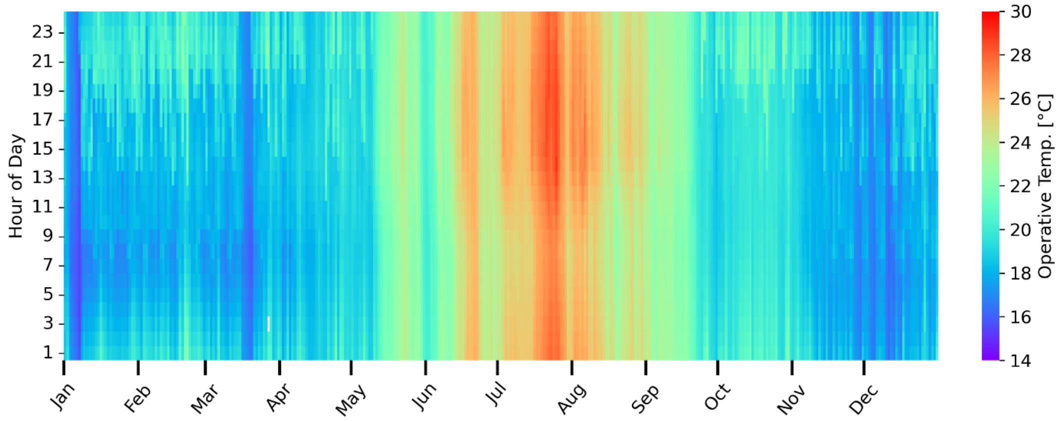


Figure 94 Carpet Plot t_db B2.5 Average of all principal areas Y2022

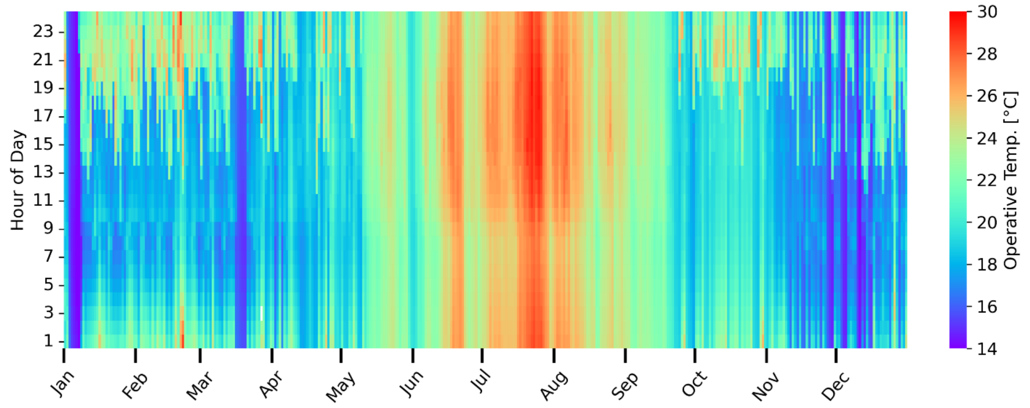


Figure 95 Carpet Plot t_db_act104aa B2.5 Y2022

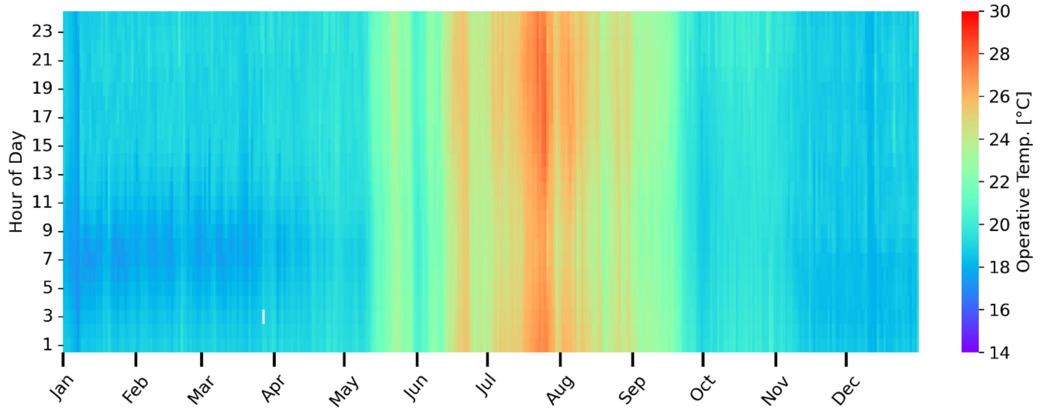


Figure 96 Carpet Plot t_db_act105aa B2.5 Y2022

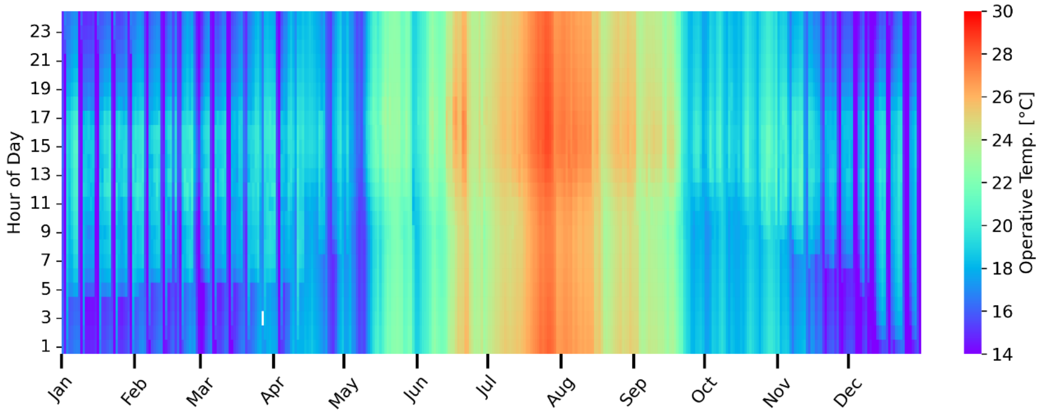


Figure 97 Carpet Plot t_db _act201aa B2.1 Kindergarten Y2022

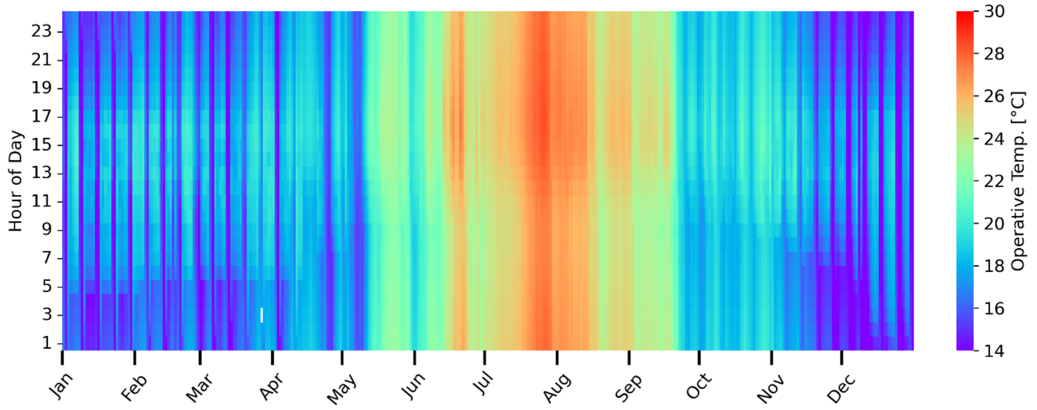


Figure 98 Carpet Plot t_db_act201 B2.1 Kindergarten average of all teaching areas Y2022

Focusing on IAQ indicators, the n_co2_bl KPI was not visualised in Part A of this report. However, the number of occupied hours below the 600 ppm threshold is probably a more representative KPI for the kindergarten than the number of hours above the 1000 ppm threshold since the generally very high ventilation rate and the low occupancy profile. Looking at aggregated results averaged on the teaching areas in Figure 99, some general considerations may be highlighted: the behaviour of standard and adapted operational settings, with respect to the monitored data, changes significantly throughout the years. Based on when the adapted conditions (mainly natural ventilation) are tuned, they could be closer both to the standard or to the adapted. Standard ventilation, which is always the same the whole year long, is more similar to the drastic approach adopted during the pandemic years of continuously ventilating the environment. Instead, since, at present, a normal ventilation schedule has been re-established, the adapted setting better represents the monitored trend.

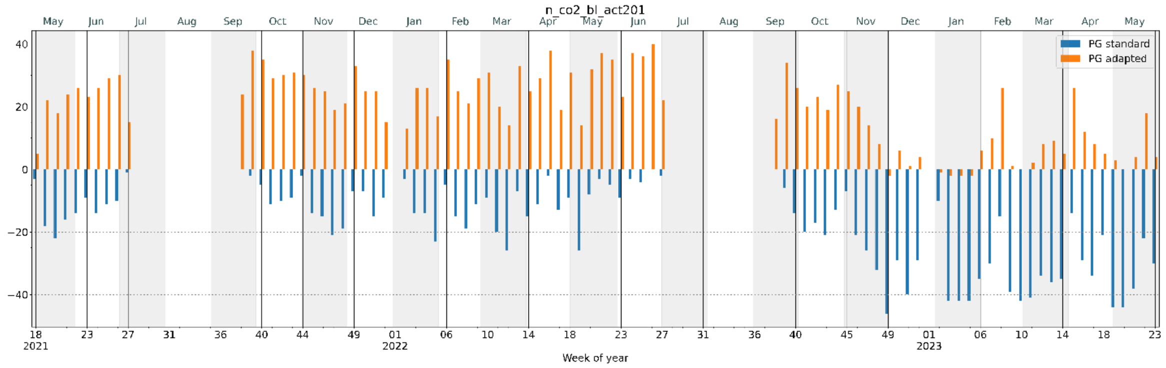


Figure 99 Number of occupied hours with CO2 concentration below 600 ppm aggregated results on all kindergarten teaching areas.

E-DYCE verification comments

Considering that Torre Pellice is located in a mountain region, the main problem in reaching the best free-running mode in terms of both thermal comfort and indoor air quality was recorded to be, even in the late spring and late-summer, finding a good balance between natural ventilation strategies and consequent natural cooling. Results show that, despite trying to apply the best strategies to maintain indoor thermal comfort and air changes (also considering the pandemic), it is difficult without the aid of visual supports and eventual suggestions to understand when the pollutant concentration is increasing above a certain level and when it is low enough not to require additional ventilation. Results also showed the relevance of both aggregated and time-series data in understanding potential problems inside the considered space: aggregated results are indispensable in case of random trends, like the CO_2 concentration in the residential unit. In contrast, time-series data is of great aid in understanding the more regular school behaviour. Also, considering different levels of spatial aggregation, such as specific rooms or thematic areas (e.g. all the teaching areas together), was useful in understanding localised problems that could disappear in an average behaviour. However, it should be underlined that people's habits tend to vary significantly over time, especially during these years moved by the pandemic evolution. Hence, while the standardised building setting has a fixed and easily interpretable meaning, the adapted setting should be updated over time to follow the changing behaviour, mainly if used to compare KPIs strictly linked to occupancy and natural ventilation schedules. Otherwise, it could be a useful indicator in a specific period to possibly suggest some operational improvements, but then it loses its efficacy and representativity.

4.3.7 Simplification analyses: calibration approaches – Demo case B2.1

Among the main issues raised during the E-DYCE project is the difficult balance between a detailed building modelling closer to reality and necessary simplification actions to keep the modelling task affordable and in perspective of future certification use. A complete insight into this point has been performed. Still, additional analyses have been conducted to assess the resilience of model calibration and performance gap computation in the years – see [12] for the complete work. The municipality school building is the most complex model among the Italian demo cases, with its four floors, the surroundings, and numerous internal zones. The impact of different simplification approaches on model verification and performance gap computation focusing on thermal comfort indicators has been analysed and deeply addresses the consumption indicators. In particular, the operative temperature and the Adaptive Comfort Model (ACM) are considered: ACM POR (Percentage Outside the Range) is defined as the percentage of hours in thermal discomfort, adopting Cat. II boundaries calculated in line with EN 16798-1. The measured dry bulb temperature is used and compared with the simulated operative to compute both indicators on monitored data.

Several model simplification actions regarding both building-level construction and zoning approaches are considered in the analysis, resulting in five modelling solutions. Notably, the building is considered in its completeness, hence a single model with all the relevant surroundings, and considering the different floors as separate models. Moreover, different thermal zones' aggregations of the entire model, going from room details to multi-space aggregations according to the orientations of windows (North/South) and finally to floor averages, are tested. Concerning instead the single-floor models, it was analysed the impact of pursuing a detailed building inspection for both structural and operational model settings and of adopting the information retrieved from the Tabula dataset[13] in case of detailed building information is not available. For this resilience analysis, the chosen calibration period goes from 15/07 to 15/08 2021, during school closure to avoid the impact of random operational settings. Instead, the resilience of the calibrated models on occupied free-running periods has been tested in spring and autumn 2021 and 2022.

Figure 100 shows the calibration signatures results of the three best cases. A result inside a 5% error range is reached in all cases, in line with ASHRAE reference suggestions[14] Table 17 shows the obtained calibration error values. Concerning the full models, the floor aggregation offers the best performance, although the specific building typology and orientation may influence the results. Focusing on the single-floor model (ground floor), the Tabula setting shows a downshift that the adopted calibration procedure could not balance. Concerning performance gap results shown in Table 18, results on the single-floor models are significantly better than those obtained on the whole model with floor aggregation. The floor aggregation standard and adapted conditions give similar results and, in some cases, standard ones better follow the monitored trend as if compensating for modelling limitations. In the single-floor models instead, adapted conditions allow to reach the overall best performance, and the model fed with realistic building parameters is more resilient in the long term than those fed with Tabula inputs.

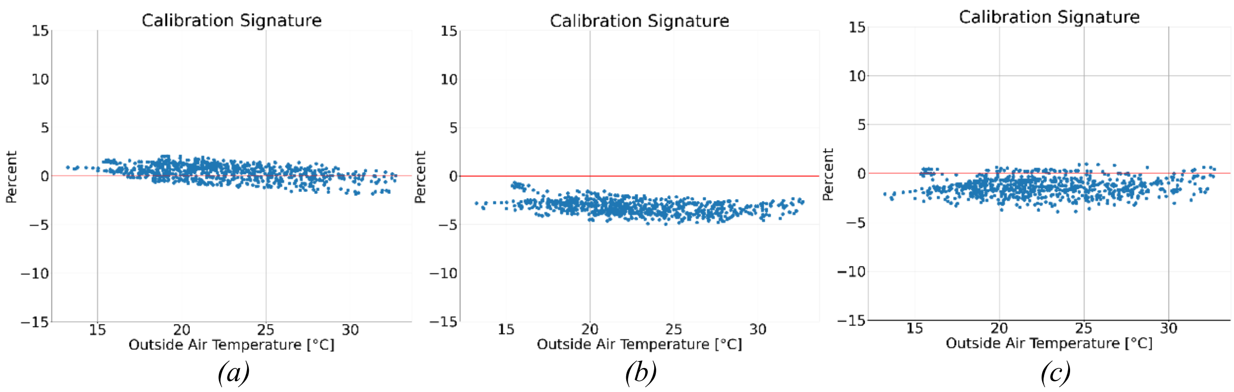


Figure 100 Calibration signatures: (a) full model with floor aggregations, (b) ground floor with Tabula inputs and (c) realistic (standard adapted) inputs.

[13]TABULA, EPISCOPE, TABULA Webtool (n.d.). https://webtool.building-typology.eu/#bm

[14] ASHRAE, ASHRAE Guideline 14-2014 - Measurement of Energy, Demand, and Water Savings, 2014.

Table 17 Final calibration errors achieved with the different models [8].

Model setting	MBE	RMSE	$Error_{TOT}$	Simulation time (s)
Full model – floor agg.	-0.101	0.248	0.268	1524
Single floor – realistic	0.394	0.472	0.615	148
Single floor – Tabula	0.976	0.922	1.322	148

Table 18 Performance gap results in different model settings considering the classroom average

	ACM – POR [%]		ACM cat I [n.h.]		ACM cat II [n.h.]		Operative Temp. [°C]	
	STD	ADP	STD	ADP	STD	ADP	STD	ADP
Full model – floor agg.	9.18	11.04	-443	-658	-48	139	-2.33	-1.19
Single floor – realistic	-1.86	-0.95	253	17	-50	10	0.32	0.27
Single floor – Tabula	-2.33	-1.19	323	-58	130	161	-0.33	0.03

E-DYCE verification comments

Results of this analysis demonstrate that cut models (at the floor or the apartment level) can reach optimal results, comparable to a fully detailed model but allowing different kinds of applications, thanks to their lightness, including real-time web services, hence demonstrating the feasibility of future applications of the E-DYCE proposed fully integrated process. In fact, for detailed performance gap analyses reported in part A of this deliverable, the single floor models of demo case B2.1 were used after a more detailed calibration process – see the Deliverable D5.1 – based on a deeper inspection (e.g. by fixing shadings in the rooms) and additional calibration steps based on human observation, which allow to reach an optimal result on a single floor, comparable to the full model one.

4.3.8 Simplification analyses: sensor distributions

The scope of this Section is to analyse the potential effect on building performance analyses of different sensor density coverages. The analysis compares the measured data variations from the sensors positioned in the same building. The analysis is conducted in both school and residential Italian demos with the aim of potentially suggesting sensor simplification strategies to reduce the cost of the E-DYCE measuring infrastructure. In line with Deliverables D5.1 and D5.4, the Italian demos implement a single zoning sensoring distribution, even if CO_2 sensors cover only the major rooms in the three residential buildings. This section focuses on temperature and CO_2 measurements.

This Section's scope is to analyse the potential effect on building performance analyses when different sensor density coverages are assumed. The analysis compares the variations in the measured data from the different measured data variations from the sensors positioned in the same building. The analysis is conducted in both school and residential Italian demos to potentially suggest sensor simplification strategies to reduce the cost of the E-DYCE measuring infrastructure. In line with Deliverables D5.1 and D5.4, the Italian demos implement a per-room single zooning sensoring distribution. Nevertheless, CO_2 sensors are installed only in the major rooms in the three residential buildings, even if CO_2 sensors cover only the major rooms in the three residential buildings. This section focuses on temperature and CO_2 measurements.

Temperature distribution

Considering temperature distribution, box and whisker plots are elaborated to compare single sensor measurements during the summer and winter seasons. These graphs allow to analyse the statistical distribution of a data series by plotting, in addition to outliers, the minimum, first quartile, median, third quartile, and maximum values. Figure 101 and Figure 102 report the box and whisker plots for temperature sensors in the municipality **school building B2.1** for summer (May to September 2022) and winter (October 2021 to April 2022), respectively. In summer, the last two floors show a more homogeneous distribution of temperatures, even among different types of zones, while in winter, main zones (e.g. act201 – classrooms) are homogenous, with variations among the different activities. The ground floor is also mainly homogeneous in summer even if the median of temperatures of the entire floor is slightly lower than the one of the above ones, such as expected in terms of heat vertical distribution. Similarly, the kindergarten is colder thanks to its semi-buried nature. In particular specific activities, such as Act207 (technical room) is not heated in winter, and similarly the stairs (act202) show higher peak variations due to their free-running nature.

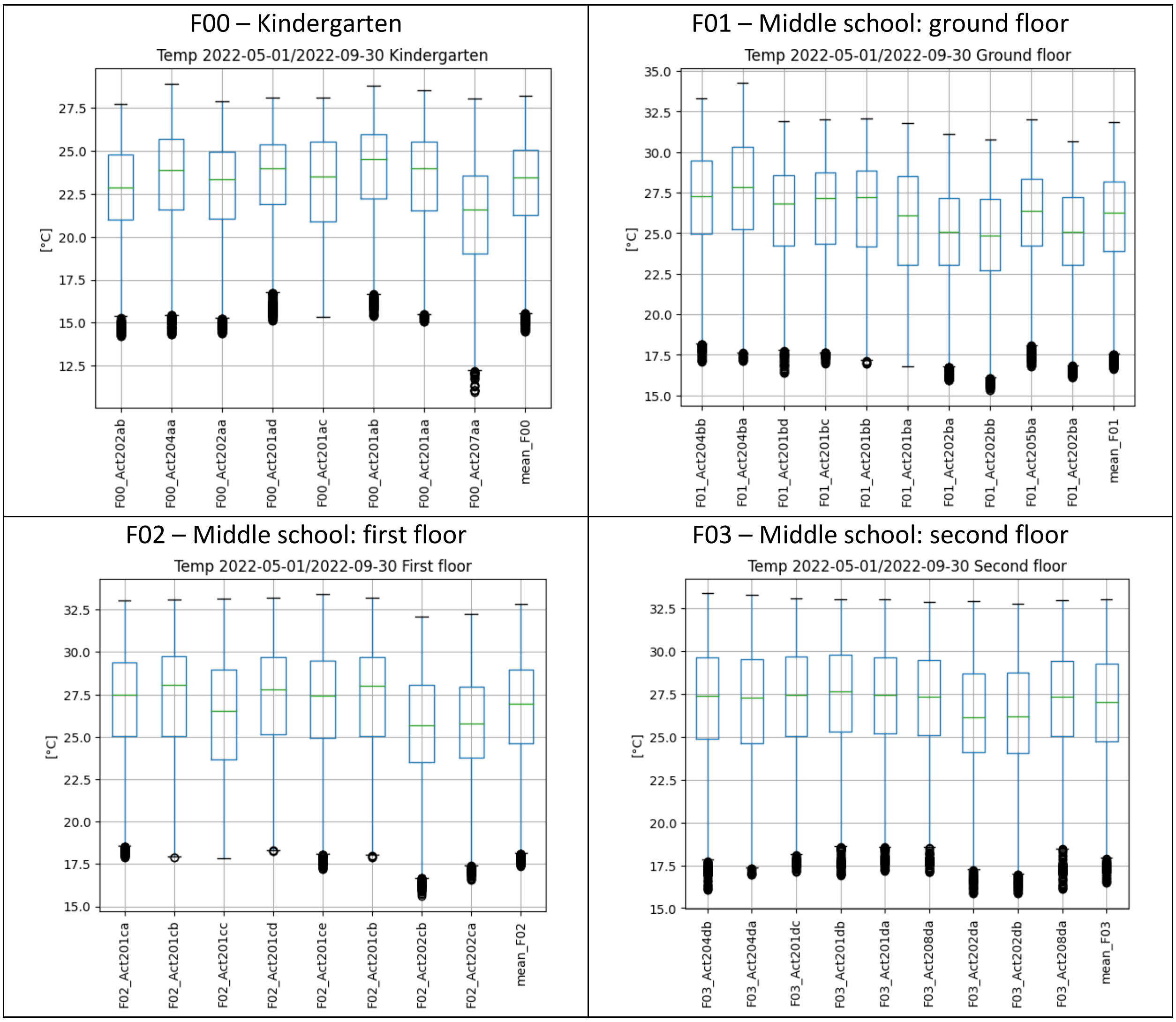


Figure 101 Statistical temperature distribution for the summer season inside the school demo B2.1

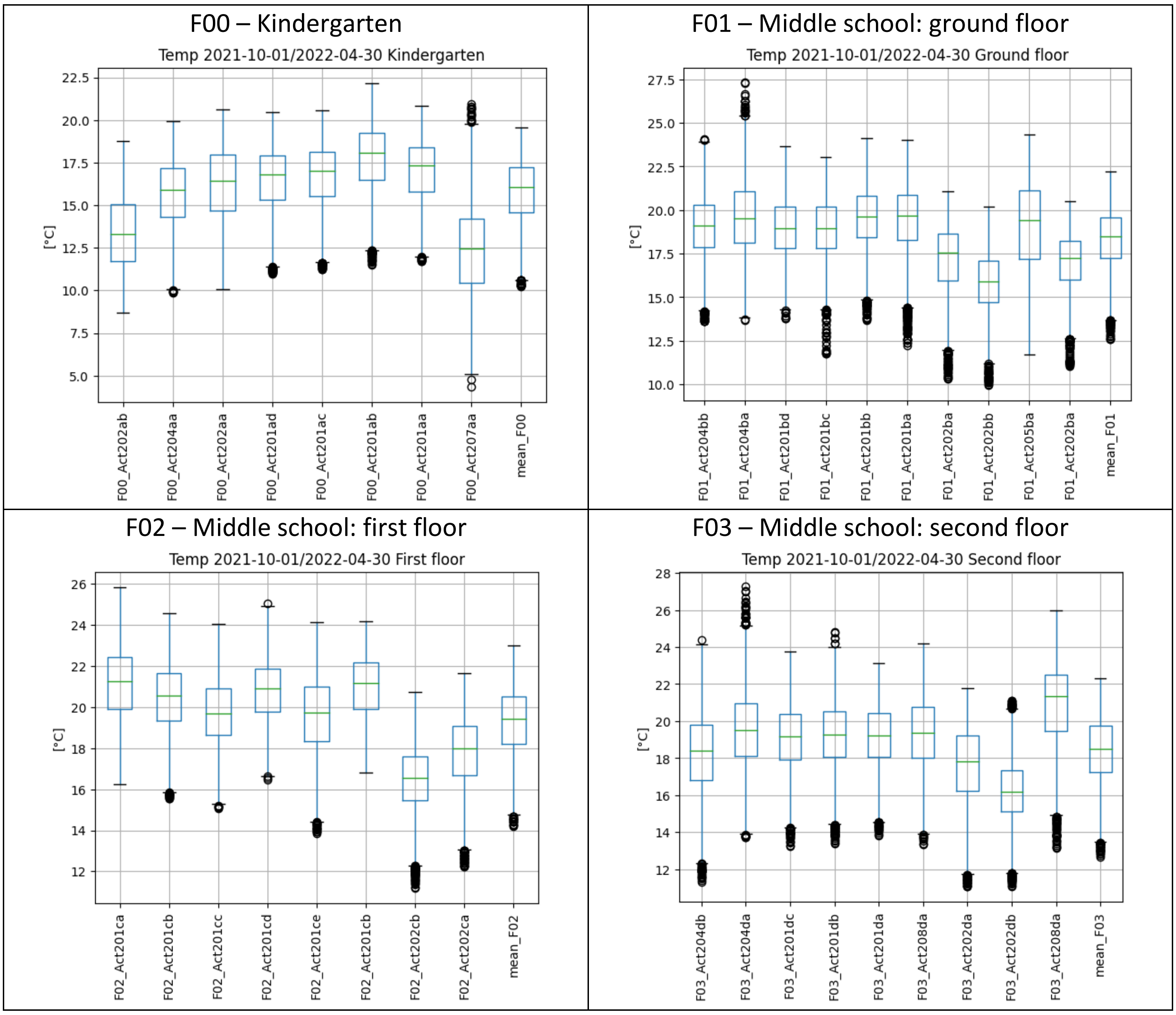


Figure 102 Statistical temperature distribution for the winter season inside the school demo B2.1

Additionally, a second analysis is performed by plotting for each sensor the percentage distribution of the number of hours in different temperature classes considering the summer, Figure 103, and the winter, Figure 104, periods. These tables confirm the statistical results, showing how the higher floors are hotter in summer. In contrast, in winter, the hottest space is the first floor, followed by the ground one, potentially because confining above and below with heated spaces. Classrooms confirm a general homogeneous temperature distribution per floor, with some variations potentially due to different ventilation approaches.

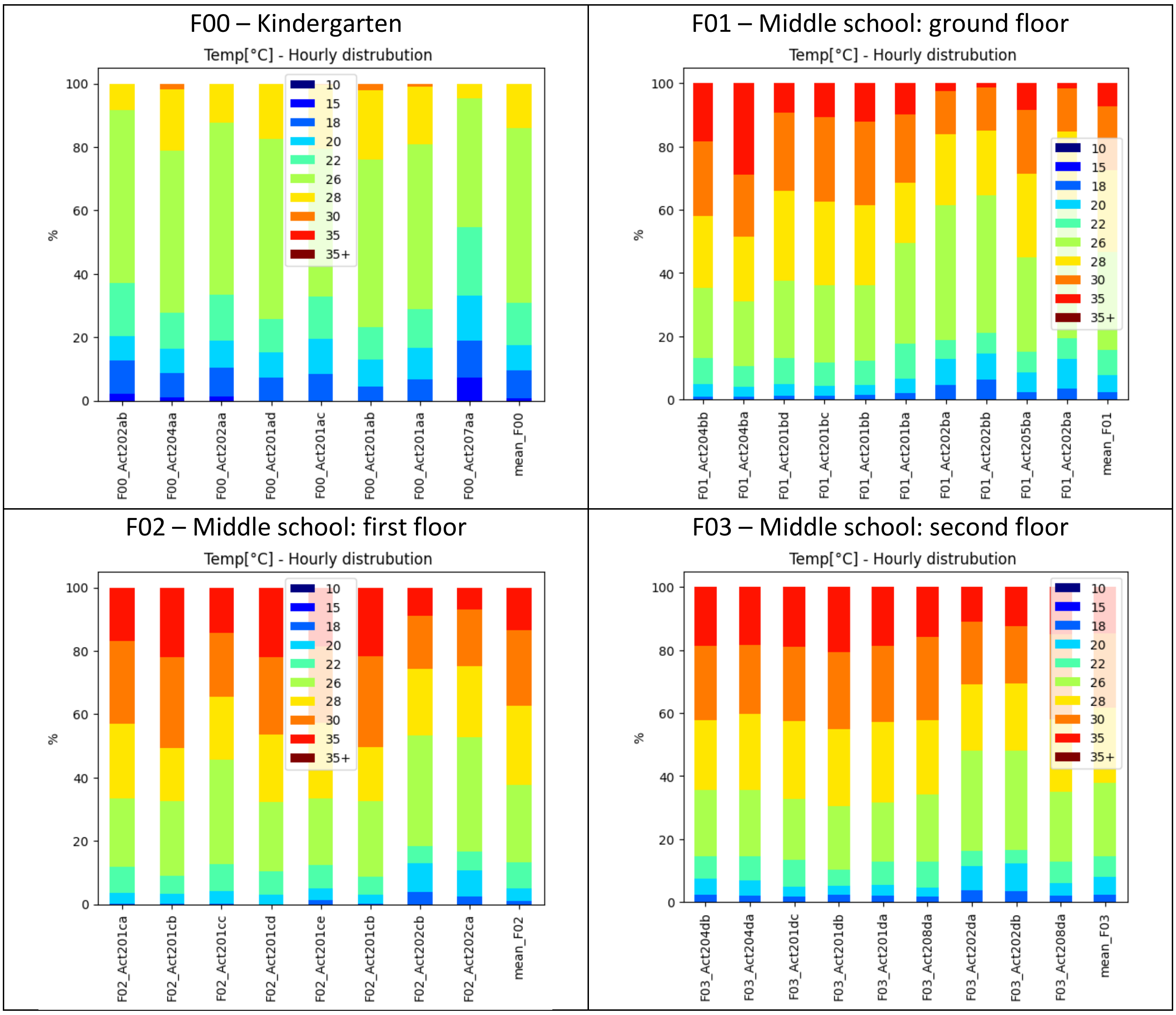
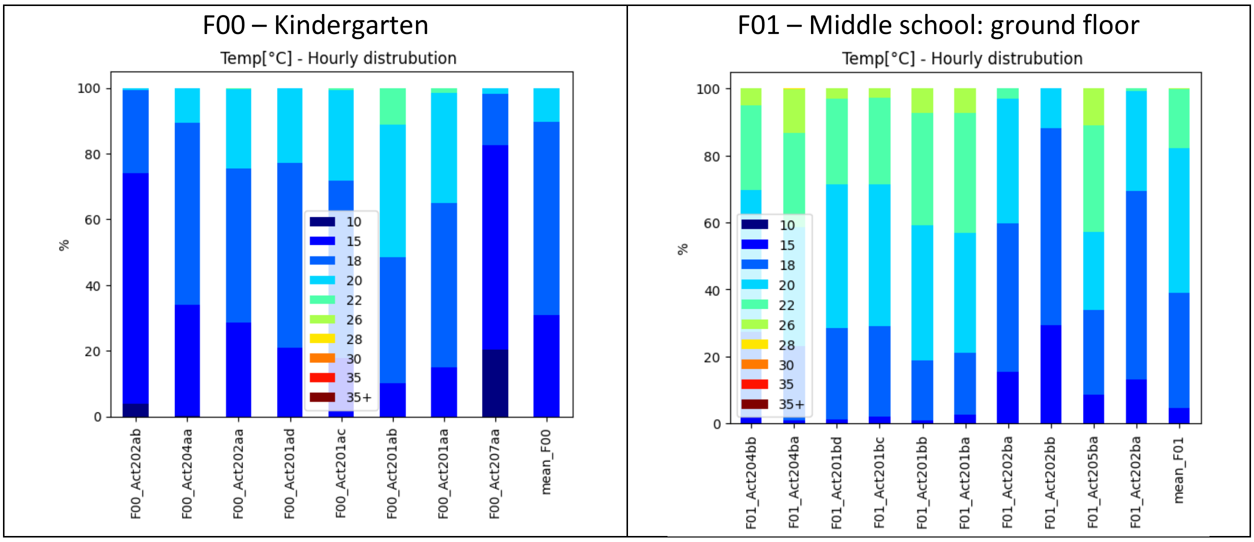


Figure 103 Percentage distribution of the number of hours per temperature classes – summer season school demo B2.1



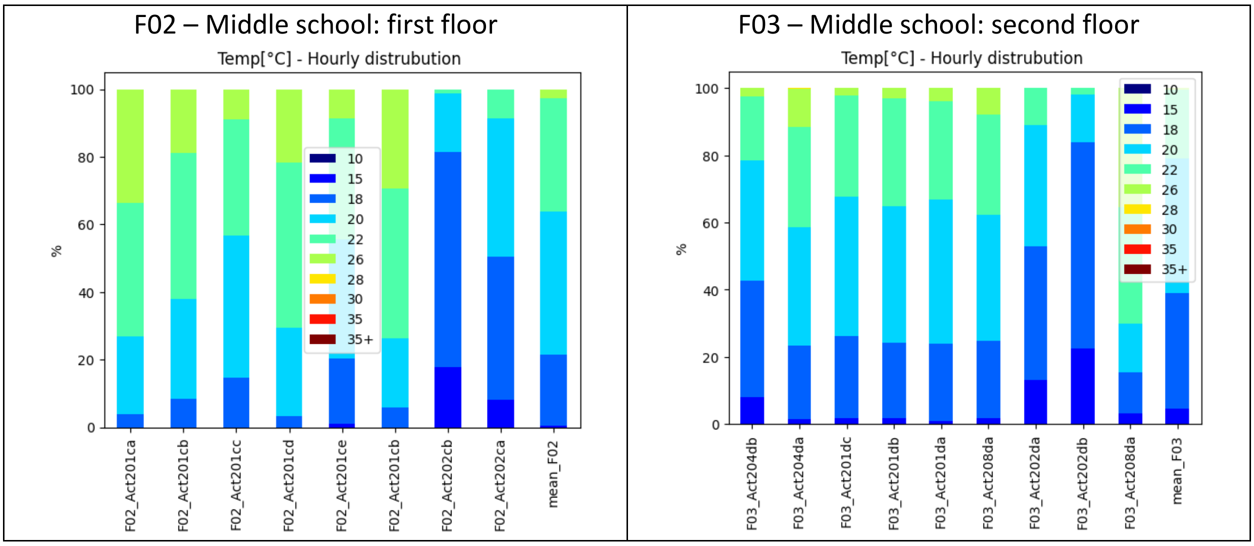
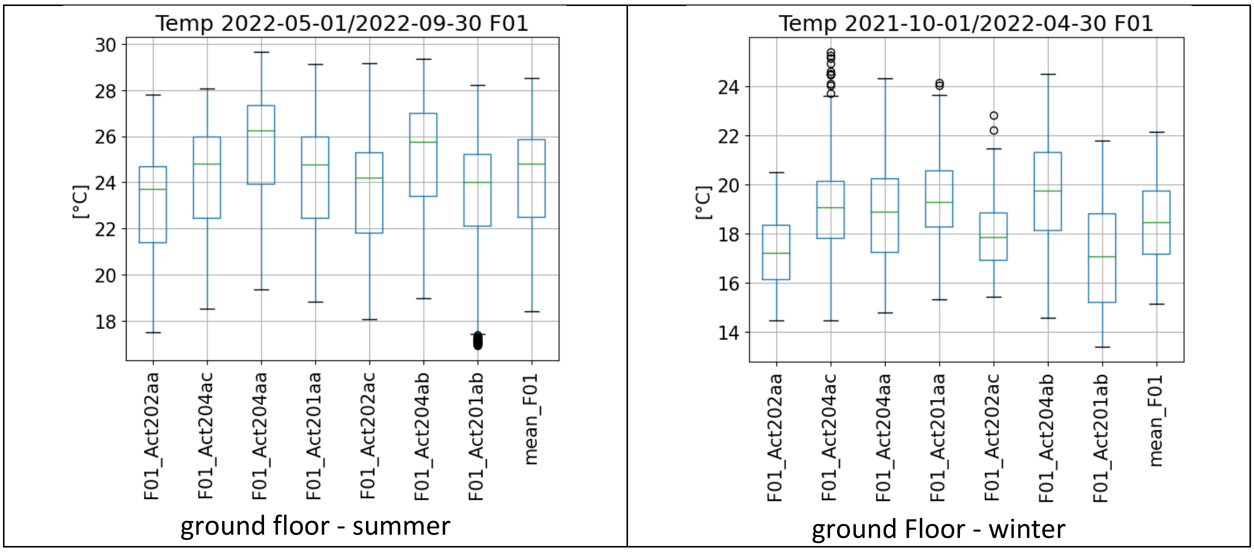


Figure 104 Percentage distribution of the number of hours per temperature classes – winter season school demo B2.1

The same analysis is extended to the second **school building B2.2**. Results, summarised in Figure 105 and Figure 106, underline homogeneous trends in the first floor in both seasons and a more spread behaviour in the ground one, such as expected due to the unconditioned basement and the presence of the entrance. Median values in summer are lower than in the middle school B2.1 being B2.2 an historical building with higher thermal masses in deep rock and brick walls and the absence of thermal insulation. In winter, the results are slightly more inhomogeneous with respect to the middle school, mainly because B2.2 has a different heating regulation system with single-room thermostats that are remotely activated only during the occupation. The middle school has one thermostat per heating zone involving several rooms. For example, the kindergarten has one thermostat.



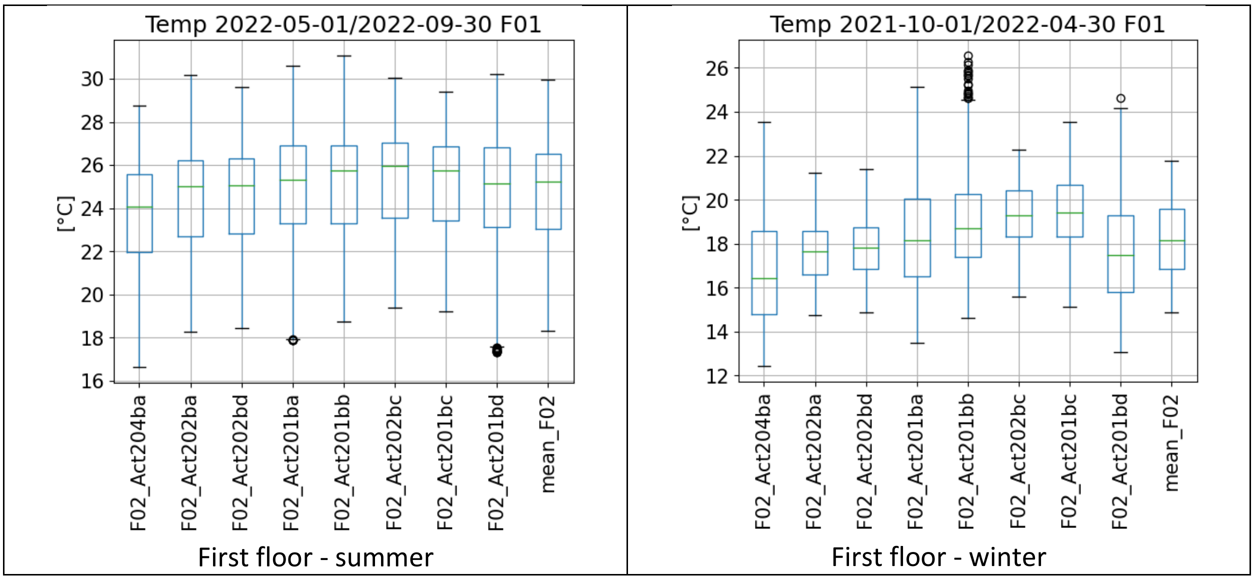


Figure 105 Statistical temperature sensor distribution for both seasons inside the school demo B2.2

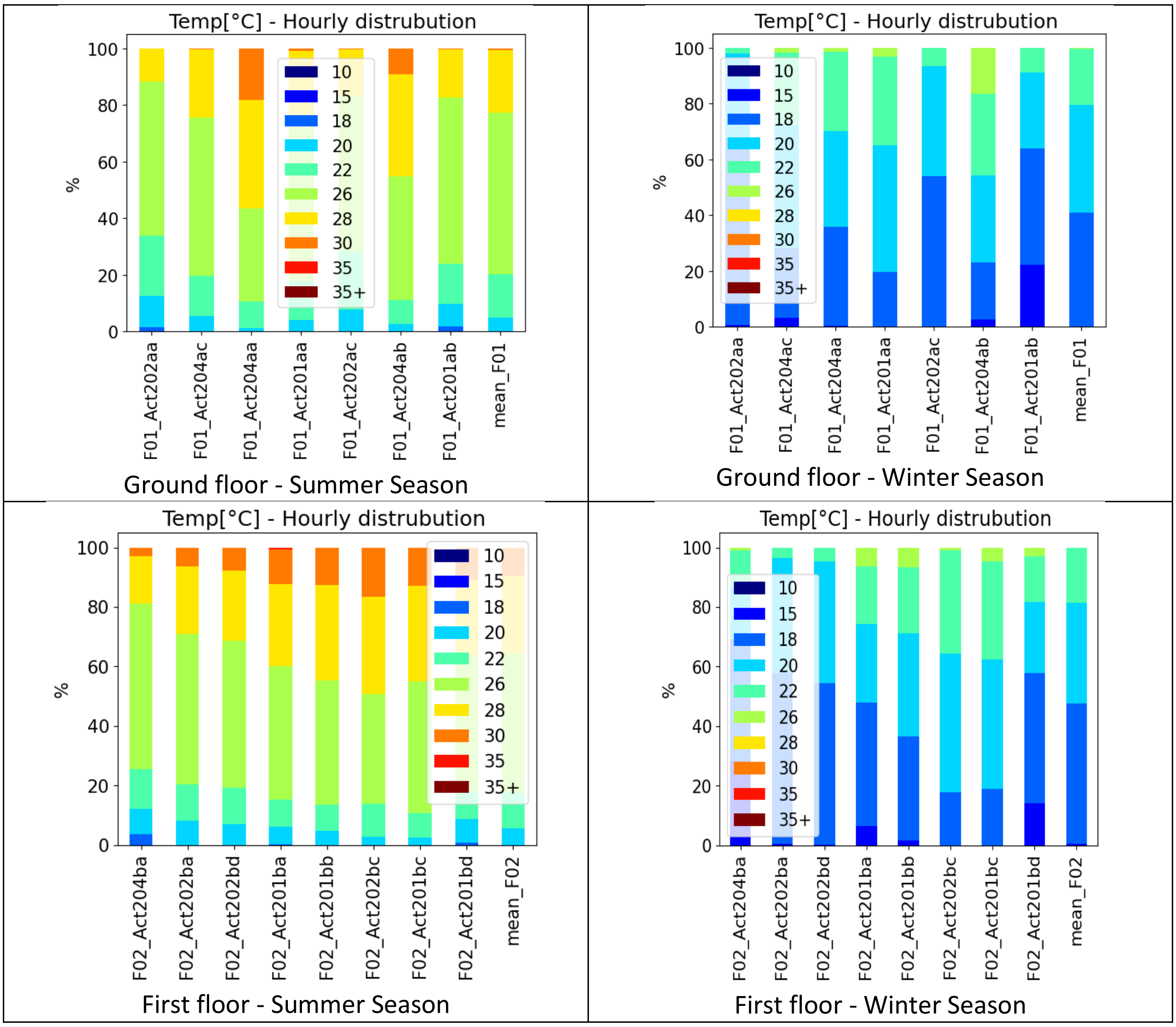
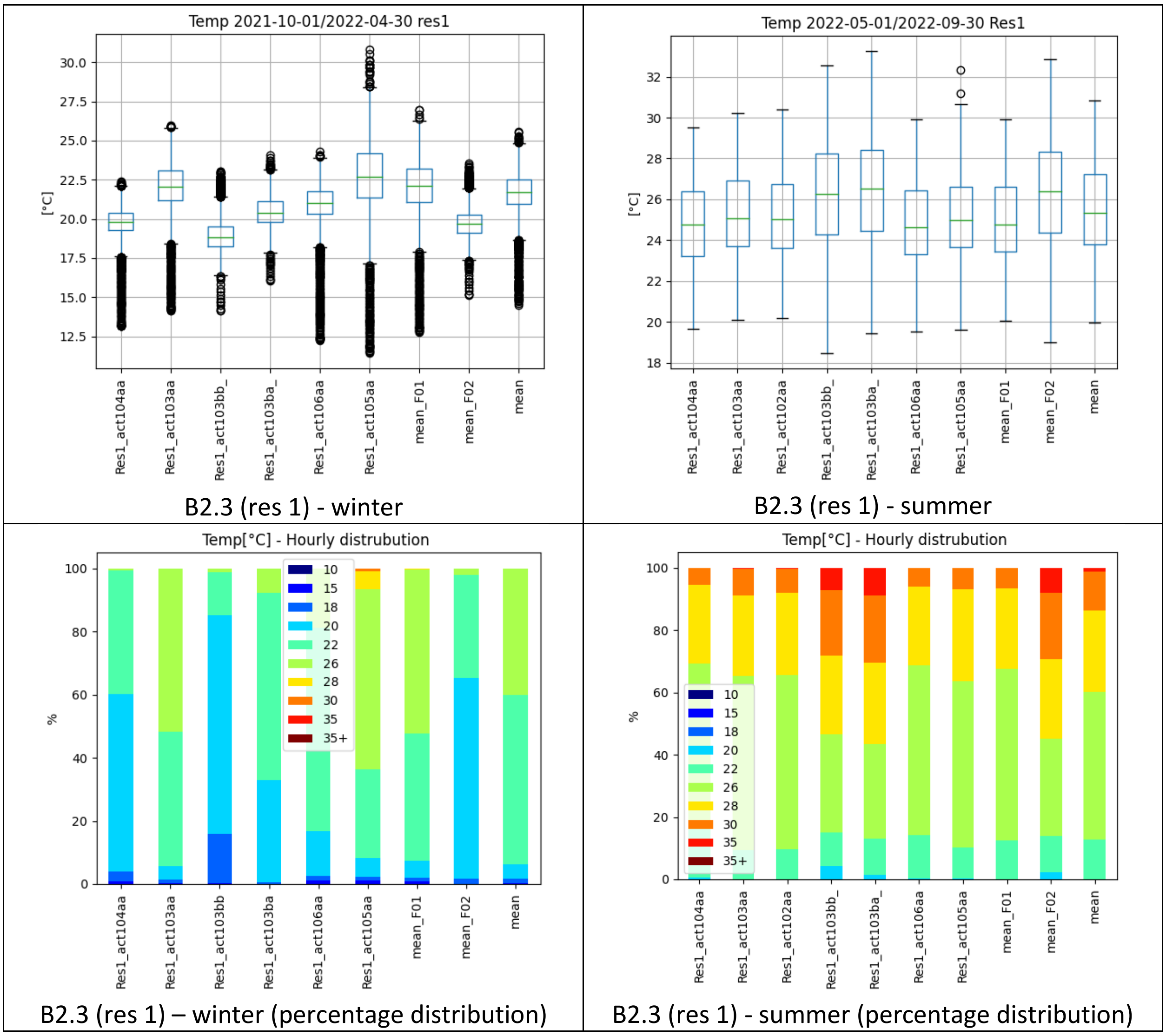


Figure 106 Percentage distribution of the number of hours per temperature classes – school demo B2.2

Considering residential buildings, Figure 107 reports results for demo B2.3. Results show that, in winter, temperature variations occur among the different rooms, especially on the living ground floor. This is due to the presence of a secondary bedroom (mainly not used) to the differentiation between the kitchen (act104aa), which is served by radiators and facing north, and the living room (act105aa), served by radiators and the smart fireplace facing south. The graphs suggest that in single houses may be important to detect the temperatures in the main rooms, especially when the zones do not have thermovalve on radiators and are interested in different usage profiles and orientations. This outcome is even more evident in old buildings with massive walls. In summer, the differences are smaller. The last floor is, as expected, hotter than the ground one, reversing the winter conditions, and the acrt103ba, facing south, is again slightly hotter than the act103bb facing north. Not having any cooling system and being the doors between zones left open in summer, temperatures are more homogeneous suggesting that a single sensor per floor can represent the general behaviour of the house.



B2.3 (res 1) - winter

B2.3 (res 1) - summer

B2.3 (res 1) – winter (percentage distribution)

B2.3 (res 1) - summer (percentage distribution)

Figure 107 Statistical temperature sensor distribution for both seasons inside the residential demo B2.3 (top) and percentage distribution of the number of hours – classified (bottom).

CO_2 sensor distribution

Regarding **demo B2.1** (middle school and kindergarten), a seasonal comparison in CO_2 value distribution is performed by comparing each room with the average values of the specific floor and the entire building. Results are shown in Figure 108 and Figure 109 using a box and whisker plot displaying the minimum, first quartile, median, third quartile, and maximum values, plus the outliers plotted as separate dots. Boxes show the range between the first and third quartiles. Each table focuses on a specific season to detect variations due to ventilation for IAQ during the heating and the neutral/fee-running periods.

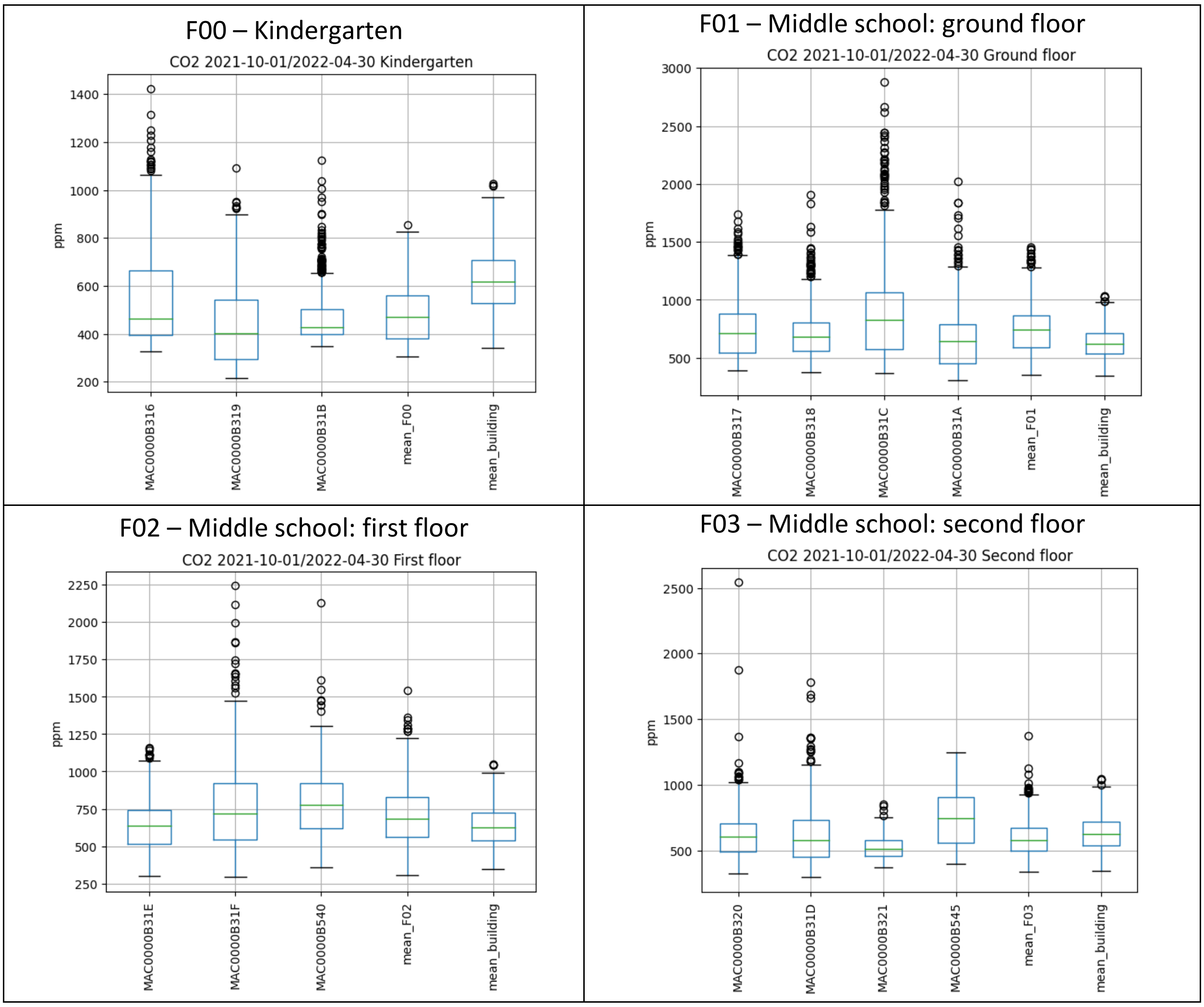
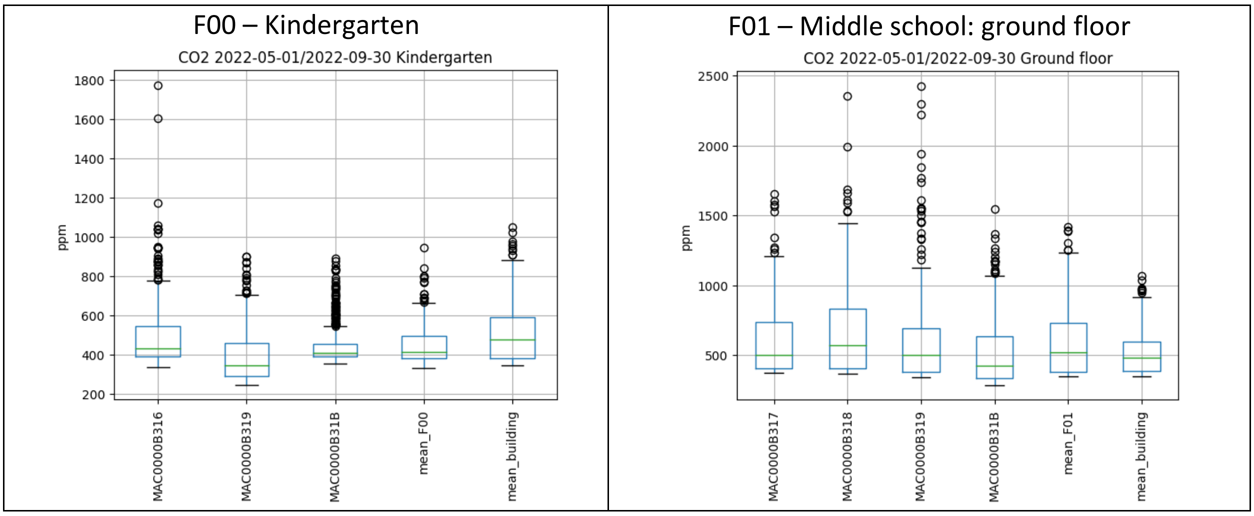


Figure 108 Demo B2.1 box and whisker plots reporting CO2 measured statistics for each room. *Results are plotted per floor, including average floor values and the total building averages. Winter season from October 2021 to April 2022.*



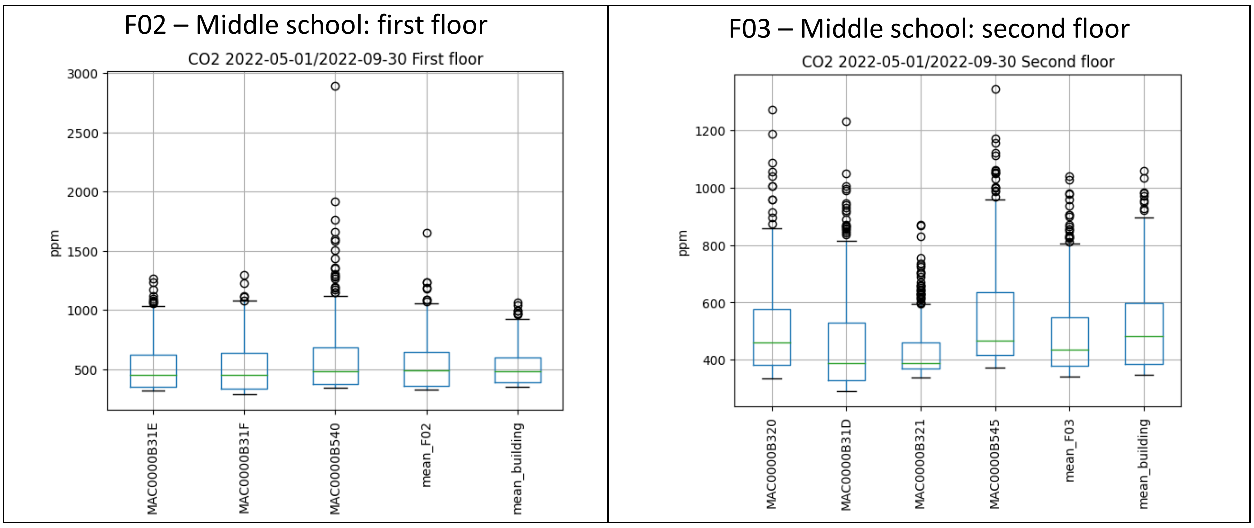
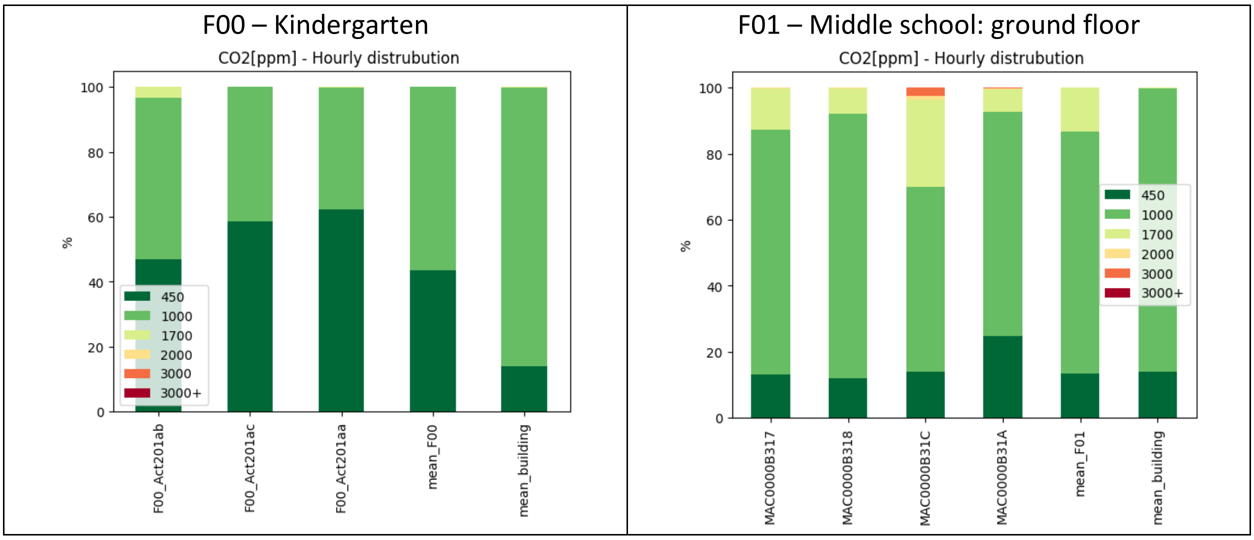


Figure 109 Demo B2.1 box and whisker plots reporting CO2 measured statistics for each room. *Results are plotted per floor, including average floor values and the total building averages—free-running season from May to September 2022.*

The analysis shows a general homogeneity in CO_2 statistical representative values (boxes and median), although CO_2 levels are maintained quite low for a free-running building due to a strict internal Covid recommendation policy supporting long window opening periods. Some probes are potentially envisaging low-battery periods showing too low minimal values in respect to environmental conditions – see for example B319. This has been solved during the second monitoring year by substituting batteries, not considering that probe calibration processes may be aligned with replicability costs. Nevertheless, the analyses of IAQ levels are not only based on averages, but they primarily include peak detection to avoid medium term exposition to high CO_2 concentration. Looking at the outliers it is visible a large potential variation suggesting that for IAQ a probe per the most used classrooms may constitute a good compromise to also support IAQ control such as proposed in the DMV and natural ventilation section above. The distribution of CO_2 levels in the percentage of total hours for different thresholds is also reported to give consistency to the statistical variations – see Figure 110 and Figure 111 considering the winter and the summer periods. Results confirm the previous outcomes, but the limited number of hours outside the 1000ppm threshold in the majority of classrooms may suggest that in that building, under this rigid window opening protocol, sensors may be used for short term inspections and furthermore fixed sensors may be positioned in critical cases to reduce installation and maintenance costs.



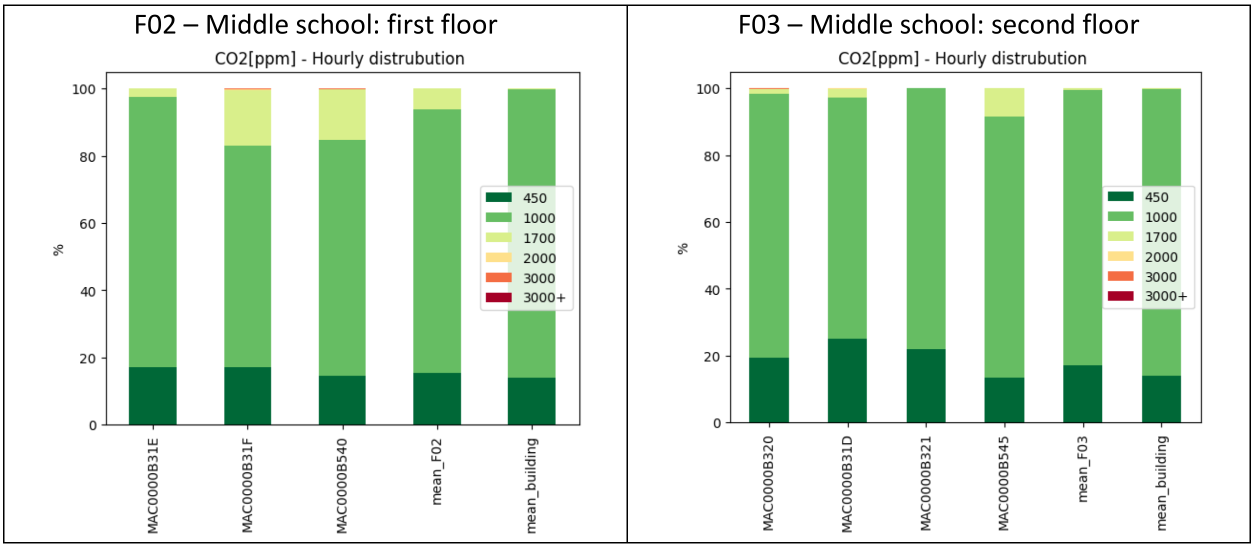


Figure 110 Demo B2.1 bar graphs reporting the CO2 measured percentage of hours per different concentration classes for each room. ***Results are plotted per floor, including the floor values and total building averages. Winter season from October 2021 to April 2022.***

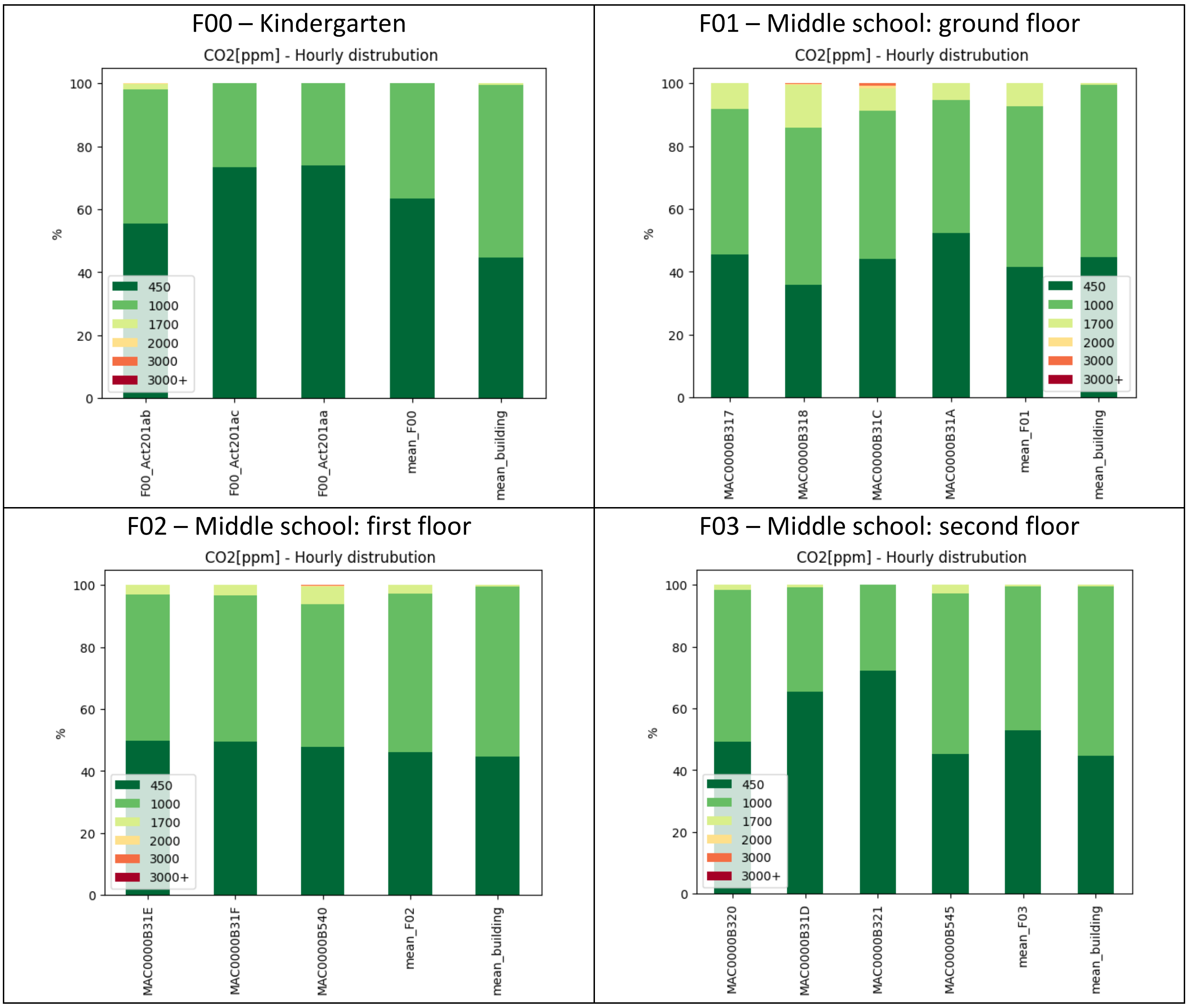


Figure 111 Demo B2.1 bar graphs reporting the CO2 measured percentage of hours per different concentration classes for each room. ***Results are plotted per floor, including the floor values and total building average—free-running season from May to September 2022.***

The same analysis is performed for the second school demo building, i.e. **demo B2.2** – high school. The results of Figure 112 are partially comparable with the ones previously discussed. In this demo, higher variations between classrooms are detected, with some cases in which the median CO_2 level is even higher than 1000 ppm. This behaviour suggests that, differently from the previous school in which windows were left almost open all the time due to Covid-specific building recommendations, different natural ventilation behaviours are applied. For this demo, it is suggested the activation of the sensor visual alert in order to suggest to students when opening windows reducing CO_2 peaks but limiting heat losses in winter. Also in this case, it can be possible to consider a reduction in the number of sensors by focalising them in the most critical cases that overpass 1000 ppm with their boxes.

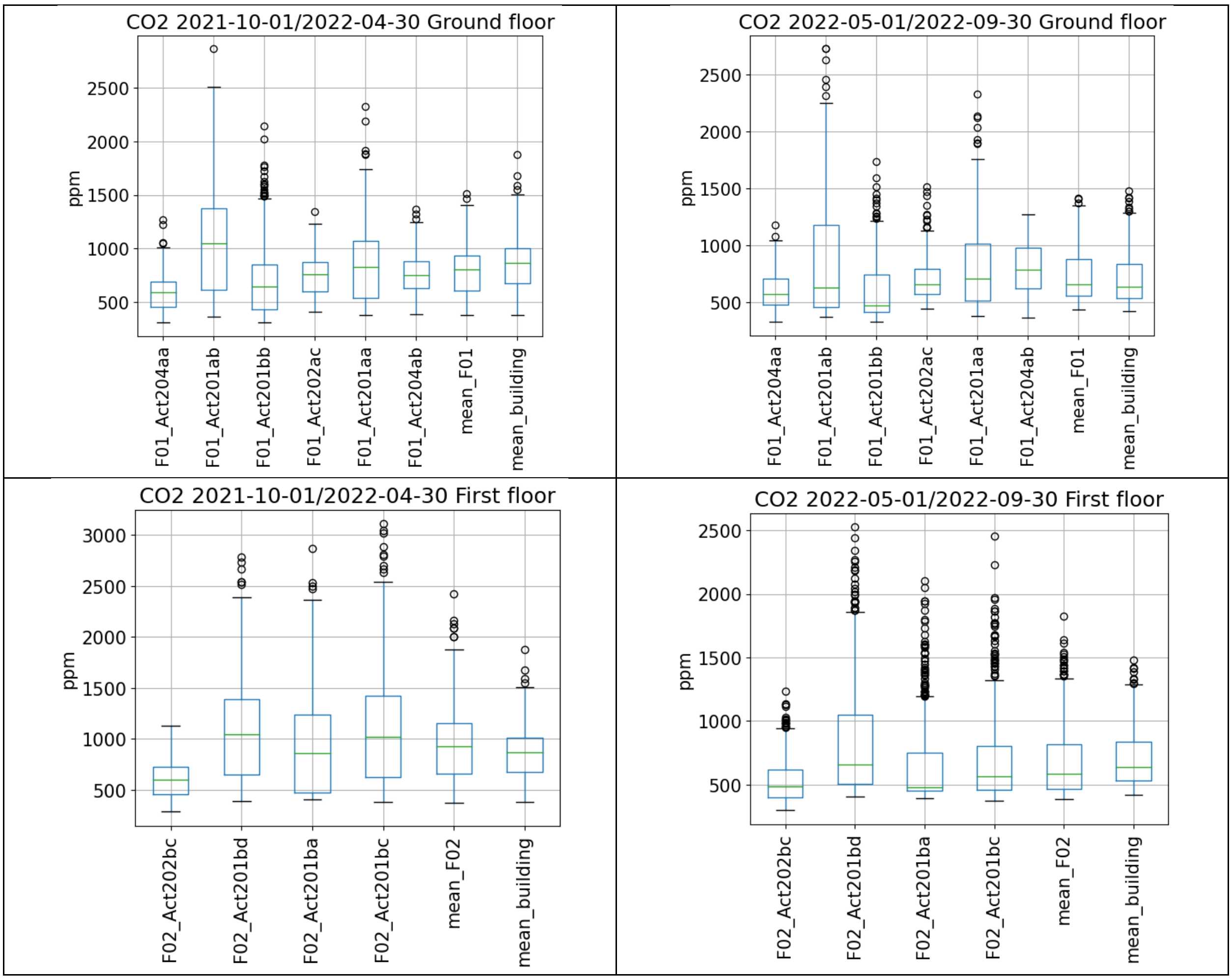
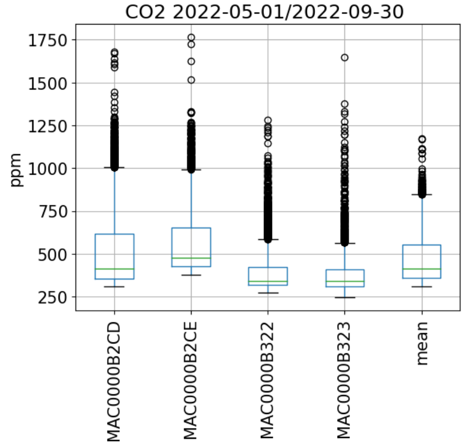
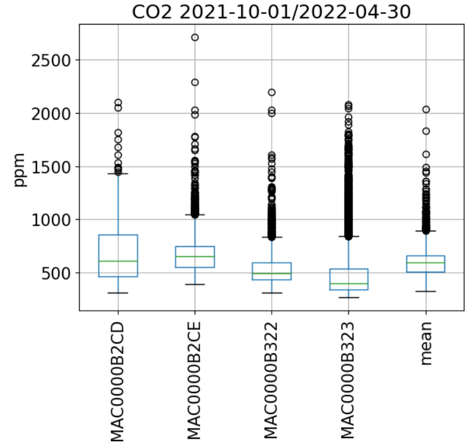


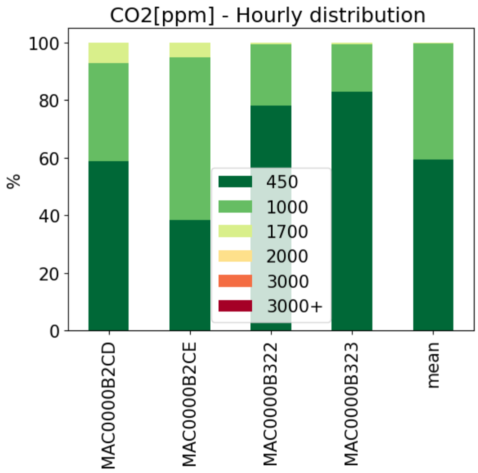
Figure 112 Demo B2.2 box and whisker plots reporting CO2 measured statistics for each room and average building values reporting aggregated values for (left) the winter seasons from October 2021 to April 2022, and (right) the summer season from May to September 20

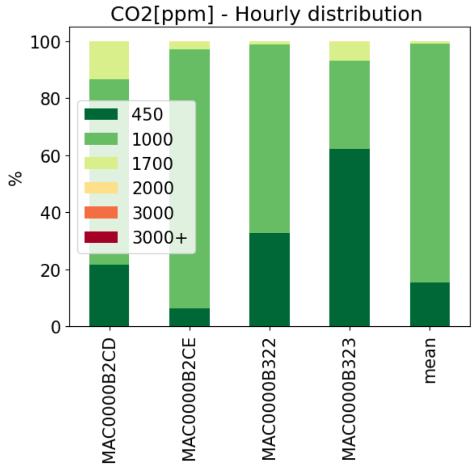
Regarding the residential cases, only **demo** cases **B2.3** and **B2.4** have more than a CO_2 sensor, allowing comparison. In particular, the demo B2.3 has four sensors positioned in the living room, study room and the two main bedrooms. Similarly, demo B2.4 has 3 CO_2 sensors, one covering the living space and the other two the main bedrooms. Figure 113 reports measured results for both demos.

Demo B2.3

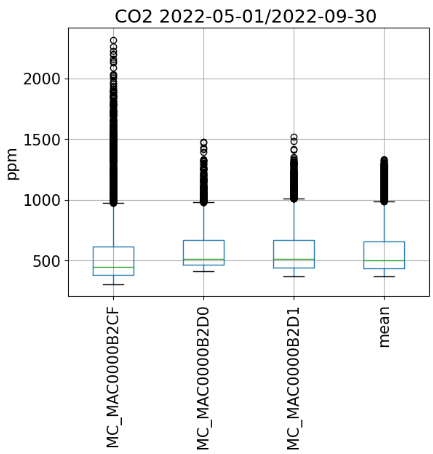


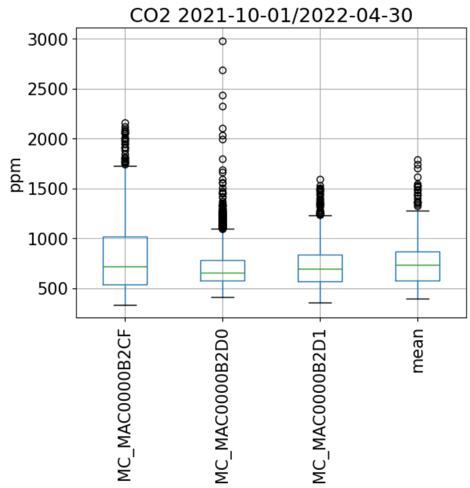






Demo B2.4





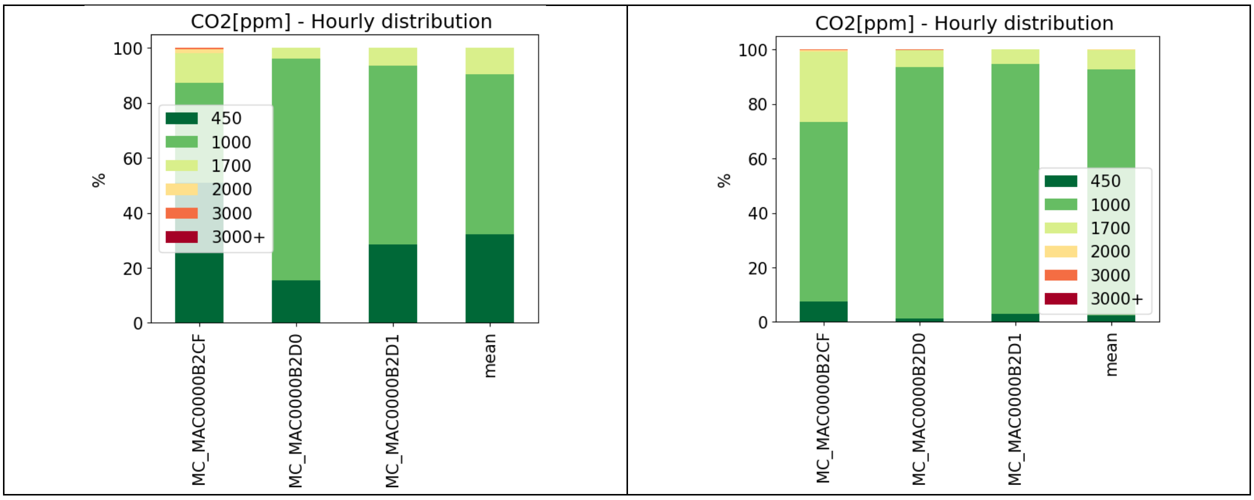


Figure 113 Demo B2.3 (above) and demo B2.4 (below) box and whisker plots reporting CO2 measured statistics for each room and percentage bar plots reporting CO2 measured distributions *for (right) the winter seasons from October 2021 to April 2022, and (left) the summer season from May to September 2022.*

For residential buildings, it is underlined, such as expected, a variation between night and daily spaces is underlined mainly in the outliers. This suggests defining the number of CO_2 sensors on the basis of the end-user expectations, such as improving the IAQ levels during the daytime or evaluating CO_2 peaks in bedrooms during sleeping times. Differently by schools or other public buildings, in residential spaces IAQ evaluations may be considered an extra feature, and the positioning of sensors may be justified together with users to support a deeper knowledge of building performances and a mean to support controlled manual ventilation.

E-DYCE verification comments

Summarising results, temperature sensors may be potentially reduced by focalising their presence in the main rooms for residential spaces and representative rooms for each primary activity in school buildings. Additional temperature sensors may be helpful to understand specific phenomena (e.g. temperature behaviours in a confining, un-conditioned space or bathroom/corridor behaviours). Still, they may be positioned for particular purposes and eventually used in focalised monitoring campaigns. A general suggestion may be distributing sensors in line with the heating control logic to verify local performance distributions. Concerning CO_2, recommendations differ with respect to the installation scope: in schools, a room-per-room logic may be useful to detect, in occupied classrooms, the CO_2 variations, suggesting actions and allowing to evaluate local performances that may differ, in the short run, significantly. A reduced number of sensors located in critical rooms can generally allow punctually improving self-actuation, but a per-room approach is needed to apply IEQ protocols. Differently in residential demos, the CO_2 distribution may be defined after the inspection and a discussion with tenants about their habits. We suggest having at least one CO_2 sensor in the most used daily room and one in the main bedroom, especially if these two zones are separated. A single sensor may be considered if doors are left open and if similar ventilation schemes are adopted. In residential cases, it is also essential to minimise sensors for additional reasons: reduce installation and maintenance costs, allow the user to take advantage of measured data without over-pressing them with exceeding information, and increase the acceptability for sensor installation.

4.4 Applications in Switzerland demo sites (B3)

4.4.1 Monitored data identification for applied extended functionalities

The 4 Swiss case studies show different levels of monitoring of different levels of interest. Following the D5.2 results regarding the difference between monitored (operational) data and adapted simulation of the buildings, the focus was put on operational data analysis. Indeed, despite the existence of both dynamic models and monitoring in the buildings, none of them could be implemented in the PREDYCE tool. The reason for this was the lack of communication means of monitoring and the complexity of the dynamic models. The monitoring systems in the other 3 Swiss demonstration buildings are not sending data to FusiX because of the absence of API solution. Despite numerous demands on our side, the technology provider never developed such a communication. This is a significant indicator of how technical difficulties may be a serious barrier to the automatic E-DYCE system and stresses the need for an alternative technology-neutral approach to the methodology application.

Regarding Centurion, the monitoring is connected to FusiX but the issue came from the size of the dynamic model. The size of the building didn't allow a compatible model with PREDYCE. As the focus was put on buildings with fluid connection, it was decided to focus on IEQ impact of ventilation systems for the different Swiss case studies. The extensive monitoring available in Loex and Centurion allowed for good data quality. The focus of the following sub-sections will be the IEQ KPI's analysis and the impact of the ventilation systems on the IEQ in the different buildings.

4.4.2 Extended IEQ analyses and data analysis

During the project, 4 buildings were monitored with different levels of monitoring. Innovation in the monitoring systems was brought by the use of monitoring 'suitcases'. These suitcases use LORA bandwidth communication to collect the different probe signals in the building. This allows for quick and flexible installation in the different spaces of the building. The issue observed with this kind of instrument however is the range of the LORA signal. In building B1.3, the building was too large for complete monitoring. The focus was put on one alley to fit the range of the LORA signal. Even there, when installing the LORA antenna on the 3rd floor, some probes on the 6th or 7th floor struggled to establish the connection, taking up to a month to finally connect and send monitoring data. Fortunately, this happened on only one of the 22 installed probes.

In addition to this, the CO_2 probes were programmed to not reset to 400 ppm every 2 weeks. This standard procedure on CO_2 probes was thought to be a potential source of error in the case of spaces with bad air quality and low to no air renewal. However, after a year of measurement, some probes started to show drifts in the CO_2 measurements. These drifts were all identified as negative drifts, i.e. the value in ppm was depreciated by the counter. After exchanging with the probe manufacturer, it was identified that the drift is linear and can therefore be corrected in post-processing of the data. The test is done so that for each week if the minimal value is below 400 ppm, all values are incremented by the difference between 400 ppm and the minimal value over the week. This data manipulation could be avoided by leaving the initial setting of recalibration when monitoring a space where a minimum air renewal is expected.

An illustration of the faulty data and the corrected curve can be seen in Figure 114. We observe that the amplitude of the peaks stays equivalent but the maximum value (which is of interest in our case) is affected by the correction.

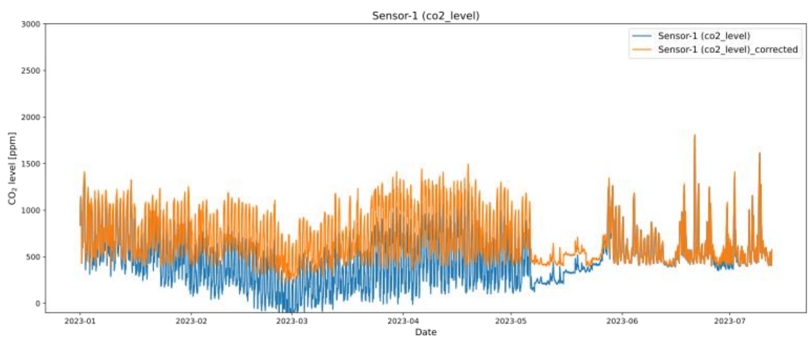


Figure 114 Sensor 1 reading for CO2 measurements before and after correction of the drift in post-processing.

As the CO_2 level was not measured in all desired buildings at the same period, humidity was also used to compare the different indoor environmental quality. To allow for comparison, the EN16798 standard defines 3 categories of comfort (Category I between 30 and 50%, Category II between 25 and 65% and Category III between 20 and 70%). Figure 115 shows a histogram of relative humidity measurements in a room in Loex building in 2022. The vertical lines show the comfort class limits according to EN16798 standard.

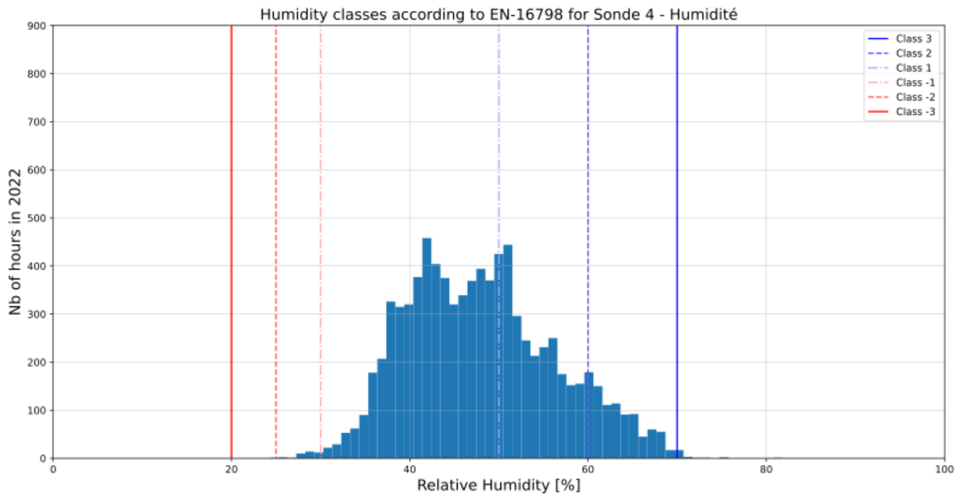


Figure 115 Histogram of relative humidity measurement for probe number 4 in a bedroom of Loex building

This histogram allows for a comprehension of the general behavior of the space monitored. However, no information can be found regarding the periods when the humidity is too high for example. To solve this issue, carpet-plots of the humidity class were produced for the different years of available data, mainly 2022 and the first half of 2023. The carpet plot visible in Figure 116 can be compared with the previous histogram of Figure 115 as it represents the hours where the measurement is in the different comfort classes, with class I in white. The carpet plot allows us to observe which period of the year shows different behaviors or if certain behaviors are repeating at certain times of the day. For example, on probe number 4 in the building Loex, we observe that the period of October 2022 was showing high measured humidity in the bedroom, with values even exceeding the Class 3 limit of comfort. Although the high humidity values are mostly measured in the autumn season, the carpet plot shows that the humidity in the monitored space is relatively high during the whole year.

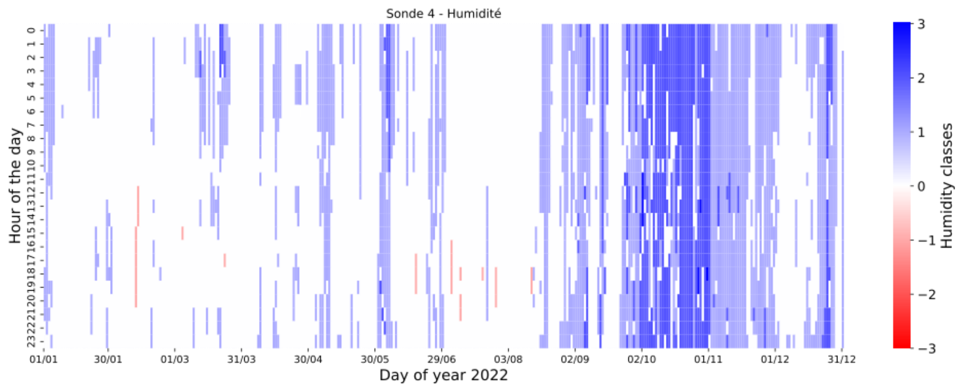


Figure 116 Carpet plot of the humidity comfort class of probe number 4 in Loex building during the year 2022

Finally, the last monitored IEQ quantity is the indoor air temperature. As for humidity, carpet plots of the temperature class according to EN16798 were produced for individual sensors. (see Figure 118) As the temperature comfort classes depend on the outdoor mean temperature of the last 48 hours, the histograms concerning the comfort classes were produced differently. It was decided to show the difference between the measured indoor temperature and the comfort temperature. The output can be seen in Figure 117. Vertical lines show the limits of the comfort classes. The 0 of the x-axis represents the comfort temperature according to EN 16798.

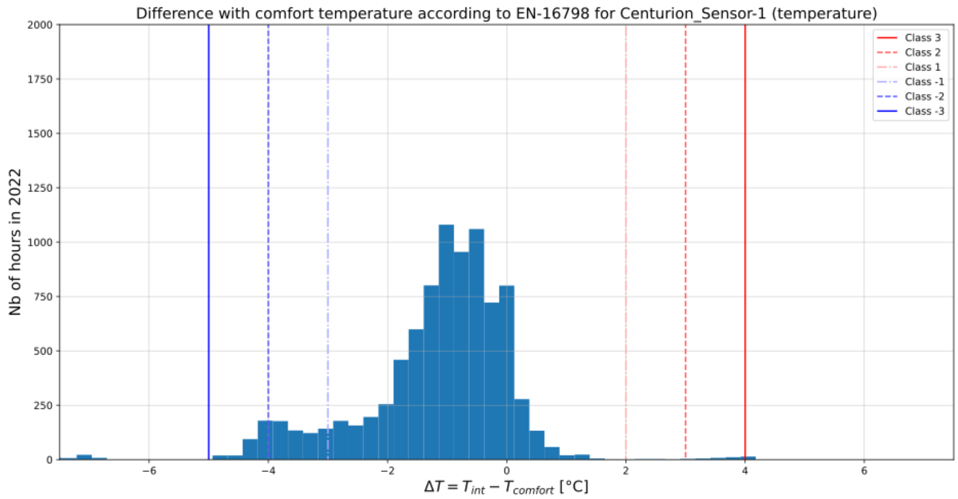


Figure 117 Histogram of the difference between the EN16798 comfort temperature and the measured indoor air temperature for probe number 1 in Centurion building

Such visualization allows a good understanding of the thermal comfort in the monitored space over the year. Again, it can be useful for further comprehension to understand the behavior over time. This can be done by analysis the carpet plot of the thermal comfort classes of the sensor as shown in Figure 6.

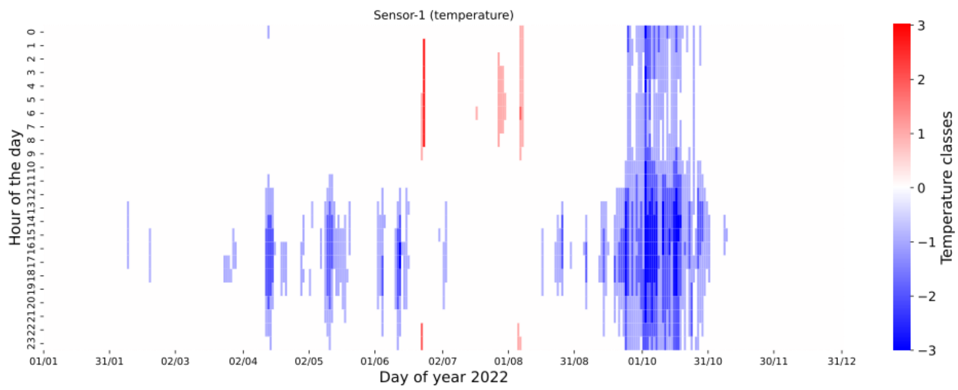


Figure 118 Carpet plot of the temperature comfort classes over the year 2022 for sensor 1 in Centurion building.

4.4.3 Renovation roadmap – Mechanical ventilation changes in different multifamily buildings

The focus of this section will be the description of the ventilation changes in the different Swiss case studies. The comparison of their effect on indoor environment quality and energy efficiency in the buildings is the focus of the following section.

During the project time, the building owner of Centurion decided to change the ventilation system of the whole building. The change occurred in April 2022. The new ventilation system consists of VCZ ventilators from Aereco, working with a constant pressure differential. This allows the air flow to be modulated according to the opening size of the air inlets and outlets in the rooms. The inlets and outlets have different air flow rates depending on the relative humidity of the local (see Figure 119). This type of ventilation should allow modulation of the air flow rate to the occupation. Unfortunately, the IEQ monitoring data have been available only since early 2022. Therefore, only 14 weeks are available to compare the similar period of the year before and after the change of ventilation. Regarding energy monitoring, the heat counter that was planned for the building to be installed mid-2021, only got connected on the 5th of May 2022. The comparison for energy will therefore have to be done with the energy bills of the heating system.

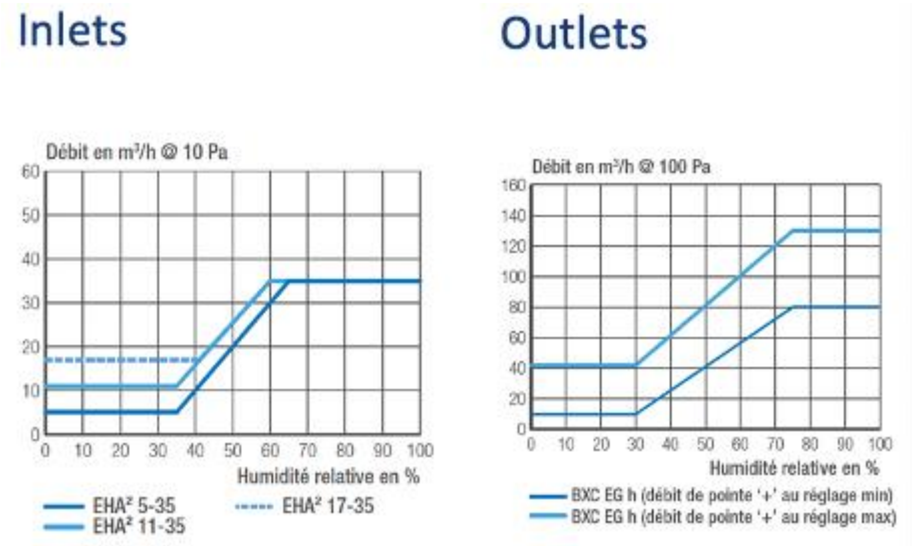


Figure 119 Air flow rate variation with respect to relative humidity for the inlets and outlets installed in Centurion

Following the IEQ monitoring of the Loex building, it was observed that the CO_2 level in some rooms of alley 17 was above all recommendations (reaching levels above 3000 ppm, see Figure 120). The schedules of ventilation were programmed with a night stop of the whole ventilation system from 10 p.m. to 6 a.m. By the time the owner gave its green light for the modification of the ventilation schedule, it was the first of November 2022 and the schedules were changed to have low-speed ventilation all night long. In May 2023, an experiment was conducted by introducing a shorter night stop but only on alley 17 where most of the probes are. The stop would be for 2 hours, from 4 am to 6 am. The idea was to evaluate if such a small stop would influence the IEQ. In fact, the initial reason for the ventilation stop at night was the energy savings that this would create, both electrical (ventilators) and heat (due to air renewal).

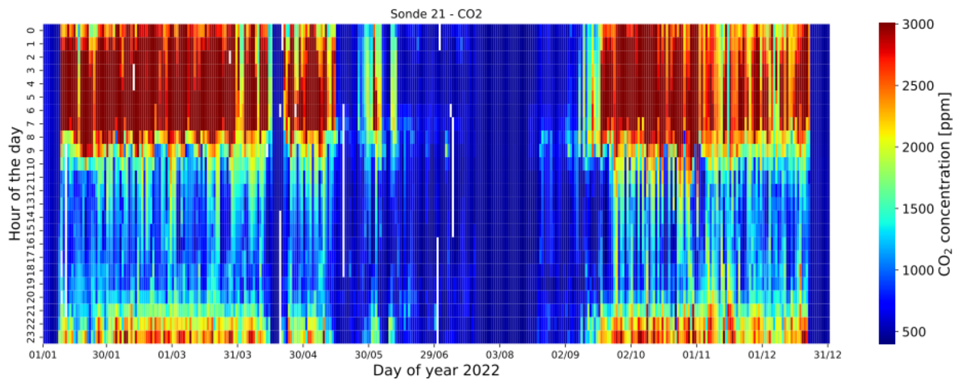


Figure 120 Carpet plot of the CO2 concentration in a room of Loex building.

In the building Grand-Pièce, the installed ventilation system is a double flux with heat recovery. Temperature and relative humidity are monitored in most apartments. Available CO_2 sensors were used at the beginning of 2023 to monitor the level in different bedrooms of the building. However, only 6 sensors were used to characterise 5 bedrooms indoor conditions and unfortunately, 2 sensors had issues when recording the data, leaving 3 bedroom sensors and one sensor in the exhaust air vent.

The different monitoring in the buildings allows for comparison of pre and post-intervention to a certain extent. Recommendations of use to the owner were made following the analysis of the data. The analysis of the performance of the different ventilation systems and their comparison is performed in the next sub-section.

4.4.4 Post-intervention evaluation – Change of ventilation

To summarise the different ventilation systems monitored, the following Table 19 Swiss case studies and the different ventilation systems installed during the project Table 19 was produced. It summarizes the available monitoring per building and ventilation scenario in addition to outlining the different intervention dates.

Table 19 Swiss case studies and the different ventilation systems installed during the project

Building	Ventilation system	Date of installation	Date of interruption	Monitoring of IEQ	Monitoring of energy
 Centurion	Single flux (extraction only)	Before the project start	4.4.2022	T, Hr and CO_2 hourly, started in 1.1.2022	Monthly (energy bills)
	Hygrovariable extraction and inlets	4.4.2022	Until now	T, Hr and CO_2 hourly	Hourly from 5.5.2022
 Loex	Single flux, two speed with night stop (22-6)	Before the project start	1.11.2022	T, Hr and CO_2 hourly	Weekly aggregated
	Single flux, two speed, no night stop	1.11.2022	No interruption except one alley (8.5.23)	T, Hr and CO_2 hourly	Weekly aggregated
	Single flux, two speed, no night stop except in one alley (3-6)	8.5.2023	Until now	T, Hr and CO_2 hourly	Weekly aggregated
 Grand-Pièce	Double flux with heat recovery	Before project start	Until now	T, Hr hourly CO_2 hourly between 21.1.23 and 27.4.23	Monthly (bills)

4.4.4.1 Ventilation change in Centurion

The first building to focus on will be Centurion. The evaluation will first try to outline the difference in indoor environment quality. Indeed, the hygrovariable ventilation depends on the relative humidity of the indoor spaces. The effect of the ventilation should be straightforward in humidity measurements. To compare both periods, before and after the change, a boxplot of the relative humidity measurements per week of the year was computed for the two periods (see Figure 121). For a better understanding, the comfort classes are drawn. It can be observed that the boxplot before the ventilation change tends to reach class II comfort in their interquartile values for a high number of weeks. In addition, the minimal value of the boxplots can sometimes reach values outside the class III limit. This outline airflow rates are too important for the ventilated space. After the change, interquartile values hardly reach values outside the class I limits. In addition, the maximum and minimum values stay within the class III limits. It must be noted that the analysis was performed using iso calendar weeks. This explains the existence of values for week 52 on the right side of the plot. This corresponds to early January measurements. From the analysis, it is possible to conclude that the IEQ comfort is higher after the change, at least concerning humidity.

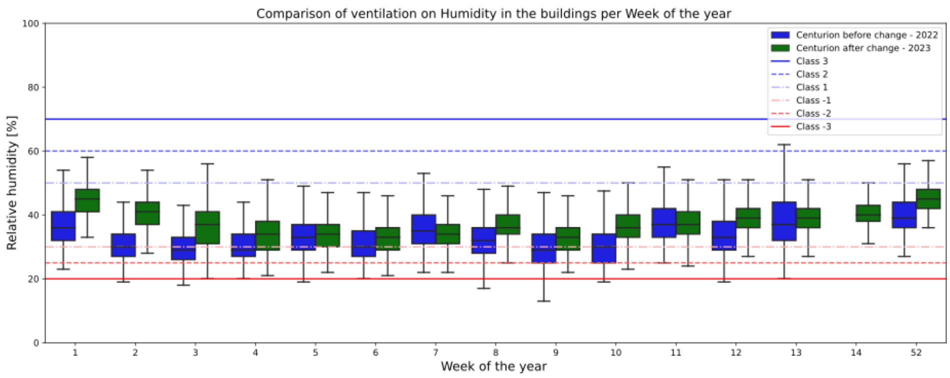


Figure 121 Boxplot of relative humidity measurement in Centurion for the different weeks of the period. Horizontal lines represent the comfort classes according to EN 16798

To confirm this statement, an analysis of the CO_2 measurements can also be made. The boxplots by week of the year still show good improvement in the CO_2 concentration in the monitored space (see Figure 122). The interquartile reduces after change and the maximum values are considerably lower after the ventilation change. The interquartile range of the measurements after the change even stays below the threshold of 1,000 ppm, meaning that 75% of the data stays below this threshold after the change. CO_2 concentration highly depends on occupation and ventilation rate. The variation over a day and even a week can be important, with locals often reaching the minimum and maximum values multiple times a day. By comparing the boxplots by hour of the day, interesting information can be extracted (see Figure 123) Indeed, the standard occupation schedules can be understood from such measurements. Going back to the comparison of the ventilation, we observe a strong difference during the ‘occupied’ hours (i.e. 8 pm to 8 am). Still, the values are considerably less important even during the rest of the day, outlining an efficient ventilation modulation to the occupation.

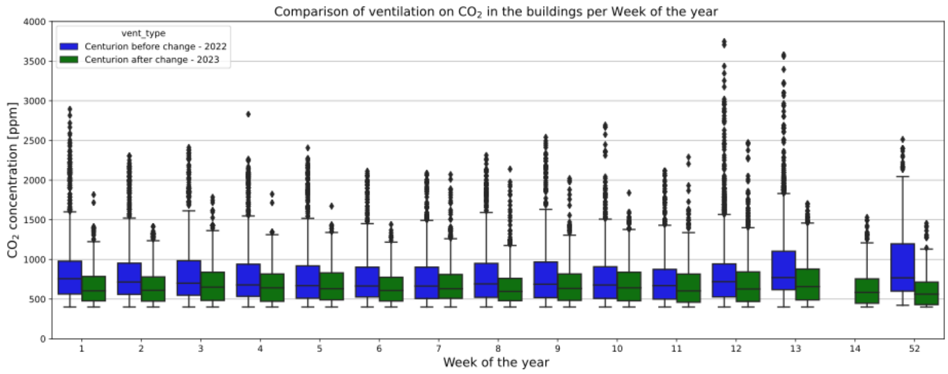


Figure 122 Boxplot of the CO2 concentration in Centurion for different weeks of the year. The outliers are shown on the boxplot

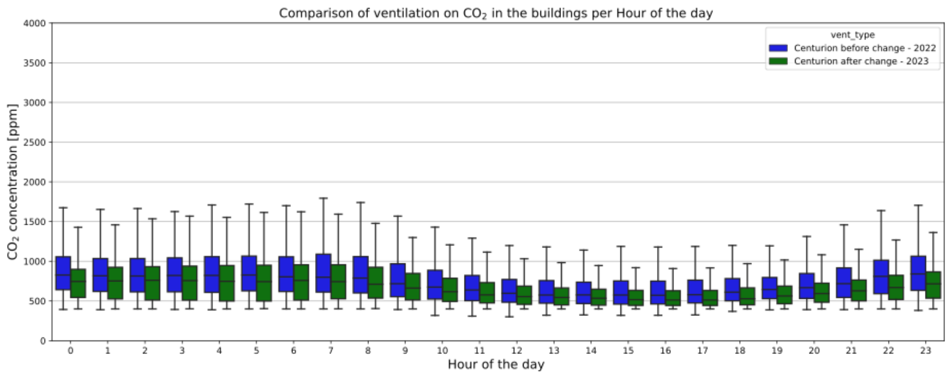


Figure 123 Boxplot of the CO2 concentration in Centurion by hour of the day. The outliers were here hidden for better readability

After confirming the improvement of comfort in both relative humidity and CO_2, the remaining IEQ quantity to evaluate is the indoor air temperature. Temperature comfort, as explained in a previous subsection, is not straight forward and depends on outdoor conditions. Therefore, comparing boxplots performed during two different years with different external conditions could lead to errors in interpretation. However, both considered periods are in the heating season where the indoor temperature is more influenced by the heating system than the outdoor conditions. When comparing the similar boxplots as done for the previous quantities, no conclusion can be made (see Figure 124)

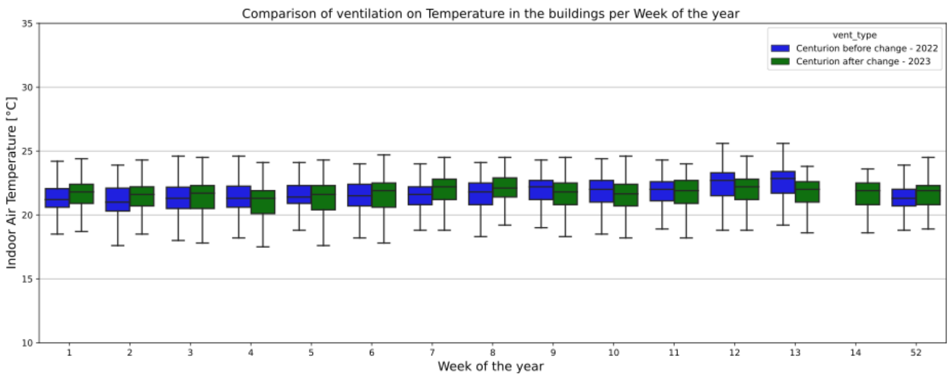


Figure 124 Boxplot of the indoor air temperature for Centurion by week. The outliers were hidden of the plot.

The missing information on such a graph is the limit of the comfort classes. As they vary with the external temperature, they cannot easily be shown on the boxplot, unlike for humidity. However, it is possible to compute the difference between the measurements and the expected comfort temperature. Histograms of such computation can be seen in Figure 125, showing the indoor temperature difference with the comfort temperature and allowing us to see if measurements exceed the comfort limits defined by EN 16798. When looking at the results, no clear improvement can be outlined. On the contrary, we observe a tail to the histogram, showing that a significant amount of measured points exceed the lower comfort limit. The amount of datapoints in these limits is low in comparison with the rest of the data. Looking in detail, one sensor seems to have been placed outside in 2023. Except for this minor observation, the analysis of the indoor temperature doesn't support any improvement in the thermal comfort of the building. It must be stated that the comfort before the ventilation change was already sufficient according to the monitored data.

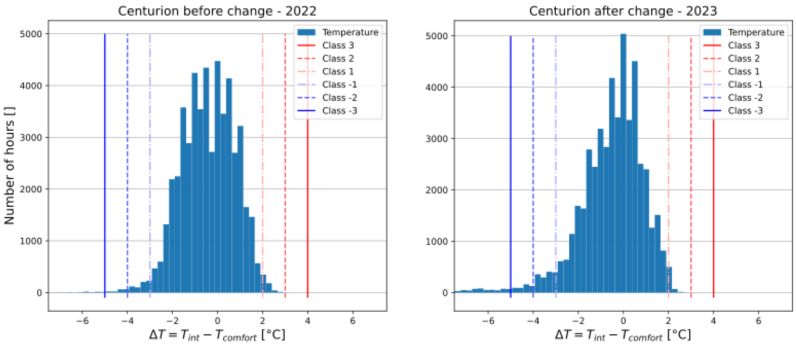


Figure 125 Histograms of the difference between the indoor air temperature and the comfort temperature for the two considered periods

The second aspect of the impact of a ventilation change, after IEQ, is the energy consumption for heating. As stated in the previous subsection and in Table 19, the heat counter on the gas heater was only installed after the ventilation change occurred. The comparison must therefore be made on the energy bills. The bills were shared by the building owner and cover the period between 15/12/2020 and 31/05/2023. Therefore, we have more than a year before and after the ventilation change. As energy consumption strongly depends on outdoor consumption, a possible way of analyzing the data is the energy signature. Although this is usually performed with weekly aggregated data, it can also be done with monthly value. The issue is the loss of information in the monthly averaged temperature. Additionally, the number of data needed for comparison is multiplied by 4 the needed time for measurement if monthly values are used. The comparison between the energy signatures before and after the ventilation change is shown in Figure 126.

The comparison of the energy signature points doesn't show any improvement in energy consumption. Their alignment is like the points before the ventilation change. No improvement can be concluded from the energy signature. In Geneva, there is an obligation to follow the heat consumption of large buildings. The "Indice de dépense de chaleur" or "IDC" represents the normalized final heat consumption of a building. Its computation follows strict rules and is normalized by heating degree-days[15] The computation is usually performed in MJ/m^2 and is done every year. By using the tool to compute the IDC value for each 12-month interval available with the energy bills, we can observe the evolution of the indices (see Figure 127). The evolution of the "indices" evolution shows an energy saving of around 20 MJ/m^2 (5.5 kWh/m^2), i.e. around 5%. Such a small saving would hardly be seen on an energy signature.

[15] https://www.ge.ch/document/directive-relative-au-calcul-indice-depense-chaleur (Directive relative au calcul de l'indice de dépense de chaleur » , OCEN, 20.10.2022)

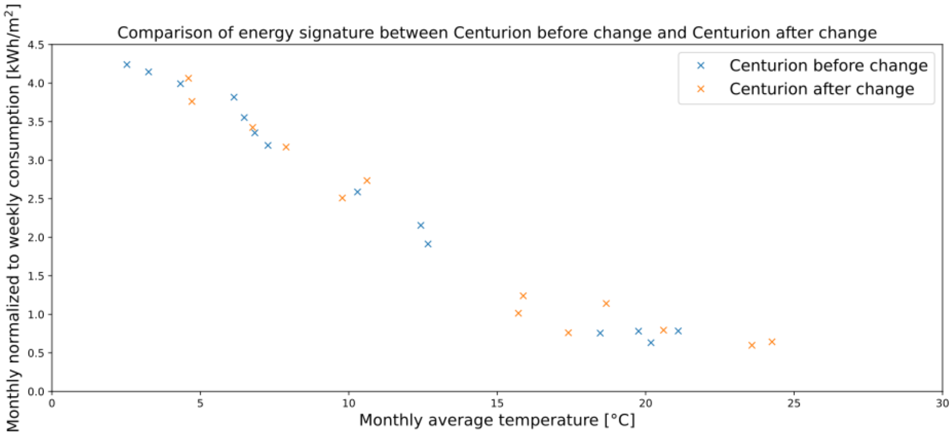


Figure 126 Monthly energy signature for Centurion gas heater, before and after the change of ventilation. The consumption is aggregated as weekly values and normalized by the heated floor area

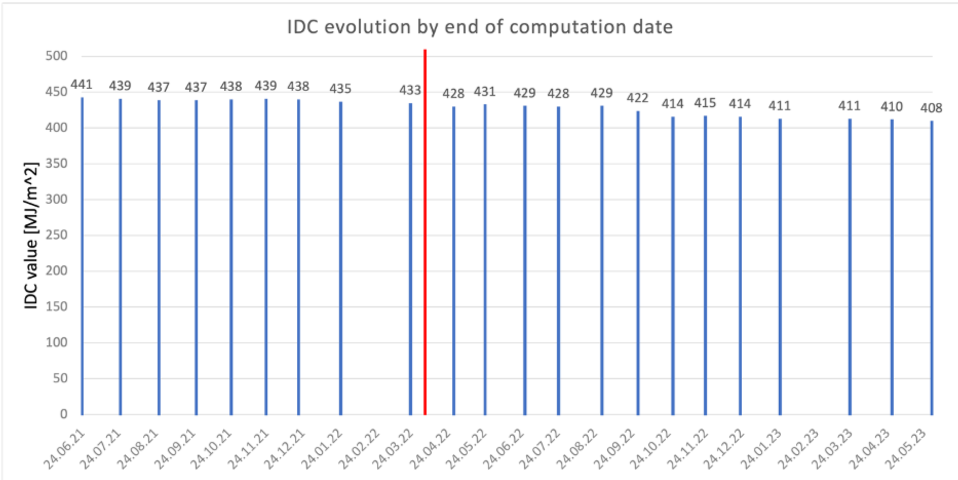


Figure 127 Evolution of the "IDC" computed with a year of bills, with the ending date of the x-axis. The red line represents the date of change in the ventilation system

The ventilation change in Centurion significantly increased the indoor air quality, with no significant effect on the measured indoor temperature. The energy savings of the change are low.

4.4.4.2 Ventilation change in Loex

As described earlier, the CO_2 concentration in some rooms of Loex building was reaching the unhealthy threshold of 3,000+ ppm (see Figure 120). A change in the ventilation schedules allowed for continuous ventilation at night. The effect of the change can easily be seen in Figure 16. The absence of ventilation during the night hours led to a consequent level of CO_2 concentration during the heating period. This is reduced by the continuous ventilation at night. Still, some measurements indicate values above 2’000 ppm between 3 and 7 a.m. (see Figure 128). Measurements are performed in both the bedroom and living room of each monitored apartment, explaining the spread of the measured concentration.

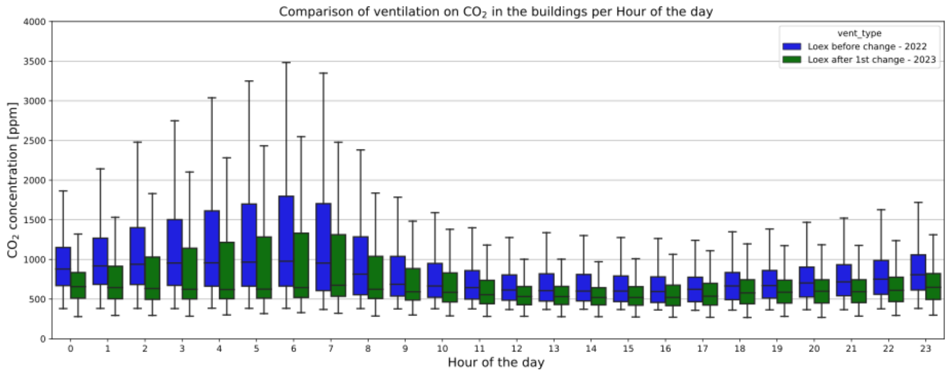


Figure 128 Boxplot of CO2 concentration in Loex before and after the ventilation change for the same period (1st of January to 8th of May)

Regarding relative humidity, higher overall values are observed at all times of the day (see Figure 129). This cannot lead to conclusions regarding the effect of ventilation on this aspect of IEQ. It can just be observed that the measurements could exceed class III before the change. However, as the ventilation schedules were not modified in the afternoon, the reason for this must lie in different outdoor conditions between the 2 periods.

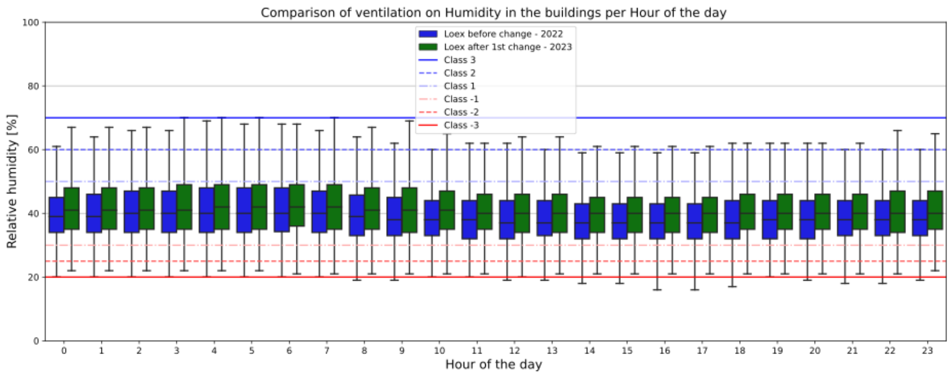


Figure 129 Boxplot of the relative humidity in Loex by hour of the day for the comparison period

Finally, when looking at the temperature repartition with respect to the comfort temperature, we observe a slight shift to the left side, meaning the air is colder after the ventilation change (see Figure 130). This can be expected as the heat losses are more important if the ventilation is on. In addition to decrease in temperature, we observe on the energy signature of the oil heater that the period after the ventilation change shows a higher energy consumption (see Figure 131)

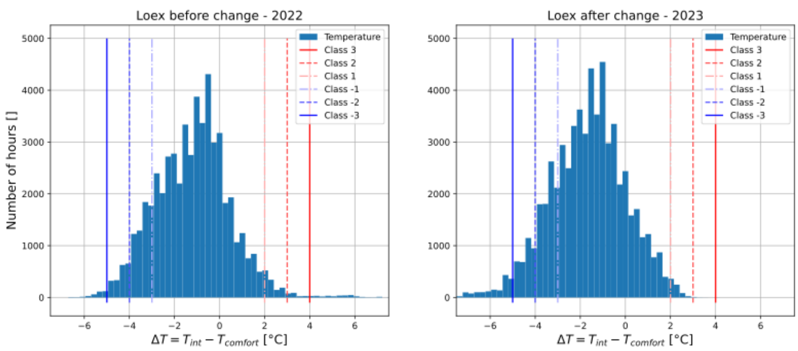


Figure 130 Histograms of indoor temperature difference with the comfort temperature before and after the ventilation change in Loex

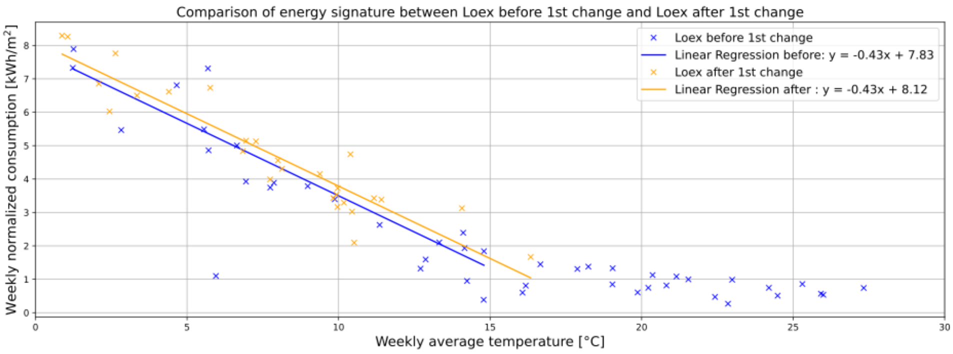


Figure 131 Energy signature of Loex before and after the ventilation change. The linear regression is performed on weekly consumption above 1.5 kWh/m2

The ventilation change in Loex drastically improved the air quality in the monitored space. However, this improvement has a cost due to the absence of heat recovery on the ventilation system. This outlines the need for IEQ consideration when evaluating the building's performance. The focus of the building owner is clearly on the energy aspect and it led to the ventilation stop at night. This example might be more common in Geneva where the energy-related politics can lead to such ventilation interruption despite its need during the night.

4.5 Applications in Cyprus demo sites (B4)

The Cypriot case study was chosen for two reasons. Firstly, it concerns extreme weather conditions in a hot country in Europe, with energy consumption for air conditioning dominating, and secondly, this building was designed with a maximum of bioclimatic techniques implemented by the architectural design team who designed the building. Many of these techniques, apart from the insulation of the envelope, are not correctly or not at all considered by the current energy certificates: night-time cooling by ventilation, effect of thermal mass in the presence of night-time ventilation, presence of ceiling fans, intermittent operation of the building.

For this document, we wanted to test the application of the simplification techniques for dynamic simulation as described in the E-DYCE 3.5 deliverable and to use software other than Energy+. We used DIAL+, a public software package developed and marketed by Estia, which offers the possibility of carrying out rapid parametric studies. It calculates the free running temperature of a building, heating, and cooling demand, solar gains with complex external masks, and natural light. The DIAL+ software was also used to design the building. In Deliverable 5.2 we have a zone-by-zone simulation of the entire building and we found that the actual consumption corresponded quite well with the dynamic simulation according to the typical and complete E-DYCE protocol shown in the other case studies. We therefore have the actual consumption and a more complete simulation to calibrate our simplification with the simulation of one representative part of the building.

4.5.1 Simplification of the building zoning according to E-DYCE deliverable 3.5.

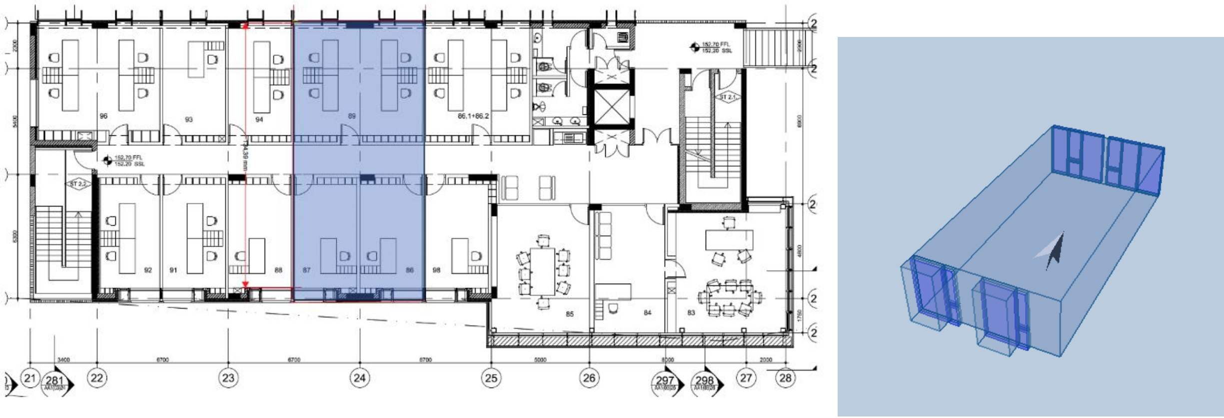


Figure 132 Zone simulated in the DIAL+ software

According to the simplification recommendations, selecting a representative zone can be a credible solution if the extreme zones with significant differences in the envelope typology and exposal to the climatic conditions. We selected a zone with both south and north exposition. We considered the top story, with the roof exposed to external conditions. This configuration can be similar to offices in the middle stories with lateral walls exposed to the exterior. As we see in the next paragraph, the cooling and heating demand of this zone is coherent with the EPC calculations which were similar to dynamic simulations of the whole building under norms conditions.

4.5.2 Monitored data identification for applied extended functionalities

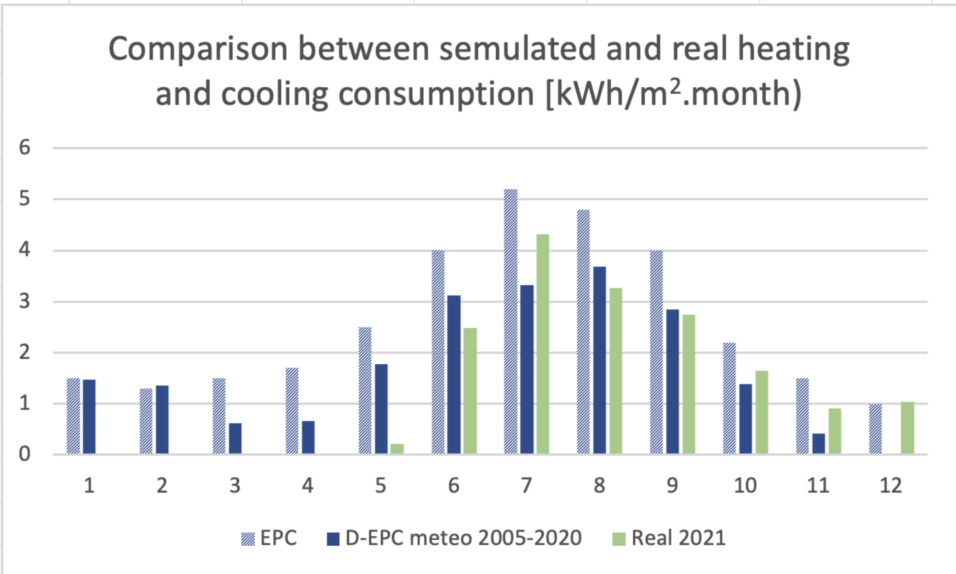


Figure 133 Zone simulated in the DIAL+ software

As we see in the Figure 133, the dynamic simulation shows lower energy consumption than the EPC for the whole building. The total f_Q_h_c is 27.7 kWh/m2y for the EPC while for the D-EPC is 16.6 kWh/m2y (66%). The real consumption is nearer to the D-EPC rather than the EPC. We have desegregated energy consumption measurement of the mechanical services giving 16.6 kWh/m2y May-December, the same as the dynamic simulation for the meteo file corresponding to representative values 2005-2020. We simulated the year 2021, and energy consumption was 5.5% higher due to a warmer summer. We consider the mean temperature 2005-2020 because we like to generalize the sensibility analysis results.

To calculate the adapted conditions of use, we analyzed the interior temperature monitoring results, and we chose a typical temperature level during the hours of use and outside the hours of use. We selected as typical summer temperature 25°C and winter temperature 23°C during the hours of use and free running outside the use hours. In the next figure somebody may remark that the behavior in the offices can be very different, some people put air conditioning at 28°C, some at 26-27°C, and some at 22-25°C. Some software like Energy+ gives the possibility to fix a different temperature every hour. More "general public" software gives the possibility to fix only one set point temperature. So, the observed interior temperature should be aggregated, and this is what we did. In the next figure (Figure 134) we can see that the DIAL+ adapted simulation is similar at the time to no one of the real simulations and to all of them. We can see that the free running temperature of the building during the night when the weather is very hot on both measurements and simulation remains at 28°C even during days of outside temperatures 40°C during the day and 28 during the night. During the day everything depends on the occupation, the window openings, the intermittence, and the air-conditioning set point temperature.

Figure 134 interior temperature in 6 offices during typical summer days in Cyprus (26 July and 24 Aug 2023)

4.5.3 Effect of night cooling.

Everything was designed so that the users kept the windows open. However, due to internal security regulations, the building managers do not allow window opening during the night and the security personnel shut down the open windows. The users are not happy and the designers neither, however, to change this internal security regulation it is needed to intervene in other service decisions or to the municipality hierarchy. We managed to allow 2 weeks of test night cooling. And this was during the first summer hot days. The users were very happy and during the morning they preferred to work without air-conditioning even though the exterior temperature was higher than 26°C which is the most probable set temperature observed.

Simulated energy savings are 39.6 kWh/m2 cooling needs instead of 58.1. We see also in Figure 135 that comfort conditions out of the hours of use are sensible better. With these results, we may calculate the Cooling Reduction Ratio (CRR) defined in the framework of the IEA Annex 62, Ventilative cooling [1] as CRR = (Qref-Qscen)/Qref where Qref is the cooling demand of the reference building according to standard conditions and Qscen is the scenario cooling demand according to adapted conditions corresponding to a passive or optimized ventilation strategy. In our case here CRR = (58.1-39.6)/58.1 = 0.32

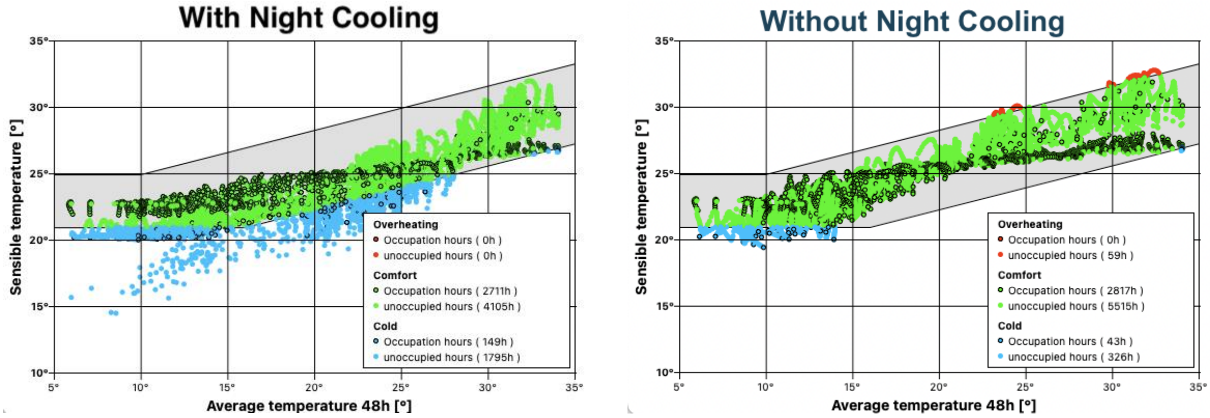


Figure 135 Comfort with night ventilation (left) and without ventilation (right)

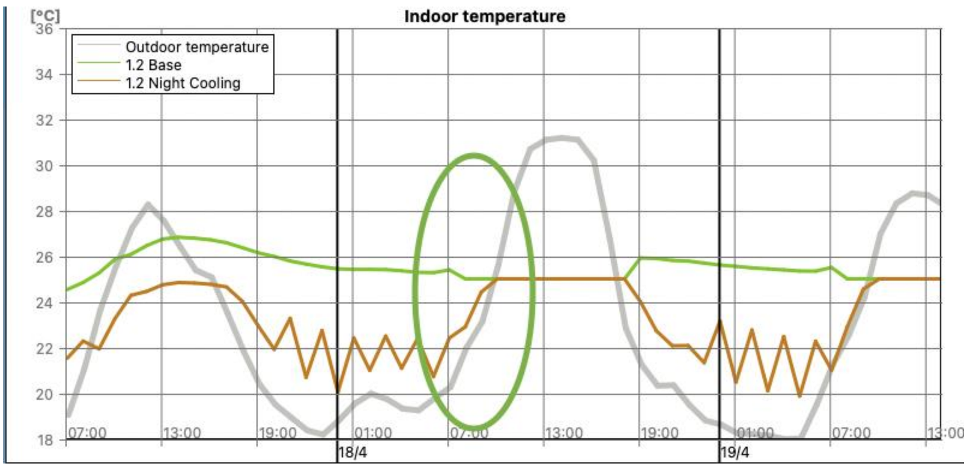


Figure 136 Zoom on internal temperature during the morning with night cooling showing that event during a hot day from 7 in the morning up to 10 in the morning the comfort is natural without air conditioning

E-DYCE dynamic simulations according to the adapted conditions show that free running is possible even with air-conditioned buildings. The benefits are not only quantitative reduction of energy consumption. The quality of comfort without air conditioning is incomparable to air conditioning comfort. Users enjoy just fresh air every day until mid-June and with the presence of a ceiling fan this may be extended until the end of June with more extended hours up to noon (where temperature rises at 28-29°C)

4.5.4 Effect of ceiling fans or cross ventilation in windy places.

Air movement reduces significantly operative temperature. We may have two approaches to measure the effect of the ceiling fans:

In an air-conditioned space, we may use the E-DYCE approach and adapt the conditions of use obtained by questionnaires or measurements. User questionnaire indicated that instead of setting the temperature at 25°C they set it to 27 with a ceiling fan or instead of 26 to 28. Energy savings of degrees offset may be quantified with a dynamic simulation with adapted conditions and calculate the CRR as we did for night cooling. However, the installed ceiling fans of the demonstration case are not very well adapted to office use. The lowest speed is perceived as too high, creating undesirable droughts and noise. In other cases, we found very low energy consumption ceiling fans (3-33 W) modulating the fan speed to very low speed (less than 10% of the maximum) to the full speed. The case study fans have 50-150 W power input, meaning a lower modulation range and higher noise generation. The use rate assessed by the questionnaire is 10-40% according to the season whereas in other cases we have reports of 100% use if very low speed is available and no air conditioning is present. In the case where air conditioning is not present, we may assess the free-running indicators.

D-EPC simulation with standard conditions and adapted 27°C instead of 25°C currently reduces cooling demand to 47.9 kWh/m2y instead of 58.1, offering 10.2 kWh/m2 savings of cooling demand and a CRR of 0.18. 18% of energy savings with 100% use is a good cooling reduction ratio but with 10% use is only 1.8% and with 40% use 7% savings. This stresses the importance of the ceiling fan choice (Very low energy consumption and large modularity range) to rise the percentage of use. In the case study, an optimisation measure is to operate an electronic modification in the fan control to reduce its rotational speed.

1. No fan, windows during day 2. No fan, window day/night 3. fan and window day/night

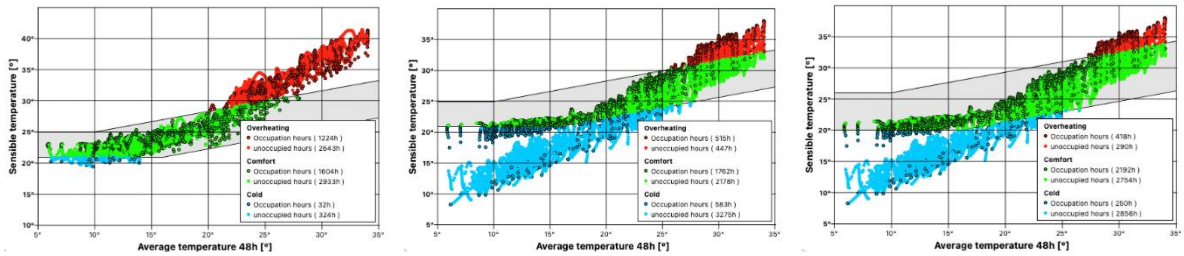


Figure 137 Hours of overheating (outside zone 2 of EN 15251, outside of zone 3 with ceiling fan at position 1)

The overheating hours during occupation hours pass from 1655 with now extra cooling ventilation to 1224 with daytime optimum ventilation (ventilate with window opening when T in < T ext) and from 1224 hours of overheating to 515 with day and night optimum ventilative cooling. With an air velocity of 0.3m/s (ceiling fan passing from 0 to 1), we are reducing in normal summer conditions the operative temperature to ~1°C. This corresponds to passing from class 2 to class 3 with EN 15251 and according to the DIAL+ comfort graphs, we save more overheating hours passing from 515 to 418 hours of overheating.

In the Cyprus climatic conditions 0.3 m/s of air movement (a ceiling fan at position 1 or cross ventilation with opposite windows when outside wind > 1 m/2) combined with day and night ventilation is not sufficient to comply with EN 15251 comfort conditions. However, many residential, office and almost all school buildings do not have air-conditioning, or they have and use it very occasionally to cool the room before going to sleep or the office when it is very hot and someone is there. People use other alternatives if air conditioning is unavailable or judged too expensive. Time shifting to earlier hours, use of adiabatic cooling of the air combined with fans, washing the floor or wetting the trees and outside space, adapting dressing, and using individual fans.

In [13] we evaluated the effect of ceiling fans on a standard shoe box room positioned in different climates and we found that in central and northern Europe climates it is possible to assure complete comfort with a combination of ventilative cooling and a ceiling fan, even under the conditions of climatic change with the worse IPCC scenario. In the E-DYCE methodology, we better formalize the scenario standard and adapted conditions of use. Thus, we may create a standard static EPC for a building under standard conditions of use and calculate the CRR of a passive strategy with a D-EPC methodology for a passive technique that is not considered by the existing EPC protocol and evaluate the energy savings under adapted conditions of use made possible by the presence of a passive strategy. The fact that EPC and DEPC give similar results under standard conditions according to deliverables 5.2 to 5.5 make the IEA indicator CRR applicable event if it is calculated to a sector of the building according to E-DYCE 3.5 methodology (we calculate relative specific energy performance and savings).

4.5.5 Effect of thermal mass combined with other passive techniques.

The architect of the project asked us if the "design obsession" with thermal mass has the expected impact on real consumption. In addition to the financial cost, this choice has impacts on office flexibility (no possibility of passing the cables under a raised floor). The architectural cost was not only felt on the compromises to find a low carbon impact massive material, in this case, anhydride screed) but also a design cost testing all these alternatives. The question of all this effort has an impact on real performance in legitimate. And this is a typical E-DYCE question. We applied the methodology used for renovation roadmaps but to post-analyse the design choices.

DIAL+ simulated 6 scenarios variating thermal mass by 3 steps:

- Heavy: floor, roof, exterior walls concrete, interior walls metal structure and Rockwool
- Light: Floor with screed, roof and exterior walls with metal structure and Rockwool,
- Very light: Floor, roof, and all walls with metal structure and Rockwool

One set of scenarios is with adapted conditions of use without ventilative cooling and no ceiling fan presence and the other with both passive strategies applied perfectly.

Table 20 heating and cooling demand with different passive strategies and conditions of use

Scenario	Q_h	Q_c	Q_hc	%variation
0.0 No ventilative cooling, no fan, heavy	6.2	58.1	64.3	0%
1.0 Ventilative cooling, fan, heavy	10.5	27.2	37.7	-41%
0.1 No ventilative cooling, no fan, light	7.4	60.8	68.2	6%
1.1 Ventilative cooling, fan, light	14.2	32.4	46.6	-28%
0.2 No ventilative cooling, no fan, extra light	8.5	63.4	71.9	12%
1.2 Ventilative cooling, fan, extra light	21.9	41.5	63.4	-1%

A quick analysis of table xx shows that the scenarios produced with the D-EPC methodology varying the conditions of use according to the applied passive strategies present very different expected performances. The effect of the thermal mass on a fully airconditioned space does not vary in a very significant way. Passing from heavy to light and extra light thermal mass the Q_hc varies to + 6% and +12% of the heating demand. Applying the implemented passive strategies, the saved energy from ventilative cooling on a heavy building (-41%) is reduced to –28% on a light building with a medium mass screed (or heavy ceiling) and disappears to a very light building. If we compare a very light building with passive technologies with another one fully air-conditioned with intermittent heating and cooling, the difference is slight. We compare Q_hc of 71.9 kWh/m2y with 63.4 kWh/m2y.

With old split units or VRV units, this difference could be significant (12-13% higher for the light building). However, with inverter split or VRV units, the starting power may be high and fall dramatically without falling off the system's SEER. This gives an advantage to the light building which will be very quickly cooled or heated, bring the space to comfortable conditions rapidly, and reduce the compressor's power by 4 or 5 without a very negative impact on its performance. We understand that much importance on thermal mass makes sense on continuous use buildings with high solar or internal gain variations in winter or on buildings using ventilative cooling in summer.

So, the E-DYCE answer to the building designer is a bit disappointing: if the passive techniques are applied by the municipality facility management yes it has a very significant impact (-41%). However, a bad ceiling fan choice reduces this potential to 30-32% and the security instructions for closing the windows during the night reduce the thermal mass impact to almost zero. Although the answer is disappointing (all this architectural cost for almost nothing) the potential is still there, and the recommendation to the building owner is to search for an electronic solution to reduce the ceiling fan speed to half of the actual one and organize the building security to enable night cooling desired and demanded by the users who tasted it.

4.5.6 Summary and Conclusions of the Cyprus Case Study.

E-DYCE methodology to test the effectiveness of passive technologies consists of defining a reference scenario and calculating it with the standard conditions to calibrate D-EPC to EPC and real energy consumption. This calibration informs also if there is a performance gap. Calibration considers not only energy performance but also indoor temperature and CO_2 concentration to adapt the set point temperature and airflow rate. In our case, there was a performance gap, and it was corrected as soon as identified in the first year of E-DYCE monitoring. Temperatures and IEQ was almost perfect, and it was no need for deep changes or correction.

With a calibrated simplified or complete modeling of the building, we test alternative scenarios, passive strategies or energy measures, with the standard of real meteorological conditions according to the desired precision (+- 7% variation on Q_hc measured in 2021).

We calculate the variation of dynamic passive or smart technologies that our validated software may calculate, and we add them or subtract them from the reference EPC heating and cooling requirements to take them into account on the real energy consumption.

Passive technologies in our case count for 41% of savings and it is not a good idea to ignore them in the existing EPC's. Especially now that we need to reduce the technical installations to reduce drastically the indirect CO2 emissions.

4.6 The Geneva territorial demo case (B5)

Geneva Cantonal Energy office, project partner, during the E-DYCE project was elaborating the energy regulations to apply the energy-Law. E-DYCE results were feeding the regulation strategy and architecture in an ongoing process. This process changed considerably the initial regulation orientations and put more emphasis on real energy savings and performance rather than calculations and took seriously into account the performance gap issue.

The methodology was to generalize interesting aspects applied in detail in the case studies of section 4 and apply them to 20 statistically significant buildings representing the general situation of 12'000 residential buildings of 20 million m2 of surface area in the whole canton of Geneva and extrapolate the simulated or observed impacts on the entire canton building stock. The owner of the 20 buildings holds more than 350 residential buildings / 550 staircases representing ~5% of the canton's residential buildings. Upscaling conclusions also constitutes feedback to the building owner. These recommendations are presented in the next section.

Methodology and basic results are presented in deliverable 5.2, here we show a very rough summary.

An independent official EPC expert visited the 20 buildings. Another building expert from E-DYCE project revisited the buildings to certify the credibility of the EPC generation (surfaces, U values, assumptions, conditions of use). The E-DYCE expert compared the EPC expected energy consumption with historical data collected since 1994 and created 4 scenarios of renovation roadmaps for each building corresponding to the regulation-imposed strategies, i.e..

- Light business as usual scenario without energy upgrading
- High energy performance refurbishment (~55 kWh/m2 of final heat energy)
- Very high energy performance refurbishment.
- Adaptation of the building for abandoning fossil fuels without deep refurbishment.

The cost of these scenarios was evaluated with the EPIQR method. Both the government's energy department and the owner of the buildings have been asking questions about the real impact of energy-saving strategies as well as about methodological issues: what frequency of measurement, which indicators are most relevant, how to reduce the gap between calculated and actual performance, how to assess more realistic energy savings, and so on. The upscaling of the results on 20 buildings to 20 million m2 of the whole canton enabled the cantonal energy service to evaluate the efficiency of energy-saving programs based on real energy consumption.

4.6.1 Measurement or simulation?

Comparison of the simulated and measured heat performance diachronically E-DYCE evaluated the performance gap for existing low energy performance buildings and renovated buildings.

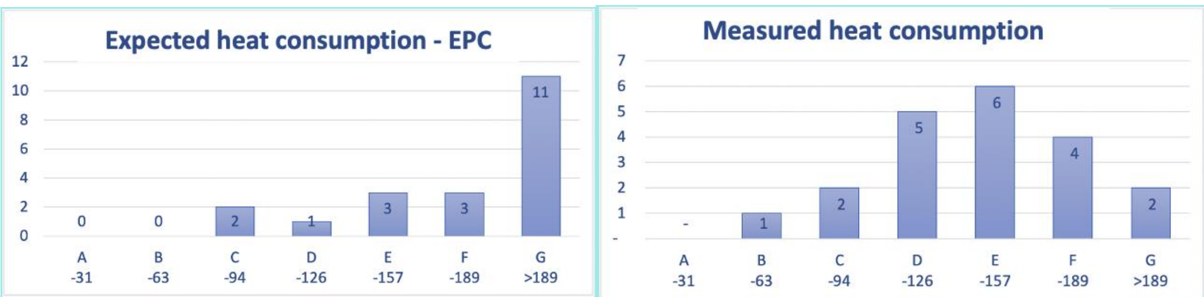


Figure 138 distribution of classes according to simulated and measured heat consumption

This comparison shows that although the EPCs predict catastrophic energy consumption class G for 11 buildings out of 20, the real energy consumption is much better distributed. If the EPCs show very high expected energy consumption and the real one is lower, the expectations of energy savings are overestimated.

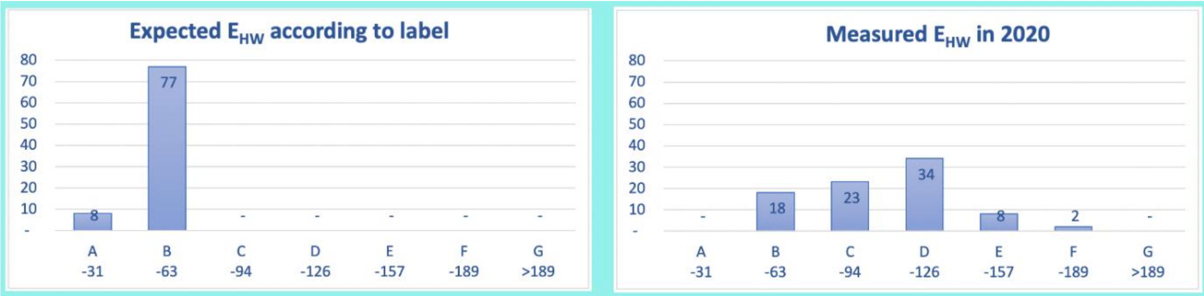


Figure 139 distribution of classed according to label simulated and measured heat consumption

Analysis of the real energy performance of 85 nZEB shows that instead of having all of them in classes A & B, no building is of label A and most of the buildings are of classes D, E, F. Comparing diachronically the energy consumption of the renovated and non-renovated groups of buildings data interpretation lead to an important piece of information.

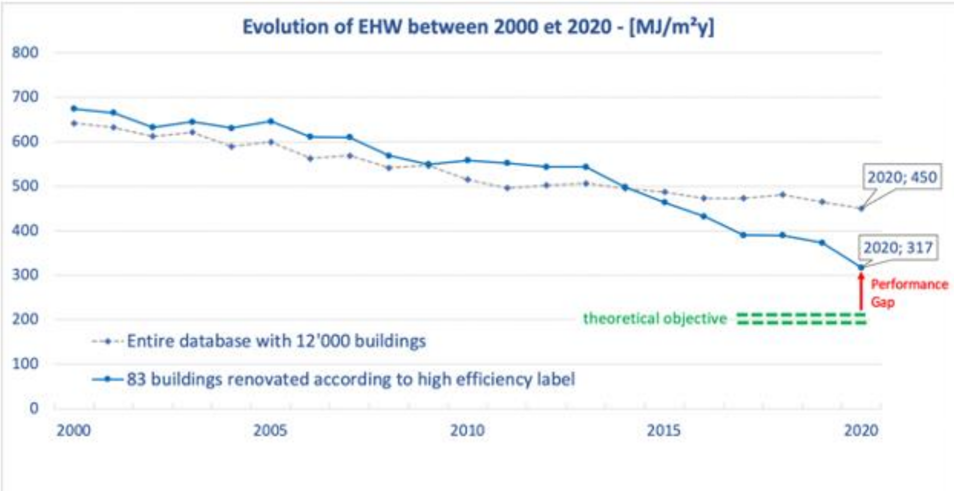


Figure 140 Comparison of the evolution of heat consumption of the entire set of buildings of the canton and of the group of subsidized deep renovations by the canton between 2010 and 2018

Comparison of energy consumption monitored data informs decision makers on several aspects. Interpretation of the two curves informs the Geneva Energy Office and the building owner that:

- Although the energy label of the huge majority of the 12000 buildings of the canton did not change, their energy consumption has been reduced significantly.
- At the beginning of the century, a building was classified as “very bad” if it was consuming more than the mean which was 600 MJ/m2y and regulations were using this threshold to impose energy-saving actions. Today this threshold corresponds to 450 MJ/m2 and this reduction is mainly due to optimization of the building operation and not of the building envelopes (0.5%-0.8% renovation rate between 2000 and 2020).
- The deeply renovated buildings, two years after commissioning should show the heat consumption promised by the High-Performance Energy Label, between 200 and 220 MJ/m2. This energy consumption was 317 MJ/m2y in 2020 showing a performance gap of ~150%. The positive

observation is that this gap is reducing, and the knowledge and communication about this knowledge during E-DYCE project played a big role in taking urgent actions for performance gap reduction.

- On this graph, the Energy Office may read the policy gap between the theoretical objective and the real energy performance of a group of buildings with statistical significance. In this case, we show the entire set of renovated subsidized buildings. An informed policy gap gives the possibility to anticipate policy failure.
- The yearly monitoring time step is sufficient to test the real efficiency of public policies.
- Simulated EPCs cannot see all these aspects which concern operational energy savings of the same order of magnitude of envelope renovation saving potential.

The answer to the question is that both simulations and monitoring of energy are necessary. Simulations to define the objectives and monitoring to verify their success.

4.6.2 Use of yearly time-step monitoring data to test public policies

We used the comparison method to test other public policies implemented in the past or under implementation. We compare the mean heat consumption declared by the building owners fulfilling a legal obligation to do this. This data is public and until recently they were “sleeping” without significant exploitation. We used them to extrapolate what we found with the E-DYCE small sample (4 buildings) and bigger sample (20 buildings). In the big sample, analyzing the real consumption, we have the intuition of higher energy consumption and a smaller performance gap of existing non-optimized buildings with single glazing. We asked the building owner of the E-DYCE statistical sample to provide us with data describing the entire building stock. We identified a significant number of buildings complying with Law Article 56A imposing the replacement of single glazing of U value higher than 3.5 W/m2K. The comparison of figure 29 shows clearly the efficiency of this article of the Law. Noncomplying buildings consume much more than the building stock mean. Complying buildings were consuming more before and now they have similar statistical characteristics with the mean energy behavior. This is a significant evidence of policy success.

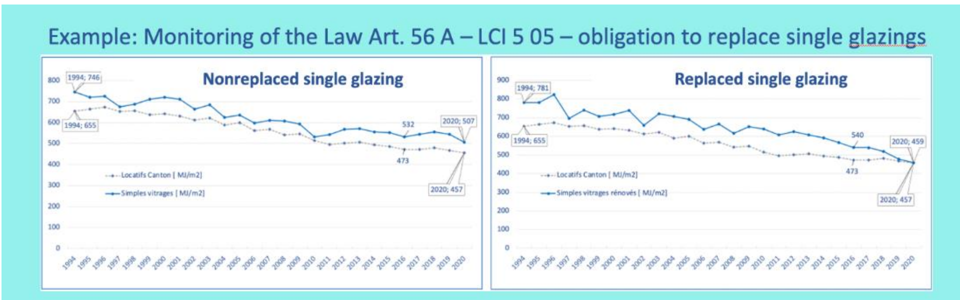


Figure 141 Comparison of declared heat consumption of buildings with replaced and non-replaced single glazing

Analyzing the results on the “small sample” we tried to evaluate the policy success of the measure that we analyzed in section 4, demand control ventilation. There is a public subsidy proportional to the energy savings of single-flow ventilation to demand control ventilation as described in section 4. This public program has been running for the last 6 years and both public authorities and the building owner are interested in evaluating the real impact of this measure. The first is to decide whether to continue or not the subsidy, and the second is to promote or not this investment profiting also from the public partial financing going up to 30% of the cost.

We applied the same method comparing the yearly heat consumption for a group of buildings that took benefit of the program and the entire building stock and we “zoomed” on the case study of section 4 analyzing its energy signature before and after implementation of the measure.

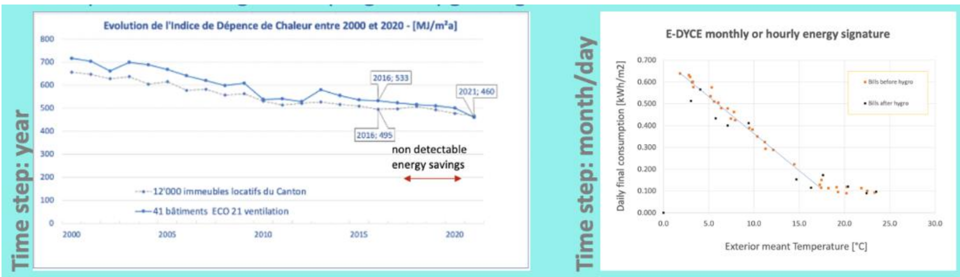


Figure 142 Comparison of declared heat consumption of buildings with 41 buildings that implemented the public program ECO21 demand control ventilation measure and energy signature of E-DYCE case study

Analysis of the yearly step data does not give significant evidence of the measure's success and impact on real consumption. Especially the first 3 years of the program. We had to wait 4 years to have a significant statistical sample of buildings and sufficient time series of data to detect energy savings.

Although it is better to control events 4 years later than trust only EPC predictions, the waiting time is too long. We used the energy signature of the case study building Centurion as described in section 4 and we found coherent energy savings with those observed after 4 years of observation. The energy signature shows the energy savings almost immediately some months after the measure implementation.

The initial energy savings of the public program were calculated using the official EPC calculation method before and after the implementation of the action. This official calculation with standard conditions of use showed 60 MJ/m2y energy savings. Energy inspections of the 20 E-DYCE buildings showed that in reality, 55% of the buildings stop ventilation during the night although they deteriorate air quality (see Swiss case study in section 4). Adapting the EPC calculation with the observed real conditions of use brings projected energy savings to 27 MJ/m2y anticipating a major part of the performance gap. However, stopping ventilation during the night, happens exterior temperature is ~5°C lower than the monthly mean used in the standard EPC calculation method. Using D-EPC calculation, with hourly simulation and adapted conditions of use according to inspection observations, anticipated energy savings are reduced to 16 MJ/m2y, very near to 18 MJ/m2y measured on the energy signature of this building. This real energy saving seams low compared to the statistical observation on 41 buildings. This feedback to the owner leads to the decision in the next year's optimization measures to include control of the operational settings (temperature, ventilation pressure during day and night, hot water production settings) to further optimize the building's energy performance.

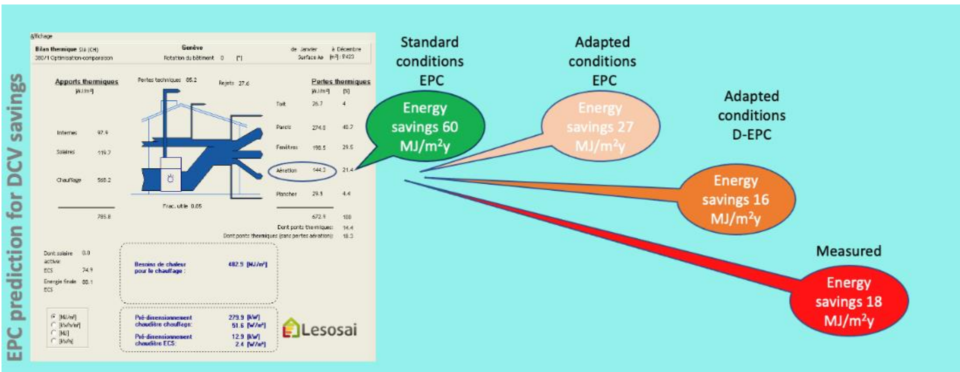


Figure 143 From EPC calculations with standard conditions of use, to EPC adapted conditions of use, D-EPC adapted conditions of use, measured energy savings

4.6.3 Extrapolation of the observed performance gap to the building stock

Using the values calculated on the statistical sample of E-DYCE buildings we may extrapolate the effect of the performance gap to the entire building stock of the Canton.

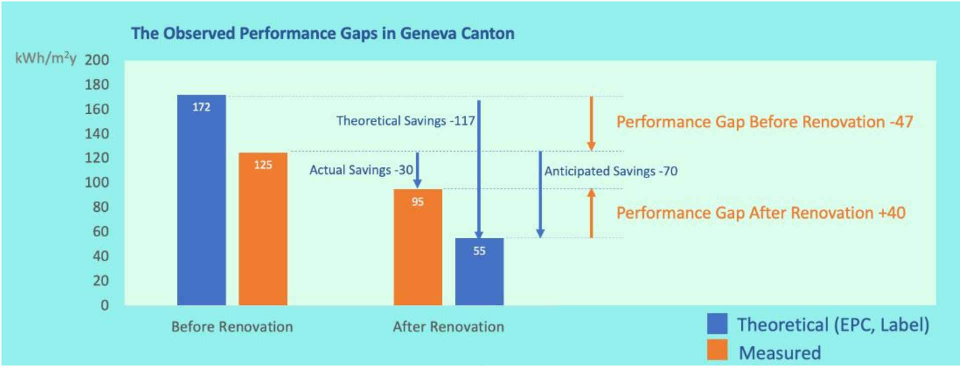


Figure 144 Evaluation of the performance gap before renovation and after renovation, compared to theoretical, anticipated, and real energy savings in Geneva Canton

Using the EPC calculated and measured data of the E-DYCE statistical sample we define the representative heat consumption before renovation. 172 kWh/m2 is the extrapolated heat consumption of the 20 E-DYCE EPCs and 125 kWh/m2y is the mean measured heat consumption of both the statistical sample and the entire set of 12,000 buildings of the canton. 95 kWh/m2 is the heat consumption in 2020 of the set of 85 subsidized labeled deep renovation and 55 kWh/m2 is the objective of the label corresponding to the minimum performance previewed in the official renovation permit. Before the renovation, Geneva residential buildings were supposed by the EPCs to consume 172 kWh/m2y and they consume 125 kWh/m2y. After renovation, the minimum expected heat consumption by the label, accepted by the authorities as an energy objective in the signed renovation permit, and the subsidy contract is 55 kWh/m2y. With these data, we may evaluate the theoretical savings to 117 kWh/m2y and the actual savings to 30 kWh/m2y. Taking into account not the theoretical energy consumption before renovation but the real one, the projected and expected anticipated savings are more realistic and even fully realistic supposing a null performance gap. However, the measured heat consumption presents 40 kWh/m2y of performance gap. Reducing the theoretical savings by 47 kWh/m2y of negative performance gap overestimating real performance by EPCs and 40 kWh/m2y of performance gap missing the label objectives, also calculated by the official EPC method we remain with very poor actual savings of 30 kWh/m2y instead of theoretically 117. It is only 25.6% of theoretical objective susses (the one considered by the authorities in their energy policy if they base their projections on calculated EPCs) and 70 kWh/m2 of anticipated savings according to real energy consumption. Comparing actual savings to anticipated ones the degree of success is better but still low, 42.8%. To increase the success rate serious measures should be taken to reduce the performance gap after renovation. Knowledge of the amplitude of the performance gap after deep renovation of residential buildings led Geneva Canton authorities to take measures from building owners and their energy experts to reduce it.

4.6.4 Conclusions on the territorial scale demo version

In this case study we produced high-quality primary data on the theoretical and measured energy performance of a statistically significant sample of 20 buildings representing 12,000 residential buildings of 20 million m2 of surface area. We evaluated the gap between measured and projected energy savings for various real situations drawn from running public energy-saving programs. We quantified the gap between expectations and reality leading to a policy gap. Identification of a policy gap anticipates a policy failure with correction measures. In all cases of identified policy gaps, measures were taken and they are explained in the next section on scaling-up.

5 PART C: E-DYCE scaling-up

This part collects the main obtained impacts and lessons learned correlated to the application to the project demo cases of the whole E-DYCE methodology, including the DEPC approach and the extended functionalities. The treated topics are:

- **DEPC and KPIs** discussing the application of the E-DYCE principal approach,
- **Data and platform** discussing the outcomes correlated to data acquisition, management, and processing, including visualization and elaboration via automatic platforms,
- **Monitoring and simulations** discussing topics connected to model development, verification and usage and to the adoption and usage of building monitoring solutions,
- **Scaling up to the territorial scale** discussing the implications of the extension of the E-DYCE functionalities to the territorial scale in a scenario that involves not only building stakeholders but also policy makers,
- **Barriers and challenges** discussing the lessons learned correlated to current application in the larger scale of the E-DYCE approach considering potential legislative and additional barriers.

5.1 DEPC and KPIs

__Impacts__

- Using the E-DYCE platform and the DEPC approach we can include in the energy analysis dynamic behaviors, including thermal mass activations, smart control logic,
- E-DYCE approach allows for the integration of adapted conditions that to a certain extent capture the actual operation of the buildings and by that can minimize the performance gap,
- The DEPC and E-DYCE platform allows the production of weekly aggregation of energy KPIs and therefore provides more rapid detection of energy good and misbehavior,
- The DEPC approach, different from the EPC, allows for consideration and quantification of IEQ and different comfort domains considering the complexity of comfort analyses,
- DEPC and correlated KPIs allow us to take advantage of the free-running building behavior that is currently not valorized.

__**Lessons learned**__

In this section are listed key conclusions and observations from development and practical work with E-DYCE DEPC protocol and KPIs development:

- Developed DEPC protocol can provide a wide range of KPIs regarding energy, comfort and free running. In total up to 28 KPIs were identified for professionals, and from these 7 KPIs were identified for non-professionals (tenants).
- The DEPC protocol provides an exhaustive list of KPIs that do not necessarily have to be delivered to each building. The scope of analysis is determined by ambition and data availability individually per building case, which underlines the high flexibility of E-DYCE DEPC approach.

- DEPC accommodates the following possible assessments: asset standard condition (modeling), asset adapted (modeling) and operational (measured). In this manner, E-DYCE DEPC is closely aligned with the current EPC, providing an operational assessment of both energy performance and Indoor Environmental Quality (IEQ), while it also aids the building performance optimization and helps maintain realistic expectations from the renovation measures.

- DEPC protocol gives flexibility to whether the analysis is performed at the mono-zone level or multi-zone level, but this should be determined by building case and consider energy services and/or environmental indicators. The general strategy should aim for simplification. When possible, consider buildings/apartments as mono-zone models. In this way, it opens up for utilization of the existing measurement infrastructure within the building or its stepwise upgrade, depending on the scope of the assessment intended.

- Concerning KPIs definition, the individuation of the critical zone remains an open question and also the further use of the obtained results. At present, multizonal (highly detailed) models were used, and hence the identification of the critical zone is left to a post-processing analysis of all zone results, but if, in the future, only average and critical results should be provided, its definition should be better discussed.

5.2 Scaling up to the territorial scale (Geneva)

Impacts

- Using the E-DYCE methodology we have shown the possible methodological bias basing expected energy savings of large-scale energy programs only on simulated values.

- We have shown how the developed methodology enables public authorities, owners, and energy experts to calculate realistic anticipated energy savings using adapted conditions of use, either on the existing EPCs or D-EPC.

- We have shown how a series of monitoring data may generate information about the success of an energy-saving program. Yearly time step data, easy to obtain on energy bills are a good complement to EPC's to verify a strategy or policy success.

- Monthly data, which may be obtained also from energy consumption bills may produce an energy signature, a sufficient instrument to identify very rapidly, some months, compliance or performance gaps.

- In the optimization process, higher-resolution data are useful to identify, understand, and correct the rapid performance gap.

- D-EPC allows for evaluating anticipated energy savings with higher credibility for dynamic phenomena, variable ventilation, heat gains, or dynamic control strategies.

Lessons learned

In this section are listed key conclusions and observations from the application of several E-DYCE methodology ideas in the scaling-up case study:

Knowledge of the real energy performance of the buildings is complementary and necessary information, changing the stakeholder's attitude. Knowledge of real energy consumption and its evolution led the Geneva authorities to oblige buildings with energy consumption higher than the canton's mean to take energy optimization measures. Defining the energy-saving objective in a credible way and formal engagement on a minimum admissible threshold using standard conditions of use, allows energy-saving experts to calculate using realistic conditions of use the credibility of succeeding these objectives. Identification of performance is a necessary step to understand it and correct it also in a territorial scale. Compulsory declaration of energy performance, yearly time step for all the buildings, and monthly time step for buildings benefiting from public subsidies lead to rapid identification of performance gap, risks of policy gap, and anticipate policy failure. Geneva Canton introduced a subsidized program for design assistance to the building owners and all participating projects present a performance gap of <15% instead of 50-80% observed in the near past. Geneva's 30-year experience of imposing energy consumption monitoring and declaration shows the strength of complementary requirements to calculate EPCs with the measured energy. It is recommended that public administrations managing EPC deployment develop rapid mechanisms for data collection of real energy consumption and remove legal barriers so that these declarations are public. Basing energy-saving expectations on theoretical simulations with unrealistic conditions of use is a risky trap for exaggerated unrealistic energy-saving expectations raising the risk of policy gap and finally policy failure. The performance gap that cannot be corrected after commissioning is a real risk of policy failure and a high financial risk in case of compulsory correction. Identification of the performance gap is a first step, but anticipation of it is better. Anticipation of performance gaps may be part of the architecture of energy-saving large-scale programs. In Geneva, 2-year optimization becomes compulsory for some highly subsidized measures (deep renovations) and in case of persisting performance gap correction measures are asked. Optimization monitoring becomes mandatory for the buildings that consume more than the entire building stock mean.

5.3 Data and platform

Impacts

- The E-DYCE platform can store and manage energy and environmental data coming from devices of different manufacturers working with different communication protocols and systems. The same is open to future integration following a scalable approach.

- The PREDYCE platform can automatically transform the outputs of dynamic energy simulation software (like EnergyPlus) to keep them in line with European and national norms and defined DEPC KPIs. The same can be integrated under requests for additional KPIs and actions.

- The developed DEPC protocol includes a data presentation interface, which can be utilized not only for the operational assessment but also for commissioning, fault detection, and energy effectivization of the building outside of DEPC procedure (Sensor data with different communication protocols, etc. is stored in one place).

- PREDYCE can manage both simulated outputs and monitored data to retrieve the same KPIs allowing comparisons.

Lessons learned

- Interpretation of simulation results can be complex without specific buildings, certification, and energy knowledge. Moreover, results can be tricky, and sources of errors are numerous. Hence an intermediate layer or professional figure is needed to support the building and maintenance of the middleware.

- Adapted input conditions present the intrinsic problem of being variable over time, hence it should be defined as a frequency update (or triggered by specific events e.g. occupants move). Otherwise, results meaningfulness could decrease over time.

- The PREDYCE scenario devoted to model verification support (through massive parametric simulations) is an important starting point to fasten the model calibration. However, the results of the calibrated demo models proved to be stable over the tested monitoring years.

- The availability of weather data coming from a station sufficiently near the considered building site plays a crucial role for DEPC and extended E-DYCE functionalities' applications. However, to feed dynamic simulation software it is important that all the needed weather variables are covered by the local identified station or service provider.

- At present, the definition of simulation/performance gap inputs for each building is done once and for all by manually compiling a JSON file. The compilation of the input files could be simplified through the development of a dedicated interface.

- Building spatial coordination where is what is required and can be provided by f. g. application information model in FusiX.

- Coordination and establishment of thermal zone names and computed KPIs names are required to allow comparisons.

5.4 Monitoring and Simulation

Impacts

- The use of adapted conditions instead of standard conditions in simulation models can help to improve predictions and detect more reliable performance gaps. Adapted conditions should, if possible, relay from measured data, e. g. indoor temperature, and actual weather conditions that can be used for set points and boundary conditions.

Lessons learned

Here are listed key observations and experiences from E-DCYE demonstration activities. First, are listed lessons learned that are related to monitoring and operational assessment of buildings and second are listed lessons learned from simulations.

Monitoring and operational assessment:

- The demonstration monitoring infrastructure has required significant resources for the maintenance of the data acquisition used in monitoring. Sensors/ repeaters stopped logging/sending data and required on-site visits (see more in the next bullet point). It has also demonstrated the necessity of establishing initial guidelines for the distribution and positioning of environmental sensors to suit the scope of the operational assessment. The management of the communication between the wireless indoor climate sensors and their repeater network has been demanding. Occupied spaces are challenging to access while technical rooms together with the central heating installation are easier to address.

  The real cost of reliable monitoring is therefore typically higher than the cost of the sensors, their installation, and access to the backend to which they deliver their data. Therefore, the related business models for monitoring are more likely to be ongoing service agreements (with subscription or similar) rather than 'deliver and forget' installation of the equipment (with a one-time upfront cost). Existing monitoring infrastructure should be always considered first, e. g., smart heat and/or smart electricity meters, and existing IEQ sensors.

  Operational assessment is first possible when monitoring results are logged and transferable for further analysis. Monitoring infrastructure without logging and data transfer (repeaters and gateways) is not sufficient for feasible operational assessment. In-depth operational assessment requires an interface capable of offering data presentation that is both readable and meaningful. This interface should also be flexible enough to adapt to the specific scope of the assessment.

- Currently, there is no standard regarding monitoring from operational assessment.

- Concerning output results and spatial matching between sensors and models, it should be considered that not all modeled zones or installed sensors should be included in the analysis (e.g. in the average) for several reasons e.g. since devoted to specific tasks such as measuring the surface temperature of a specific heater, located in particular zones such as roof, basement. Hence, additional effort should be made to include in the process a selection procedure for each KPI. This should be done knowing both the model and the monitoring system, together with the KPIs meaning. This is an important step to assure output meaningfulness.

Simulation:

- Transitioning from static to hourly models is in general more resource demanding.

  Considerations for building/system model simplification possibilities should be taken into account. Results indicate that geometrical model simplification for energy parameters (especially heating-dominated climates) provides reasonable results and often linear correlations between simplified models (one-zone models) and detailed models (multi-zone models) can be observed. Indoor comfort parameters are more sensitive to geometry simplification. Here it is observed that at least south/north or in general distinct orientation situations should be considered when developing the model's geometry.

- Large and detailed models that take a long time to run are still difficult to run in services such as combined PREDYCE and FusiX where there is a weekly call to execute models. It is suggested to simplify models or split them to maintain the simulation time as short as possible to allow REST communication. Splitting the model in smaller models is also a valid option.

- Efforts should be made to perform at least a basic site inspection regarding the state of the building and loads f. g. number of people, occupation routines, presence of shadings, etc.

- Given the intrinsic flexibility of dynamic simulation software, there exist multiple ways of modeling different parts of the building geometry and dynamics, e.g. the HVAC system or airflows. Hence, functions allowing to automatic modification of input model parameters to generate standard and adapted input conditions, require effort to be created and keep updated to simulation software new releases (which happen frequently). Moreover, also simulation output form is impacted by the different modelling solutions. In this sense, it is indispensable to standardize some model simplification solutions (e.g. adopting the simplified HVAC system, avoiding considering intra-zone airflow, adopting simplified glazing system optical data).

- Models might require revisions over time to keep results meaningful. Building owners might carry out renovations/retrofits that would require model updates, or tenants might move out and be replaced by new ones. In that case, adapted conditions would need revision.

- The model verification phase concerning monitored data has been proven to play a critical role in the meaningfulness of the results. A well-calibrated building is more important than defining standard or adapted conditions to retrieve results close to reality. However, the model verification phase is a complex task, lacking standardized methodology and commonly still performed mostly manually. Also, automatic and semi-automatic calibration processes must account for realistic building thermal properties and not only favor results agreement. Therefore, calibration analysis should consider narrow and adapted variation ranges per specific input item.

5.5 Barriers and challenges

The successful implementation of the E-DYCE project requires not only technical expertise but also an understanding of the policy, acceptance, and barriers related to the project's activities. This section aims to present key insights that were identified in the context of E-DYCE, as well as to provide practical suggestions for the E-DYCE project team, based on the relevant literature on policy, acceptance, and barriers in the field of building energy efficiency, focusing on EPC schemes. These key insights are presented below (see also Annex A – literature review about barriers):

- **Policy considerations:** The current EU policy framework doesn't create favorable conditions for the dynamic energy certification of buildings. In addition, it should be evaluated if and how the project DEPC contrasts with the EPC currently enforced in the MS. In this perspective and to avoid such risks, DEPC could be implemented as a voluntary scheme for end users and building stock owners interested in real use conditions and reliable energy renovation scenarios. A possible application of DEPC may be its use for financial incentives based on real and measured energy savings.

- **Financial considerations:** One of the primary barriers to EPC and DEPC implementation is the limited willingness of stakeholders to pay for EPC services. To address this, integrating EPC services into public frameworks for affordability is recommended. This integration would help overcome financial constraints and encourage a wider adoption of EPCs. Additionally, the prohibitive costs associated with carrying out due diligence should be addressed through the exploration of cost-effective solutions to alleviate the burden on stakeholders.

- **Data privacy and security:** Data confidentiality concerns are a significant barrier to DEPC acceptance (especially operational assessment). To mitigate these concerns, strict data protection measures and privacy policies should be ensured, assuring stakeholders that their data is secure. Additionally, difficulties in obtaining consent for data collection from occupants can be addressed by establishing close collaboration with housing associations and updating rental agreements to include consent clauses for data collection, ensuring transparency and compliance. In the context of E-DYCE, data privacy has been a priority which was ensured by implementing the GDPR requirements, as well as communicating the purpose of data usage before contract signing and asking the users' permission.

- **Data quality:** Lack of data quality for energy performance evaluation is another challenge. Enhancing data collection and verification processes is crucial to improve the reliability and accuracy of energy performance evaluations, a priority that aligns with E-DYCE's data-driven approach to inform decision-making and assess outcomes.

- **Occupant behavior:** Differences between predicted and actual energy consumption due to occupant behavior present a challenge for EPCs and DEPCs. Direct inclusion of occupant behavior might be inconclusive and too resource-demanding to guarantee scale-up potential. Therefore, indirect inclusion of occupant behavior by e. g. inclusion of monitored set points, CO2 concentrations should be proposed in the adapted condition of use, by e. g. control of heating systems, and determination of air flow rates/ venting.

- **Varying levels of interest:** Varying levels of interest across countries and a lack of interest in certain EPC features can hinder their adoption. Tailoring EPC features to specific country contexts and improving their relevance and usefulness based on end-user needs can address these barriers. Providing comprehensive and compelling information about the benefits of renovation is also important to motivate homeowners and increase interest.

- **Market penetration:** By enhancing reliability and compliance, EPCs can gain wider acceptance and adoption in the market, an objective that aligns with E-DYCE's efforts to establish consistent practices and standards.

- **Customization:** Limited customization of current EPCs limits their usefulness. Incorporating new features into EPCs and providing easily understandable information would enhance their usability and make them more user-friendly. These improvements can cater to the specific needs and preferences of end-users. E-DYCE contributes to this direction by providing information on the interior climate and indoor air quality to the tenants via smartphone apps and/or information dashboards.

- **Familiarity with technology:** The lack of familiarity with smart technology poses a barrier to EPC adoption. Offering educational resources and training programs on smart technology would increase familiarity and facilitate the adoption of advanced technologies, making EPCs more accessible and appealing to stakeholders.

Addressing the barriers to EPC implementation is crucial for the successful advancement and adoption of energy-efficient practices within the EU. By integrating EPCs into public frameworks, ensuring data privacy and security, enhancing data quality and comparability, and promoting information accessibility, the EU can overcome these barriers. Additionally, tailoring EPC features, improving customization, and fostering familiarity with smart technology will contribute to their wider acceptance and utilization. These efforts will facilitate the EU's transition to a more sustainable and energy-efficient built environment, supporting its overall energy conservation goals and informing decision-making among stakeholders, building owners, investors, and policymakers.

6 Conclusions and Outlook

This report consists of three parts:

Part A – summarizes activities and results obtained that are centred around E-DYCE DEPC protocol. The E-DYCE DEPC process can be formalized by fully automated data flow (processes incorporated by interlinked PREDYCE and FusiX that both compose E-DYCE platform) or can be semi-automated by manually securing the data flow that mimics the PREDYCE and FusiX connection. In that manner, the method is fully flexible and allows for different levels of advancement from modeling and monitoring. The results in part A are highly unified and orchestrated to execute DEPC protocol purposes. The E-DYCE DEPC incorporates 3 levels of assessment: standard, adapted and operational which are centered around four themes: energy, energy signature, free-running potential, and comfort. Selected KPIs are selected for E-DYCE DEPC and are illustrated for both fully automated data flow (Italian and Danish demos) and semi-automated data flow (Swiss demo).

Part B – The purpose of this section is to illustrate additional benefits and further possible assessment of buildings thanks to data availability from modeling and monitoring activities aligned to activity from part A. The outcomes included in this analysis should be considered as an extension of E-DYCE DEPC approach but not explicitly part of E-DYCE DEPC. Evaluations presented in this section are not automatized and are not bounded by the unified approach for outcomes visualizations and therefore allow for more individual and deeper analysis concerning individual requirements/interests. In this section are also elaborated observations from E-DYCE development activities. The observations are supported by results obtained.

Part C – This section collects impacts and lessons learned correlated to the application to the project demo cases and the whole E-DYCE methodology, including the DEPC approach presented in part A and the extended functionalities presented in part B of this report. Areas being summarized are DEPC and KPIs, Data and platform, Monitoring and simulations, Scaling up to the territorial scale, and Barriers and challenges.

7 Bibliography

[1] Pomianowski M. Z., Wittchen K., Schaffer M., Hu Y., Chiesa G., Fasano F., Grasso P., Method combining expert and analytical approaches towards economical energy renovation roadmaps and improved indoor comfort, CISBAT 2023 International scientific conference, Lausanne.

[2] Chiesa G., Fasano F., Grasso P., A New Tool for Building Energy Optimization: First Round of Successful Dynamic Model Simulations, 2021, Energies 14, 6429.

[3] Leirig D., Johra H., Marszal-Pomianowska A., Pomianowski M. Z., A methodology to estimate space heating and domestic hot water energy demand profile in residential buildings from low-resolution heat meter data, 2023, Energy, volume 263, Part B https://doi.org/10.1016/j.energy.2022.125705

[4] M.Vigliotti (2022) Control approaches for ventilative cooling and indoor air quality systems in a school demo-building in Torre Pellice, Master Degree Thesis, Tutors: G.Chiesa, F.Fasano, Politecnico di Torino.

[5] Elhadad, S., Radha, C. H., Kistelegdi, I., Baranyai, B., & Gyergyák, J. (2020). Model Simplification on Energy and Comfort Simulation Analysis for Residential Building Design in Hot and Arid Climate. *Energies*, *13*(8), 1876. https://doi.org/10.3390/en13081876

[6] Chao, C. Y. H., & Hu, J. S. (2004). Development of a dual-mode demand control ventilation strategy for indoor air quality control and energy saving. Building and Environment, 39(4), 385-397.

[7] Bak´o-Bir´o, Z., Clements-Croome, D. J., Kochhar, N., Awbi, H. B., & Williams, M. J. (2012). Ventilation rates in schools and pupils' performance. Building and environment, 48, 215-223.

[8] Chiesa G (2023) Fictitious cooling/heating: from free-floating thermal discomfort to energy needs, different approaches toward labelling free-running buildings, Cisbat 2023, Journal of Physics: Conference Series, under publication, 6pp.

[9] Chiesa G, Fasano F, Grasso G (2023) Impact of different thermal zone data simplification for model calibration on monitored-simulated performance gaps, Cisbat 2023, Journal of Physics: Conference Series, under publication, 6pp.

[10] Claridge D and Paulus M 2019 Building simulation of practical operational optimisation Building Performance Simulation for Design and Operation eds. J. Hensen and R. Lamberts, (London: Routledge) pp. 399–453

[11] Chiesa, G., Fasano, F., Grasso, P. (2023). Simulated Versus Monitored Building Behaviours: Sample Demo Applications of a Perfomance Gap Detection Tool in a Northern Italian Climate. In: Sayigh, A. (eds) Towards Net Zero Carbon Emissions in the Building Industry. Innovative Renewable Energy. Springer, Cham. https://doi.org/10.1007/978-3-031-15218-4_6

[12] Chiesa G, Fasano F, Grasso G (2023) Impact of different thermal zone data simplification for model calibration on monitored-simulated performance gaps, Cisbat 2023, Journal of Physics: Conference Series, under publication, 6pp.

[13] Per Heiselberg et al., Ventilative Cooling Design Guidelines, IEA Annex 62, ISBN 87-91606-38-1, Aalborg University, 2018, (https://venticool.eu/wp-content/uploads/2016/11/VC-Design-Guide-EBC-Annex-62-March-2018.pdf)

8 Annex A – literature review about barriers

The successful implementation of the E-DYCE project requires not only technical expertise but also an understanding of the policy, acceptance, and barriers related to the project's activities. This section aims to provide a review of the relevant literature on policy, acceptance, and barriers in the context of building energy efficiency, focusing on Energy Performance Certificate (EPC) schemes, and to present the challenges and barriers which were identified in the context of E-DYCE, as well as to provide practical suggestions for the E-DYCE project team. In this context, the existing literature related to building energy efficiency projects was reviewed and presented, and relevant suggestions for policy improvements that can support the successful implementation of the E-DYCE project's outcomes were provided. Potential barriers to the implementation of the project were identified and ways to overcome them were proposed, ultimately aiming that the presented findings and recommendations can help the E-DYCE project team to develop effective strategies in order to ensure the success of the project.

Various challenges and barriers for the implementation of next generation EPCs have been identified in the context of E-DYCE. Specifically, multi-family apartment buildings are a particularly challenging environment when it comes to data collection for the purpose of energy performance evaluation. The core of this issue is the multitude of stakeholders whose consent is required to install the materials and operate it. At the installation stage, getting in contact with the tenants and being able to access the apartment often takes significant effort and consumes significantly more resources than expected. A similar situation happens when maintenance needs to be carried out, although the barrier is lower when equipment is already installed. Obtaining consent for data collection (as required by the GDPR) prior to installation or when a change of tenant happens can also be a challenge, especially when the occupants do not perceive a direct benefit (as they for example would with a critical element directly controlling their heat supply). In such a context, it therefore seems important to have a close collaboration with the housing association and potentially update the rental agreement such that it includes consent to collect data for performance evaluation. Coordinating hardware upgrade and maintenance at times when the flats are being accessed for other purposes (e.g. visits when tenants move in/out or renovations) would also be a way to ease the process.

Sufficient research has been conducted on the barriers to EPC implementation, and the relevant literature has provided comprehensive insights into this topic. The potential of EPCs to play a more significant role is encouraging; however, their adoption and success in EU member states heavily rely on the perception, willingness to utilize, and interest of the end-users (Zuhaib, et al., 2022). Previous research conducted by (Abreu, Oliveira, & Lopes, 2017) and (Christensen, Gram-Hanssen, Best-Waldhober, & Adjei, 2014)has indicated that homeowners have displayed limited usage of EPCs. However, there is a widespread belief that EPCs can play a pivotal role in addressing various challenges such as decarbonization, deep renovation, access to finance, tailored advice, promoting healthy buildings, influencing real-estate prices, and contributing to overall energy conservation and sustainability (Anđelković, et al., 2021); (Wilhelmsson, 2019); (Khazal & Sønstebø, 2020); (Platten, Holmberg, Mangold, Johansson, & Mjörnell, 2019).

In order to identify the end-user perspectives towards future development of EPCs, (Zuhaib, et al., 2022) studied the end-users needs and expectations towards the next generation EPCs through a survey conducted in five European countries (Denmark, Greece, Portugal, Poland, and Romania). The survey involved a total of 2563 participants, while the target group included homeowners, landlords, and tenants that met one of the following criteria: a) They had engaged in activities such as buying, renting, selling, letting, or renovating property between 2015 and 2020; b) They had attempted to engage in activities such as buying, renting, selling, letting, or renovating property between 2015 and 2020; c) They had either taken initial steps or had plans to engage in activities such as buying, renting, selling, letting, or renovating property.

The survey findings highlight several barriers that exist in relation to EPCs. While the surveyed participants generally exhibited an energy-conscious attitude and expressed positive perceptions of the proposed features, some barriers were identified. The level of interest in specific features varied among the surveyed countries. Greece, Poland, and Romania showed a greater interest in smart readiness, real energy consumption, and financing options, while Denmark and Portugal exhibited less interest in these areas. Outdoor air pollution, district energy, and building logbooks received neutral interest overall. However, features such as comfort and EPC databases drew high interest across all five countries.

Respondents indicated a preference for information that directly relates to their homes and households. For example, feedback on real energy consumption was deemed more valuable when it provided a comparison with the previous year rather than with similar households. Regarding the EPC database, respondents found it more useful to see the energy efficiency score of similar properties rather than all properties in the neighborhood. Additionally, respondents emphasized the importance of data confidentiality when sharing information. Recommendations and financing options were considered more relevant when the proposed renovations aimed to improve the energy performance of the home.

Cost information was particularly valued in relation to renovations. However, respondents showed a limited willingness to pay for these services, suggesting the need for careful integration into public frameworks. The survey also revealed that the level of interest was highest among homeowners and tenants who were conscious about their energy use at home and viewed energy performance as a crucial factor when buying or renting property. Variations in perceptions and attitudes were observed based on factors such as urban versus rural residence and age groups. However, there were no significant differences between homeowners and tenants regarding the importance of energy efficiency when making property-related decisions or pursuing energy-efficient renovations.

The current EPCs were found to lack customization for end-users, as they primarily display the energy performance of buildings in technical terms, providing limited benefits to most people. The survey results suggest that incorporating new features into EPCs could enhance their usefulness and appeal. The authors mention that proposed revisions to the Energy Performance Building Directive (EPBD) could strengthen EPCs and make them more dynamic in Member States. The survey underscores the potential of new features that cater specifically to homeowners and tenants, providing easily understandable information. The authors recommended that under the EPBD, a central or regional EPC register be established to make information accessible to all stakeholders. EPCs should be integrated as tools for financing deep renovations in EU Member States' policies. Harmonizing the European calculation methodology for EPCs could improve comparability, instill confidence, and drive market uptake for features like smart readiness, comfort, real energy consumption, and district energy.

Furthermore, previous research on EPCs has identified three key challenges in the way of achieving a large-scale acceptance across the EU, namely: i) inadequate data quality for energy performance evaluation, ii) insufficient information to motivate renovation, and iii) limited implementation leading to a lack of a comprehensive information source for energy planning in certain countries (Pasichnyi, Wallin, Levihn, Shahrokni, & Kordas, 2019); (Mangold, Österbring, & Wallbaum, 2015).

In line with the aforementioned studies, (Li, Kubicki, Guerriero, & Rezgui, 2019), who provided a review of the EPC situation in the EU and discussed the direction of future improvements, mentioned that the wide implementation of the EPC has been slow and it is not sufficiently enforced in the EU Member States because of insufficient information, awareness, quality, and user-friendliness, which results to limited market penetration and small acceptance among users. Moreover, (López-González, López-Ochoa, Las-Heras-Casas, & García-Lozano, 2016) and (Li, Kubicki, Guerriero, & Rezgui, 2019) focus on the occupant's behavior and building smartness as a major challenge in the way of implementing the EPC. Specifically, it is stated that the behavior of the occupants is a main source of deviations, due to the limited degree of environmental awareness of the occupants. Addressing this issue would demand the adoption of building automation systems, metered energy consumption data (Jenkins, Simpson, & Peacock, 2017), as well as building smart management systems. In essence, the authors conclude that building owners and potential investors encounter significant obstacles in enhancing their buildings' energy performance, including cost concerns, time constraints, and uncertainty regarding anticipated returns on investment. Furthermore, (Li, Kubicki, Guerriero, & Rezgui, 2019) proposed a comprehensive set of EPC improvements. The proposed improvements address key challenges and aim to enhance their effectiveness and impact. These improvements include integrating EPCs with Building Information Modeling (BIM) models to streamline data consolidation, incorporating additional performance indicators to provide a comprehensive assessment of building performance, developing centralized EPC databases for increased information transparency and energy planning support, implementing quality control measures to enhance credibility and reliability, considering occupant behavior and smart technologies in EPC calculations, providing more

detailed and personalized recommendations for cost-effective building renovations, and improving the presentation of EPC information to enhance public awareness. These enhancements collectively aim to improve the speed, accuracy, relevance, and usability of EPCs, promoting energy efficiency and facilitating informed decision-making for building owners, investors, and policy makers.
In order to provide some key insights, Table 21 below categorizes the barriers identified in the literature review and provides corresponding suggestions to overcome them, ultimately aiming to contribute to the advancement of EPCs in the EU.

Table 21 Overview of barriers to EPC implementation and suggestions to overcome them.

Category	Barrier	Source	Suggestions to Overcome
Financial considerations	Limited willingness to pay for EPC services	(Zuhaib, et al., 2022)	Integrate EPC services into public frameworks for affordability; Integrate EPCs as tools for financing deep renovations
	Prohibitive costs of carrying out due diligence	(Li, Kubicki, Guerriero, & Rezgui, 2019)	
	Lack of integration of EPCs in financing	(Zuhaib, et al., 2022)	
Data privacy and security	Data confidentiality concerns	(Zuhaib, et al., 2022)	Ensure strict data protection measures and privacy policies; Establish close collaboration with the housing association and update the rental agreement to include consent to collect data for performance evaluation
	Difficulties in obtaining consent for data collection from occupants	E-DYCE outcomes	
Data quality	Lack of data quality for energy performance evaluation	(Li, Kubicki, Guerriero, & Rezgui, 2019); (Mangold, Österbring, & Wallbaum, 2015); (Pasichnyi, Wallin, Levihn, Shahrokni, & Kordas, 2019)	Enhance data collection and verification
Occupant behavior	Difference between predicted and actual energy consumption	(Li, Kubicki, Guerriero, & Rezgui, 2019); (López-González, López-Ochoa, Las-Heras-Casas, & García-Lozano, 2016)	Adoption of building automation systems and building smart management systems
Comparability	Lack of comparability between EPCs	(Zuhaib, et al., 2022)	Establish harmonized European calculation methodology for better comparability
Information accessibility	Lack of centralized EPC register	(Zuhaib, et al., 2022)	Set up a central/regional EPC register for accessibility to all stakeholders
Varying levels of interest	Varying levels of interest across countries	(Zuhaib, et al., 2022)	Tailor EPC features to specific country contexts
	Lack of interest in certain EPC features	(Zuhaib, et al., 2022)	Improve relevance and usefulness of features based on end-user needs

	Insufficient information to motivate renovation	(Li, Kubicki, Guerriero, & Rezgui, 2019); (Pasichnyi, Wallin, Levihn, Shahrokni, & Kordas, 2019)	Provide comprehensive and compelling information about the benefits of renovation to motivate homeowners.
Market penetration	Limited market penetration of EPCs	(Zuhaib, et al., 2022)	Develop and promote standardized guidelines and policies to enhance reliability and compliance
Customization	Limited customization of current EPCs	(Zuhaib, et al., 2022); (Li, Kubicki, Guerriero, & Rezgui, 2019); (Pasichnyi, Wallin, Levihn, Shahrokni, & Kordas, 2019)	Incorporate new features into EPCs and provide easily understandable information; Incorporate more user-friendly features
Familiarity with technology	Lack of familiarity with smart technology	(Zuhaib, et al., 2022); (Li, Kubicki, Guerriero, & Rezgui, 2019)	Offer educational resources and training on smart technology

As presented in table 21, the main barrier categories and suggestions are the following:

Financial considerations: One of the primary barriers to EPC implementation is the limited willingness of stakeholders to pay for EPC services. To address this, integrating EPC services into public frameworks for affordability is recommended. This integration would help overcome financial constraints and encourage a wider adoption of EPCs. Additionally, the prohibitive costs associated with carrying out due diligence should be addressed through the exploration of cost-effective solutions to alleviate the burden on stakeholders.

Data privacy and security: Data confidentiality concerns are a significant barrier to EPC acceptance. To mitigate these concerns, strict data protection measures and privacy policies should be ensured, assuring stakeholders that their data is secure. Additionally, difficulties in obtaining consent for data collection from occupants can be addressed by establishing close collaboration with housing associations and updating rental agreements to include consent clauses for data collection, ensuring transparency and compliance.

Data quality: Lack of data quality for energy performance evaluation is another challenge. Enhancing data collection and verification processes is crucial to improve the reliability and accuracy of energy performance evaluations.

Occupant behavior: Differences between predicted and actual energy consumption due to occupant behavior present a challenge for EPCs. To mitigate this, the adoption of building automation systems and smart management systems is recommended. These technologies can bridge the gap between predicted and actual energy consumption, promoting energy-conscious behavior among occupants.

Comparability: Ensuring comparability between EPCs is essential for their effectiveness. Establishing a harmonized European calculation methodology for EPCs is recommended. This harmonization would standardize calculation methods, enabling consistent and comparable energy performance assessments across different certificates.

Information accessibility: The lack of a centralized EPC register hampers information accessibility for stakeholders. To address this, establishing a central or regional EPC register is recommended. This register would serve as a comprehensive information source, enabling easy access to EPC data for all stakeholders, supporting informed decision-making.

Varying levels of interest: Varying levels of interest across countries and lack of interest in certain EPC features can hinder their adoption. Tailoring EPC features to specific country contexts and improving their relevance and usefulness based on end-user needs can address these barriers. Providing comprehensive and compelling information about the benefits of renovation is also important to motivate homeowners and increase interest.

Market penetration: Limited market penetration of EPCs is a challenge that can be addressed through the development and promotion of standardized guidelines and policies. By enhancing reliability and compliance, EPCs can gain wider acceptance and adoption in the market.

Customization: Limited customization of current EPCs limits their usefulness. Incorporating new features into EPCs and providing easily understandable information would enhance their usability and make them more user-friendly. These improvements can cater to the specific needs and preferences of end-users.

Familiarity with technology: The lack of familiarity with smart technology poses a barrier to EPC adoption. Offering educational resources and training programs on smart technology would increase familiarity and facilitate the adoption of advanced technologies, making EPCs more accessible and appealing to stakeholders.

Addressing the barriers to EPC implementation is crucial for the successful advancement and adoption of energy-efficient practices within the EU. By integrating EPCs into public frameworks, ensuring data privacy and security, enhancing data quality and comparability, and promoting information accessibility, the EU can overcome these barriers. Additionally, tailoring EPC features, improving customization, and fostering familiarity with smart technology will contribute to their wider acceptance and utilization. These efforts will facilitate the EU's transition to a more sustainable and energy-efficient built environment, supporting its overall energy conservation goals and informing decision-making among stakeholders, building owners, investors, and policymakers.

Bibliography

Abreu, M. I., Oliveira, R. & Lopes, J., 2017. Attitudes and practices of homeowners in the decision-making process for building energy renovation. Modern Building Materials, Structures and Techniques, MBMST 2016, Volume Procedia Engineering 172, pp. 52-59.

Amecke, H., 2021. The impact of energy performance certificates: A survey of German home owners. Energy Policy, Volume 46, pp. 4-14.

Anđelković, A. S. et al., 2021. Building Energy Performance Certificate—A Relevant Indicator of Actual Energy Consumption and Savings?. Energies, 14(12), p. 3455.

Christensen, T. H., Gram-Hanssen, K., Best-Waldhober, M. d. & Adjei, A., 2014. Energy retrofits of Danish homes: is the Energy Performance Certificate useful?. Building Research & Information, 42(4), pp. 489-500.

Farahani, A., Wallbaum, H. & Dalenbäck, J.-O., 2019. The importance of life-cycle based planning in maintenance and energy renovation of multifamily buildings. Sustainable Cities and Society, Volume 44, pp. 715-725.

Jenkins, D., Simpson, S. & Peacock, A., 2017. Investigating the consistency and quality of EPC ratings and assessments. Energy, Volume 138, pp. 480-489.

Khazal, A. & Sønstebø, O., 2020. Valuation of energy performance certificates in the rental market – professionals vs. nonprofessionals. Energy Policy, Volume 147, p. 111830.

Li, Y., Kubicki, S., Guerriero, A. & Rezgui, Y., 2019. Review of building energy performance certification schemes towards future improvement. Renewable and Sustainable Energy Reviews, Volume 113, p. 109244.

López-González, L. M., López-Ochoa, L. M., Las-Heras-Casas, J. & García-Lozano, C., 2016. Update of energy performance certificates in the residential sector and scenarios that consider the impact of automation, control and management systems: A case study of La Rioja. Applied Energy, Volume 178, pp. 308-322.

Mangold, M., Österbring, M. & Wallbaum, H., 2015. Handling data uncertainties when using Swedish energy performance certificate data to describe energy usage in the building stock. Energy and Buildings, Volume 102, pp. 328-336.

Pasichnyi, O. et al., 2019. Energy performance certificates — New opportunities for data-enabled urban energy policy instruments?. Energy Policy, Volume 127, pp. 486-499.

Platten, .. v. et al., 2019. The renewing of Energy Performance Certificates—reaching comparability between decade-apart energy records. Applied Energy, Volume 255, p. 113902.

Sesana, M. M. & Salvalai, G., 2018. A review on Building Renovation Passport: Potentialities and barriers on current initiatives. Energy and Buildings, Volume 173, pp. 195-205.

Wilhelmsson, M., 2019. Energy Performance Certificates and Its Capitalization in Housing Values in Sweden. Sustainability, 11(21), p. 6101.

Zuhaib, S. et al., 2022. Next-generation energy performance certificates: End-user needs and expectations. Energy Policy, Volume 161.